BENCHMARK WORKSHOP ON NORTH SEA AND CELTIC SEA STOCKS (WKNSCS)

Please note: The list of authors and the volume/issue numbers were updated in February 2023.

VOLUME 5 | ISSUE 04

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

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ISSN number: 2618-1371

ICES Scientific Reports

Volume 5 | Issue 04

BENCHMARK WORKSHOP ON NORTH SEA AND CELTIC SEA STOCKS (WKNSCS)

Recommended format for purpose of citation:

ICES. 2023. Benchmark Workshop on North Sea and Celtic Sea stocks (WKNSCS).
ICES Scientific Reports. 5:04. 324 pp. https://doi.org/10.17895/ices.pub.21558681

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Contents

i Executive summary

A benchmark process was conducted for six stocks in the North Sea and Celtic Sea area with the goal of determining appropriate data inputs for assessing status, estimation of reference points, and short-term projection which could form the basis of advice for fishing prospects. The benchmark process consisted of two meetings separated by about three months: the first was a data inputs review and the second was a model assumptions and outputs review.

Benchmarked evaluation methods were produced for:

1) North Sea, Skagerrak, Malin Shelf Haddock (had.27.46a20)

2) Irish Sea cod (cod.27.7a)

3) North Sea plaice (ple.27.4)

4) Celtic Sea plaice (ple.27.7fg)

5) North of Scotland herring (her.6aN)

6) North of Ireland, West of Scotland herring (her.6aS7bc)

North Sea Haddock is a category 1 assessment using the standard ICES Stock Assessment Model (SAM):

The previous model for this stock was replaced by SAM in this benchmark primarily because the originator of the previous model is about to retire and a SAM approach is better understood by a wider swath of the ICES community presently. Furthermore, because the old model is incompatible with MS-Windows 12 and it will not be updated, it was deemed desirebale to switch to a SAM assessment. The SAM model fitting for this stock showed good fitting diagnostics and the approach was easily accepted as the benchmarked approach. Haddock are notiously sporadic recruiters and this makes the choice of stock-recruit relationship for determining the reference points difficult but this is well know feature of this stock and other haddock stocks and did not preclude the estimation of reference points.

Irish Sea cod was assessed as a category 1 stock that used the Stock-Synthesis 3 model approach:

Irish sea cod was previously classified as a category 3 stock. It was proposed as a category 1 assessment for the present benchmark and used the highly adaptable stock-synthetis modelling approach. The main issues for this assessment are less about the model approach than about data and a stock structure. The stock has not experienced many commercial fishery removals for a number of years while a recreational fishery along the English coast has been roughly quantified. The productivity dynamics of the stock seem largely extrinsically driven (i.e. spawner biomass influence on recruitment is the not the primary determinant of stock growth presently), at least during the current low stock size period. A post benchmark process to determine an ecological/climate conditioned sustainable fishing mortality (which has become termed Feco) was consquently calculated for this stock. The next benchmark for this stock should consider recreational catches from across the stock area and should revisit the definition of what area and data constitute information pertinent for this stock.

North Sea plaice is a category 1 assessment using SAM:

This assessment combined survey indices to cover the whole stock area well. Age dependent natural mortality was implemented based on literature methods of producing mortality estimates for species with plaice life history. The model fittings with time variying and invariante M produced similar fitting diagnostics however. Discarding rates of plaice from this stock has historically been important and assumptions about discarding have important impact on the estimates of the reference points.

Celtic Sea plaice is a category 1 assessment using SAM:

There were considerable difficulties fitting SAM to the data for this stock. The accepted benchmark model was subsequently rejected owing to poor fit diagnostics and an ICES category 3 methods was proposed as the way forward for producting advice.

Herring North and West of Scotland and Herring in Northwest of Ireland and West of Scotland were assessed using a category 3, method 2.2 CHR rule:

Early in the data meeting it was decided to split these into two stocks as genetic, survey and migratory evidence suggests that there are at least two major components in this stock complex.

A category 1 SAM assessment was attempted for the North of Scotland stock but it was too sensitive to the inclusion of particular survey indices combined with lack of strong justification for choosing particular survey series over others. Therefore the a category 1 SAM approach was rejected in favour of the ICES category 3 CHR rule which is based on life history an optimal length. The M/k ratio (natural mortality M and von Bertalanffy growth parameter k) default of 1.5 for the method was modified to reflect actual values calculated from the data. This method adjusts catch in the recent period up or down depending on the state of the stock implied by the methods. Uncertainties remain in how split catch and survey data between this stock and the herring from western Scotland and Ireland and this will warrant future work.

ii Expert group information

Expert group name	Benchmark Workshop on North Sea and Celtic Sea stocks (WKNSCS 2022)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Daniel Duplisea, Canada
	Gudmundur Thordarson, Iceland
Meeting venues and dates	Data evaluation meeting, 22-24 November 2021, online
	Benchmark meeting, 7-11 February 2022, ICES Secretariat

1 Benchmark process

The benchmark process started in 22 November 2021 with a Data evaluation online meeting. It was followed by a hybrid meeting in February 2022. The chairs went through the ToRs, explained the role of the participants and the expected outcome of the meeting. The agenda was adopted and the list of participants is presented in Annex 1.

To ensure credibility, salience, legitimacy, transparency and accountability in ICES work all contributors to ICES work are required to abide by the ICES Code of Conduct - CoI. The ICES CoI was brought to the attention of participants at the workshop and no CoI was reported.

1.1 Terms of Reference

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:

i. Stock identity and migration issues;

ii. Life-history data. For sole, fluctuations in mean weights at age will be explored;

iii. Review current sampling levels and adjust stratification levels for landings and discards accordingly;

iv. Examine alternative assessment models to the current model

v. Explore impact of all tuning fleets on assessment estimates;

vi. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook;

vii. Examine mixed fisheries interaction;

b) Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

c) Re-examine and update (if necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

d) Develop recommendations for future improving of the assessment methodology and data collection;

e) As part of the evaluation:

i) Conduct a 3-day data evaluation workshop. Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

ii) Following the Data evaluation, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting.

2 Cod (Gadus morhua) in Division 7.a (Irish Sea) – cod.27.7a

2.1 Stock ID and sub-stock structure

An extensive history of the Irish Sea cod fishery and management can be found in the WKIRISH2 report (ICES 2017, ICES 2017). The stock structure of the Irish Sea and adjacent area cod stock is still not fully understood. A recent tagging study (2016-2018) showed a that 18% of mature (>40 cm) cod tagged in the Irish Sea were re-captured in the Celtic Sea, with no individuals tagged in the Celtic Sea recaptured in the Irish Sea. With lower fishing pressure in the Celtic Sea, the amount of fish migrating to the Celtic Sea in that period is likely to be higher.

2.2 Issue list

Table 2.1. Issues list prior to meeting

Type	Problem/Aim	Work Required	Data Required
Assessment method	The previously benchmarked assessment model (ASAP) was rejected at the WGCSE 2019 due to its large retrospective pattern in F and SSB and a consistent downward revision of SSB and upward revision of F. The stock was reviewed as part of the WKMSYSpict benchmark, however it was unsuccessful due to missing contrast.	Work needs to be considered to be done on the natural mortality M and the start-point of the data series. With a baseline shift it seems to be more appropriate to have a shortened time-series rather than including data from 1968. As an alternative to the A4A model there are various other options: Spict, Jabba and Stock Synthesis. An initial approach into Spict and Jabba concluded that neither methods is possible. A Stock Synthesis model (first run) looks promising using data up to 2019. If a category 1 assessment cannot be agreed we will intend to use the DLM suite to assess the stock and give advice.	No new catch data or survey indices are required as these data have been prepared recently. However, the data will have to be closely investigated as to which to use for the assessment. Should a category 1 assessment fail to be agreed, additional data will have to come from the DST tagging project to provide the data limited approach the highest ecological and biological precision.
Stock identity	The stock Identity and natural mortality are unclear, with an observed migration of Irish Sea cod into the Celtic Sea and environmental changes of cod experienced in the Irish Sea due to increased temperature. The increased temperature might impact on an increased natural mortality and decreased maturity in older/larger fish due to metabolic issues.	One option to identify a shift in natural mortality would be to calculate the natural mortality from the FSP survey, as the fishing pressure for the past years has been negligible. Additional work is being done on tagging to understand the biological response to increasing ocean temperatures and migratory behaviour. Using a model such as Jabba/Spict or also Stock Synthesis does not require M or recruitment function as an input.	Data from FSP survey is available
Assessment method	To review and update existing assessment model	A lot of work already completed and written up in WGCSE report	No additional data
Tuning series	In the last benchmark, four tuning series were employed, the NI-GFS Q1 and Q4 (1992/1993 -	Choice of survey indices to include in any stock assessment will be guided by assessment model performance	No additional data requirements

Type	Problem/Aim	Work Required	Data Required
	2020), the Fisheries Science Partnership survey (2004- 2020, except 2014) and the MiKNet recruitment survey (1992 to 2019). There are internal inconsistencies between survey years and inconsistencies between surveys.	(residuals, retros, leave-one out) & hence considerable sensitivity analysis will be required. Recruitment age will be age 0.	
Biological reference points	Reference points will be required to be calculated once an assessment is agreed.	For a category 1 assessment, new PA and MSY reference points calculated according to ICES guidelines & using EqSim. In addition to EqSim an alternative approach using MSE (management strategy evaluation) should be explored to account for the shifts in cod ecology over the more recent time frame. If a category 1 assessment cannot be agreed, other indicators will be assessed and explored, such as a biomass indicator or length-based indicators.	Data for this are the same as for the assessment itself.
Stock identity	The stock Identity and natural mortality as well as reproduction are unclear, with an observed migration of Irish Sea cod into the Celtic Sea and environmental changes of cod experienced in the Irish Sea due to increased temperature. The increased temperature might impact on an increased natural mortality and decreased maturity in older/larger fish due to metabolic issues.	One option to identify a shift in natural mortality would be to calculate the natural mortality from the FSP survey, as the fishing pressure for the past years has been negligible. Another option is to use tagging studies to investigate the natural mortality. Additional work is being done on tagging to understand the biological response to increasing ocean temperatures and migratory behaviour.	Data from FSP surveys and tagging projects are available.

2.3 Scorecard on data quality

For an extensive description of commercial data, data collection, raising procedures and surveys please refer to the WKIRISH2 report (ICES 2017).The data have been updated from the 2016 benchmark to include data up to 2020.

The data were presented at the WKDEM data meeting.

Recreational data was included in the assessment for the first time.

Table 1.2. Scorecard Irish Sea cod.

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				
Final indicator		**All green**		
B. LANDINGS WEIGHT		ICES estimates of landing data are considered		
1. Missing part				
2. Area misreporting				
3. Quantity misreporting				
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				
8. Damaged fish landed				
Final indicator		**All green**		
C. DISCARDS WEIGHT				
1. Sampling allocation scheme				Sampling and observer scheme as described in WKROUND and WKIRISH
2. Raising variable				
3. Size of the catch effect				
4. Damaged fish discarded				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
5. Non response rate				
6. Temporal coverage				
7. Spatial coverage				
8. High grading				
9. Slipping behaviour				
10. Management measures leading to discarding behaviour				
11. Working conditions	NA			
12. Species replacement	NA			
Final indicator				
D. EFFORT				
1. Unit definition				
2. Area misreporting				
3. Effort misreporting				
4. Source of information				
Final indicator				
E. LENGTH STRUCTURE		Length structure is not used in the assessment		
1. Sampling protocol	NA			
2. Temporal coverage	NA			
3. Spatial coverage	NA			
4. Random sampling of boxes/trips	NA			
5. Availability of all the landings/discards	NA			
6. Non sampled strata	NA			
7. Raising to the trip	NA			
8. Change in selectivity	NA			
9. Sampled weight	NA			

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
Final indicator		**NA**		
F. AGE STRUCTURE				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				
5. International reference set				
6. Species/stock reading easiness				
7. Staff trained for age readings				
8. Age reading method				
9. Statistical processing				
10. Temporal coverage				
11. Spatial coverage				
12. Plus group				
13. Incomplete ALK				
Final indicator		**Green**		
G. MEAN WEIGHT				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
7. Conversion factor	NA			
Final indicator				
H. SEX RATIO	NA			Sex ratio is not used in the assessment
1. Sampling protocol	NA			
2. Temporal coverage	NA			
3. Spatial coverage	NA			
4. Staff trained	NA			
5.Size/maturity effect NA	NA			
6. Catchability effect NA	NA			
Final indicator				
I. MATURITY STAGE				Maturity estimated at annual Quarter 1 survey aboard RV Corystes/ RV Lough Foyle
1. Sampling protocol				
2. Appropriate time period all along the year				
3. Spatial coverage				
4. Staff trained				
5. International reference set				Not available
6. Size/maturity				
7. Histological reference				
8. Skipped spawning				Not taken into account
Final indicator				

Catch – quality, misreporting, discards

2.3.1.1 Commercial Catches

An extensive review about discards, misreporting and quality of commercial data can be found in the WKIRISH 2 report (ICES 2017) and WKROUND (ICES 2012). Quality has been good in the years following the benchmark until 2020. The Covid-19 pandemic in 2020 made sampling of landings and discards impossible for quarters 2-4. Discards were raised to Q1 discards of the TR2 and TR1 fleets; landings were reported landings from all fleets. Catch at age was estimated by the assessment model which can handle missing data.

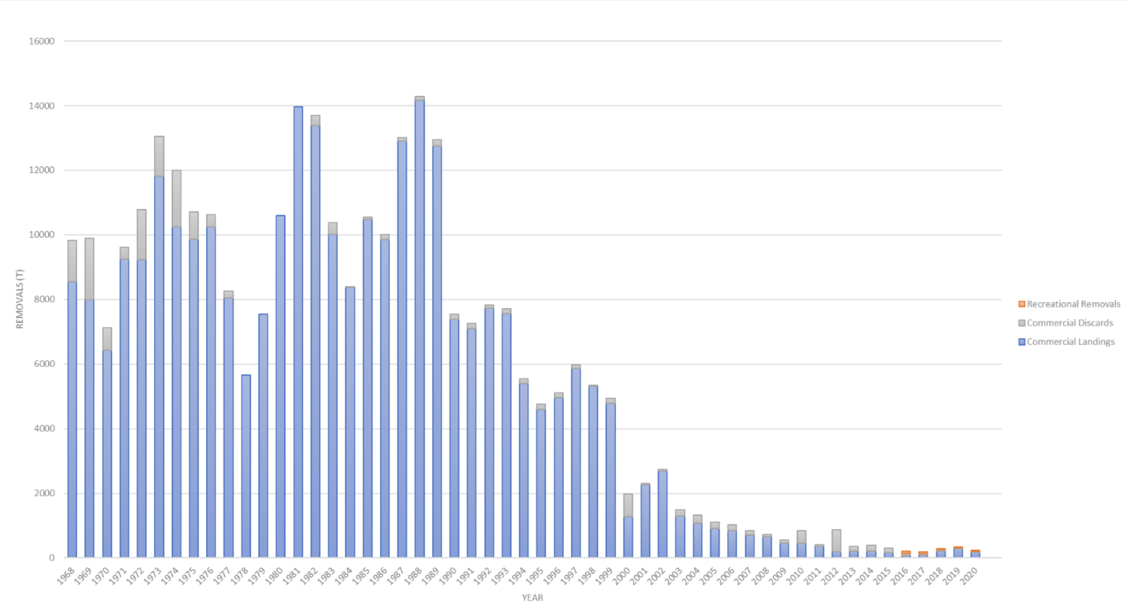


Figure 2.1. Commercial landings, discards and recreational removals.

2.3.2 Surveys

An extensive review about available surveys, in-depth survey descriptions and quality can be found in the WKIRISH 2 report (ICES 2017). The poor cohort tracking in the NI groundfish quarter 4 survey led to the inclusion of the survey as an age-0 recruit survey. Due to large discrepancies from the earlier to the later years of the groundfish surveys (years 1992-1994), survey indices started in 1995.

The MikNet survey was tested as a recruitment survey, however results were poor as there was very low tracking between larvae in June and age-0 fish in October.

2.3.3 Weights, maturities, growth, natural mortality

Catch weights were used as stock weights. An in-depth description of stock weights is available from the WKIRISH 2 report (ICES 2017).

2.3.3.1 Maturities

An in-depth description of maturity at age calculation can be found in the WKIRISH 2 report (ICES 2017). There has been a trend towards earlier maturation with 76% of age 2 fish mature in 2020 after application of the smoother (Figure 2.22).

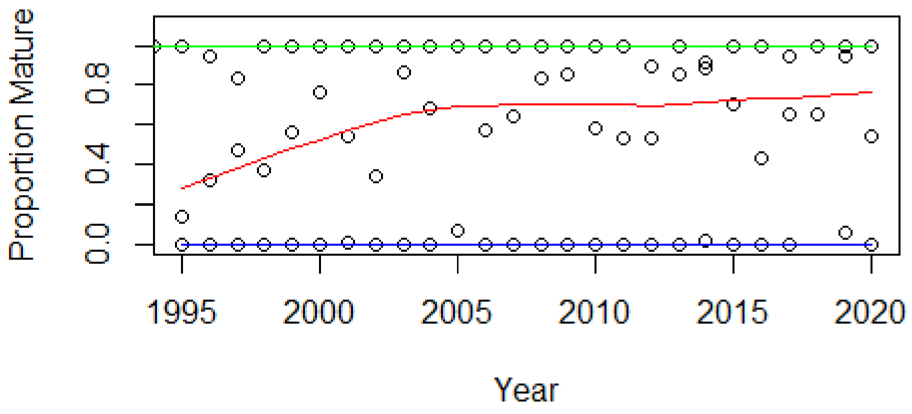


Figure 2.2. Smoothed maturity ogive, blue-age 1, red-age2, green-age 3

2.3.3.1.1 Natural Mortality

Prior to the last benchmark in 2017, natural mortality M for cod has been assumed as 0.2 across all ages and years. During the WKIRISH 2 workshop (ICES 2017) a range of natural mortality estimation options were explored and discussed, including Lorenzen, Pauly and Hoenig. The final decision was to use the Lorenzen estimations, which provided the lowest values for M. However, cod in the Irish Sea have historically shown a steep age structure, where age 6 was a plus group. While it could be debated that this was due to a very high fishing mortality in the 1970's and 1980's, there was little change in the age structure under the cod recovery program which in place since 2000. In particular the 2013 cohort, which was a stronger than average cohort had high unexplained mortality even in the absence of fishing. In particular this resulted in the last benchmarked model from 2017 not being able to cope with the strong retrospective pattern emerging from the absence of older fish in surveys and catches.

Initially it was suggested to gain an estimate of M from an in-depth analysis of the FSP survey, which has been collecting data on mature fish in the absence of a commercial fishery. Instead, readily available data from two tagging studies (1970-1972, 2017-2018) was used to estimate M, following approaches used for tuna and other species.

Open population models, such as Brownie model (Brownie and Pollock, 1985, Pollock, Hoenig *et al.*, 1989; Hoenig, Barrowman *et al.*, 1998; Hillary and Eveson, 2015) are simple models for data from multiyear tagging studies. They require uniquely marked fish that are recovered dead by fishermen/anglers and the tag information is returned, including date of recapture, location of recapture, length at recapture. In depth description of the models are provided in (Brownie and Pollock, 1985). Here just a short description of the data and the estimates.

A number of assumptions that are made on capture release open population models:

- The tagged sample is representative of the population being studied
- Markers do not affect behaviour/fate of individuals
- No tag loss

  Tag loss can be estimated with double marking techniques and parameter estimates can be adjusted for bias

- Every marked animal alive in the population at time *i* has the same probability of capture
- The fate of each marked animal is independent of the fate of other marked animals
- Resampling is instantaneous (birth, death, immigration and emigration do not occur during the resampling process)

Effect of violating these assumptions = overdispersion (underestimating variance for the population parameters, which can affect model selection procedures) but it can be diagnosed and corrected for.

The Brownie model can then be used to estimate year-specific survival and tag recovery rates for animals; Brownie model only takes into account dead recaptures.

- S_i survival probability: probability of surviving from time $\boldsymbol{i}$ to $\boldsymbol{i+1}$
- f_i tag recovery rate: probability of being killed and then being retrieved and reported
- Originally viewed as nuisance parameters because they represent the combined effect of tag-induced mortality, tag shedding, exploitation and tag reporting, however now it is possible to quantify tag shedding, tag-induced mortality and tag reporting.

An estimate of survival can be theoretically obtained from 2 years of tagging and recovery, in practice 3+ years should be used; however, there can be more recovery years than tagging years. For both tagging campaigns deemed useable for the Irish Sea cod, tagging was only spread across two years, while recovery years were up to four years.

The equation describes the natural mortality, or the probability of dying from natural causes v:

$$v = 1 - S - u$$

Where

S= the probability of surviving the year

u = the probability of being harvested

λ= the probability that a fish that has been caught will get reported (i.e. the tag is found on the fish and reported)

u, the probability of being harvested, cannot be estimated by itself, only the product, f= λu can be estimated from the tag recovery data. For further and more in-depth description of the estimations please refer to (Pollock, Hoenig *et al.*, 1989; Hoenig, Barrowman *et al.*, 1998).

Following (Hoenig, Barrowman *et al.*, 1998), and the information available about the fishery, the following assumptions and adjustments were made to the tagging data:

- Natural mortality M was considered constant across the tagging period and f was allowed to vary between years
- The catchability is constant
- Fishing happens throughout the year
- The tag reporting rate λ is very high, i.e. close to 1 (very high reward), but cannot be estimated.
- Tag loss is very low (fish were double tagged in the latter of the experiments, the probability of losing 1 tag was 0.1)
- Only fish >40cm were included in the analysis for M, they are experiencing the same selectivity and the same probability to get caught.
- Only fish released from specialized charters were included, as the post tagging survivability of the other fish (tagger experience etc) cannot be assured.
- In the earlier tagging campaign (1970-1972) only fish that were at liberty more than 4 days were included; due to the single tagging, a tag loss probability of 10% was assumed; the reporting rate is less well known, but from returned numbers can be assumed to have been high.
- Only fish tagged and re-captured in the Irish Sea were included, as the fishing pressure experienced in the Celtic Sea differs. To account for this a proportion of the tagged and not-recaptured fish were removed:

Table 2.2. Proportion of fish tagged in Irish Sea and recaptured outside. The same proportion of non-recaptured fish from the Irish Sea was removed from the numbers.

Year	Proportion recaptured outside 7.a
1970	8.1
1971	17.7
1972	12.8
2017	11.5
2018	18.4

Table 2.3. Input matrices for the Brownie model after adjusting for all assumptions, i.e. fish >40 cm, only fish tagged and re-captured in the Irish Sea, only fish at liberty >4 days, removal of total numbers proportionally to the fish that had migrated out of the Irish Sea.

Tag year	Total number	1970	1971	1972	1973	1974	1975
1970	299	67	25	5	1		
1971	654		145	37	12	3	
1972	1064			213	119	17	5

Tag year	Total number	2017	2018	2019	2020	2021
2017	1202	13	26	4	0	0
2018	1439		62	6	0	3

The outputs of application of the 2017-2018 data with constant M and time varying F were

S = 0.5097 and F = 0.0109; 0.0429; 0.0029; 0.0190 for the years 2017-2021 respectively (excluding 2020). Those values are in the range of the F estimated by the model as well as previous models.

The relationship between survival (S) and total mortality (Z) is

$S = e^{(-Z)}$

and therefore

$Z = -\log(S) = 0.674$

Calculate an estimated exploitation rate with the estimated f from the brownie model and λ, the assumed tag recovery rate (i.e. a recaptured tag is reported.) The probability of a tag return was high as there was a high reward for the fish and good communication with the fishing community was established, hence we assume a Lambda of 0.7 or 0.8 or even higher.

This results in an average estimated F of 0.021 ($\lambda = 0.7$) or estimated F of 0.018 ($\lambda = 0.8$).

With

$M_{estimate} = Z - F_{estimate}$

this calculates an $M_{estimate}$ between 0.653 and 0.655.

The same estimations were carried out for the tagging data from the years 1970-1972 resulting in F estimate of $M_{estimate}$ of 0.606 (ʎ = 0.7) and $M_{estimate}$ 0.754. However, with less knowledge about the return rate and the use of a single tag resulting in a higher tag loss rate of 0.1, we might assume a lower ʎ of 0.6 and achieve $F_{estimate}$ of 0.707 and $M_{estimate}$ of 0.653.

Another way of estimating Z (total mortality) is the use of age-based survival estimates from age frequency data. Using the FSP survey, which uses commercial gear and fishing methodology and actively targets cod Z and S (annual survival) were estimated using the R function agesurv from the package Fishmethods {Nelson, 2022 #295}.

Survey data from the years 2015-2021 was used and it was assumed that fish at age 3 are fully recruited to the fishery. To remove the effect of a single cohort moving through the years were combined. Only the stations sampled in the Western Irish Sea were included in the catch curves as the population in in the North Channel displays considerably different age structure.

As age samples were collected via a survey using a trawl, the least biased estimators are the "Poisson" and "Chapman-Robson" methods (Nelson, 2019).

Averaging the Poisson and Chapman-Robson methodologies this results in a Z of 0.90 over the past 6 years and an average S of 0.41 for fish aged 3+. With the low experienced fishing mortality, this would imply an even higher natural mortality than estimated from the tagging data.

Table 2.5. Estimations of Z and S using a range of methods in comparison using FSP survey data.

Method	Parameter	Estimate	SE
Linear Regression	S	0.31	0.031
Linear Regression	Z	1.17	0.1
Weighted Linear Regression	S	0.37	0.041
Weighted Linear Regression	Z	1.01	0.111
Heincke	S	0.48	0.013
Heincke	Z	0.73	0.02
Chapman-Robson	S	0.43	0.01
Chapman-Robson	Z	0.84	0.023
Chapman-Robson-CB	S	0.43	0.025
Chapman-Robson-CB	Z	0.84	0.059
Poisson Model	S	0.43	0.026
Poisson Model	Z	0.84	0.061
Random-Intercept Poisson Model	S	0.34	0.034
Random-Intercept Poisson Model	Z	1.09	0.102

The natural mortality M for the fish of >2.5 years is set to 0.65 after the tagging estimations, with ages 0 and 1 following Lorenzen.

Natural mortality in the model is set in blocks, starting ages 0.5,1.5 and 2.5

0.5 – 1.7

1.5 – 0.714

2.5- 0.65 (the model testing for the Lorenzen version was set to 0.35, the version testing for model estimated M was set to estimate with initial value 0.35 and the boundaries of 0.1 and 2.4). M at age 2.0 is 0.68 (between block 1.5 and 2.5)

2.3.3.2 Recreational fisheries

Recreational fisheries catches have not previously been included in the Irish Sea cod assessment, but are becoming an increasingly important component of the catch. As a result, it was important to consider how best to include recreational catches in the assessment. The overall aim was to generate a time-series of recreational removals (retained plus dead releases) for use in the assessment. This involved collating all recreational catch and length data for the Irish Sea and summarising all studies of post-release mortality of cod. These were combined to generate a time-series of recreational removals (retained plus dead releases) and length-frequency distribution for removals that could be used in the assessment.

Recreational catch estimates were provided by England for 2012 and the whole of the UK for 2016-2020. The 2012 estimate is for England only, and 2016-2020 covers the whole UK. Whilst Ireland also have access to the stock, their first national survey was conducted in 2020, but was hampered by COVID and so no catch estimates are available at present. Further surveys are planned in Ireland, so recreational catch estimates will be available in future. Surveys in 2012 covered England only and utilised three surveys: 1) a stratified random roving-creel survey to estimate CPUE (catch per day) of retained and released fish for shore and private or rented boat fishing; 2) a nationwide randomised face-to-face omnibus survey to estimate shore and boat recreational fishing effort, and 3) a separate diary record of catches of charter boats selected randomly and with known probability each quarter from a comprehensive list of vessels (Armstrong *et al.*, 2013). From 2016 onwards, an off-site survey approach was adopted involving a UK-wide randomised face-to-face omnibus survey of water sports activities to estimate the number, demography and other characteristics of UK residents going sea angling during each year, and a panel of sea anglers volunteering each year to keep catch diaries to record number and sizes of fish retained and released in each fishing trip. Annual numbers and tonnages of fish retained and released are estimated for each species using a Bayesian multi-level regression model with post-stratification (termed MRP; Hyder *et al.*, 2022). The offsite diary survey generated substantially larger catch estimates of catches for England than the onsite approach in 2012, especially for the released component. As the 2012 data are for only one year for England only and used different survey methods, it was not possible to determine the extent to which the higher catch estimates are due to survey bias, random sampling error, or changes in fish abundance. It is likely that a combination of these factors generated the differences (Hyder *et al.*, 2021). As the diary panel constitutes a consistent time-series of recreational catches, these have been used in the assessment and the 2012 results have been excluded due to the different approach. It should be noted that the onsite UK estimates used in this analysis are likely to represent an overestimate of the actual levels of catch, so represent a worst-case scenario. Numbers and tonnages Catch estimates were provided for all fishing platforms combined (shore and boat). The number and tonnage of fish retained and released, and the associated error are provided (Table 2.3). ICES area was not included as a factor in the MRP model, so estimates for 27.7.a had to be generated by partitioning national estimates. The proportion of fish caught within each ICES area estimated using a post-stratification approach (see Hyder *et al.*, 2021 for a description) was applied to the total catches estimated by MRP. For example, if the reweighting approach estimated that 10% of cod was caught in 27.7.a, and MRP estimated that 10 tonnes was caught in total, then the total catches in 27.7.a would be 1 tonne. Furthermore, the RSE provided here is based on the RSE from the reweighing procedure, which are typically larger than the errors from MRP due to the models ability to use multiple years of data. The impact of this was reduced via calculating the re-weighting RSE for the whole time-series within each ICES area rather than in within individual years.

Table 2.4. The total catches of Irish Sea Atlantic Cod by recreational fishers in the UK. RSE are given as %.

Year	Component	Number	Number RSE/%	Tonnage	Tonnage RSE
2016	kept	21787	55.4	33.71	67.4
2016	returned	53339	38.9	31.27	70.8
2017	kept	21262	55.4	32.87	67.4
2017	returned	50882	38.9	29.86	70.8
2018	kept	18939	55.4	29.31	67.4
2018	returned	42937	38.9	25.22	70.8
2019	kept	16400	55.4	25.36	67.4
2019	returned	39833	38.9	23.39	70.8
2020	kept	17993	55.4	27.84	67.4
2020	returned	27852	38.9	16.32	70.8

2.3.3.2.1 Lengths of fish caught

Extrapolating the length-distribution of fish caught in the UK sea angling diary study to the total population was not done using the MRP model. Instead, the proportion of fish caught at each length was used to generate a length distribution of recreational kept and returned fish for the whole time-series are presented (Figure 2.3).

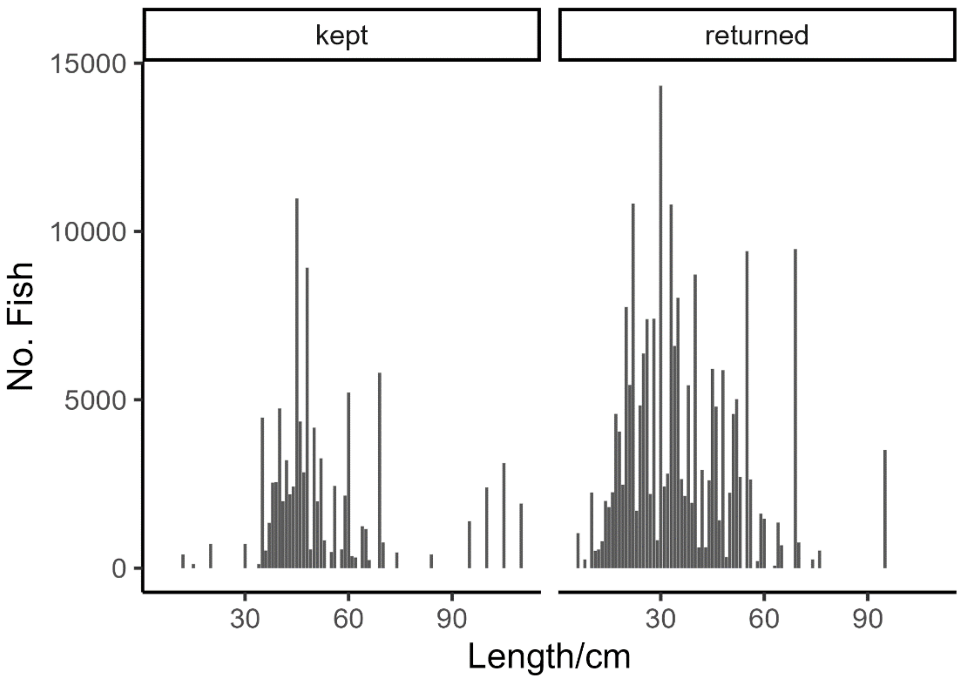


Figure 2.3. The number of fish kept and returned at length in the UK's sea angling diary program

2.3.3.2.2 Post-release mortality

No fisheries-specific studies on post-release mortality of recreationally caught North Sea cod are available. However, some studies investigating post-release mortality and potential sublethal effects have been conducted in other regions (Weltersbach and Strehlow, 2013; Ferter *et al.*, 2015a, b; Capizzano *et al.*, 2016). A telemetry study with nine cod in Norwegian coastal waters showed no mortality and no major behavioural changes when cod were caught and released under best practice conditions (Ferter *et al.*, 2015a). Another study revealed no short-term mortality of cod experiencing barotrauma when cod were able to submerge and otherwise not substantially injured (Ferter *et al.*, 2015b). Weltersbach and Strehlow (2013) estimated an overall mean mortality rate of 11.2% (SE ±22.0) for released cod in the western Baltic Sea recreational charter vessel fishery during an experimental containment study. A telemetry study in the Gulf of Maine (Capizzano *et al.*, 2016) revealed an overall post-release mortality estimate of 16.5% (95% CI: 9.9%, 35.1%) for the GOM sea-based recreational cod fishery in 2013. This cod fishery has similar fishing characteristics to the North Sea boat-based recreational cod fishery. Therefore, the post-release mortality estimate of Capizzano *et al.* (2016) could be used for sea-based catches of North Sea cod. A significant proportion of the recreational cod catch is taken by shore anglers who commonly use natural bait for fishing. Weltersbach *et al*. (2019) showed that the incidence of deep hooking and severe bleeding was significantly higher for cod caught with natural bait. In combination with rougher fishing conditions (e.g. surf, abrasion risk, longer fighting time) when fishing from shore, this results most likely in higher post-release mortality rates for shore fishing (Weltersbach and Strehlow, 2013). Therefore, it is likely that the overall post-release mortality is higher than the 16.5% estimated by Capizzano *et al*. (2016). Nevertheless, no studies on post-release mortality exist for land-based (bait) recreational cod fisheries and furthermore, little information on the proportion of bait use in different countries is available preventing a more accurate estimation. Therefore, as a precautionary approach the upper 95% confidence limit of 35.1% from the Capizzano *et al*. (2016) study is used as post-release mortality rate in the present document to derive recreational fishery removals of cod.

2.3.3.2.3 Recreational removals

The weight and number of fish removed for all three post release mortality values were calculated (Table 2.57; Figure 2.44). This was done by adding the weight and number of fish kept to the number/weight of fish returned, multiplied by the relevant post release mortality value. This assumes an average weight for fish returned that die after release.

Table 2.5. The total removals of Irish Sea Atlantic Cod by recreational fishers in the UK assuming a 35.1% post release mortality. RSE are given as %.

Year	Number fish	Number RSE/%	Weight fish/t	Weight RSE/%
2016	40509	32.0	44.68	48.8
2017	39122	31.9	43.35	48.8
2018	34010	31.9	38.17	48.8
2019	30381	32.0	33.57	48.8
2020	27769	32.1	33.57	49.9

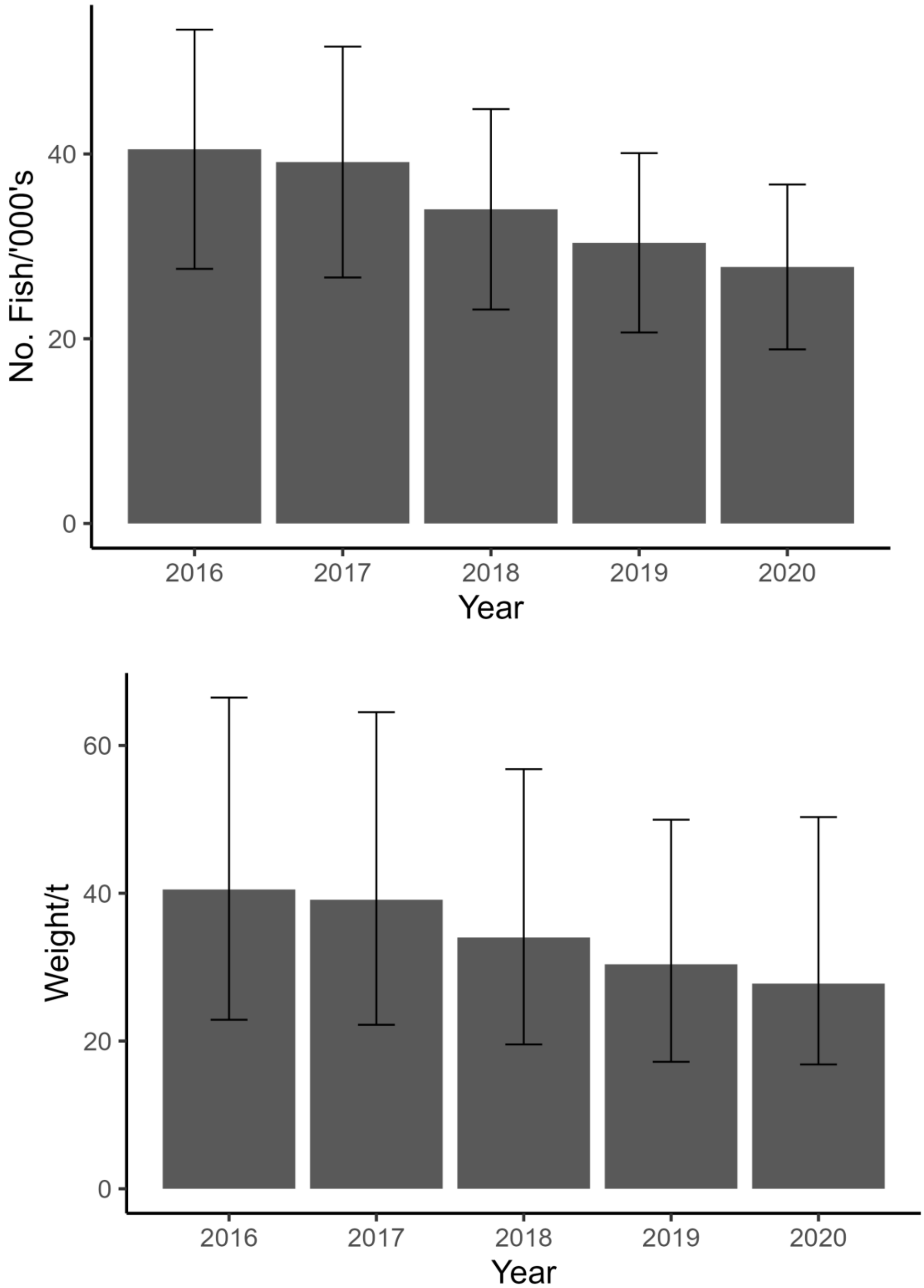


Figure 2.4. top: The total number (thousands) of Atlantic Cod removed from the Irish Sea by UK recreational fishers, bottom: The total weight (tonnes) of Atlantic Cod removed from the Irish Sea by UK recreational fishers

2.3.3.2.4 Length-frequency distribution of removals

The number of fish removed from the stock at each length category were calculated for all three post-release mortality values were calculated (Figure 2.55). However, as the sea angling diary program does not aim to extrapolate length-distribution data to the total population, the proportion caught in each length group in the raw data were used to partition the total number caught at length.

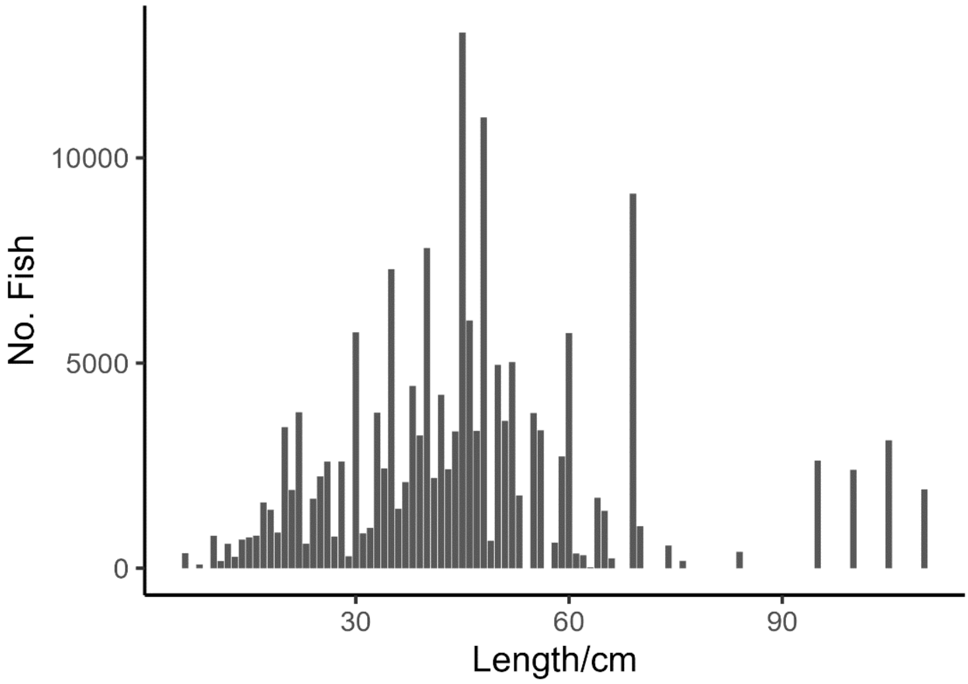
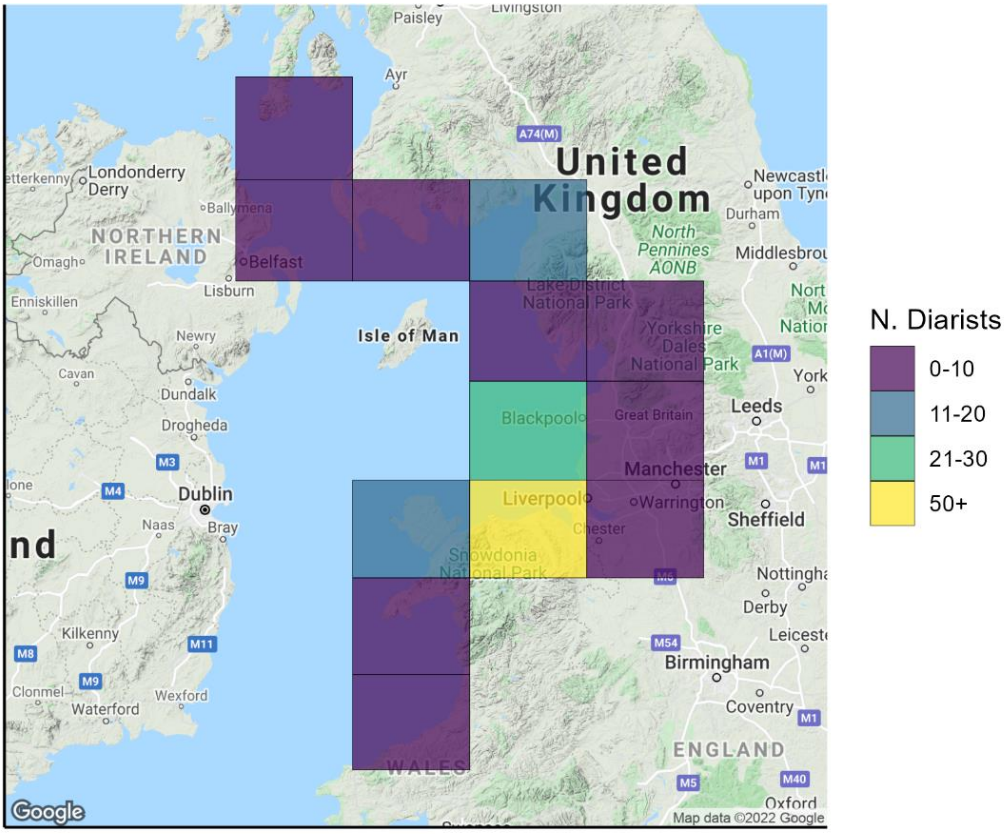


Figure 2.5. The number of Atlantic cod removed at length from the Irish Sea by UK recreational fishers assuming a 35.1% post-release mortality.

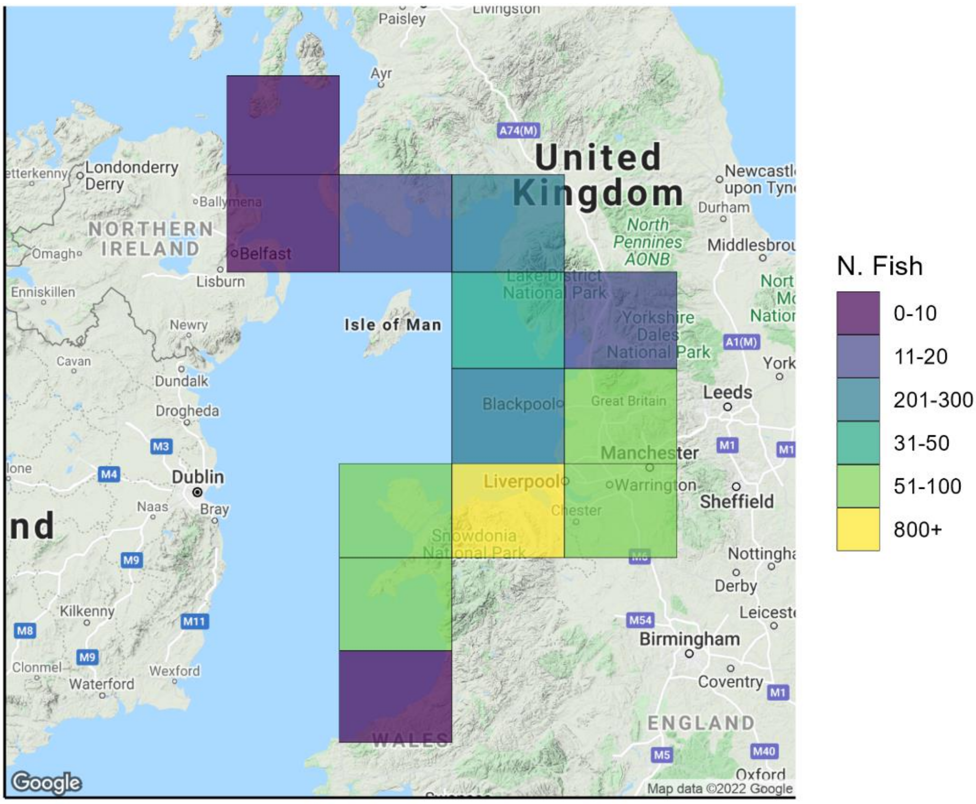
2.3.3.2.5 Issues with recreational data

Several issues with the Irish Sea cod recreational data should be noted. Firstly, as the Irish survey could not be completed due to COVID the catches by Irish recreational fishers were not captured, so the MRF removals presented here will be an underestimate. Data from the UK survey were provided mainly by diarist fishing in the eastern Irish Sea and often from shore (Figure 2.66). These may not be representative of catches across the whole stock area, and are in a completely different area to the fisheries independent surveys. The UK sea angling survey is designed to provide national estimates, so the RSEs for the Irish Sea are relatively large, and there is potential for bias due to the offsite nature of the survey. Finally, as the UK started collecting data in 2016, a full time-series of MRF removals was not available. Due to the uncertainties in the MRF data, relatively short time-series available, and substantial change in the magnitude of the commercial fishery reconstructing a time-series was not possible.

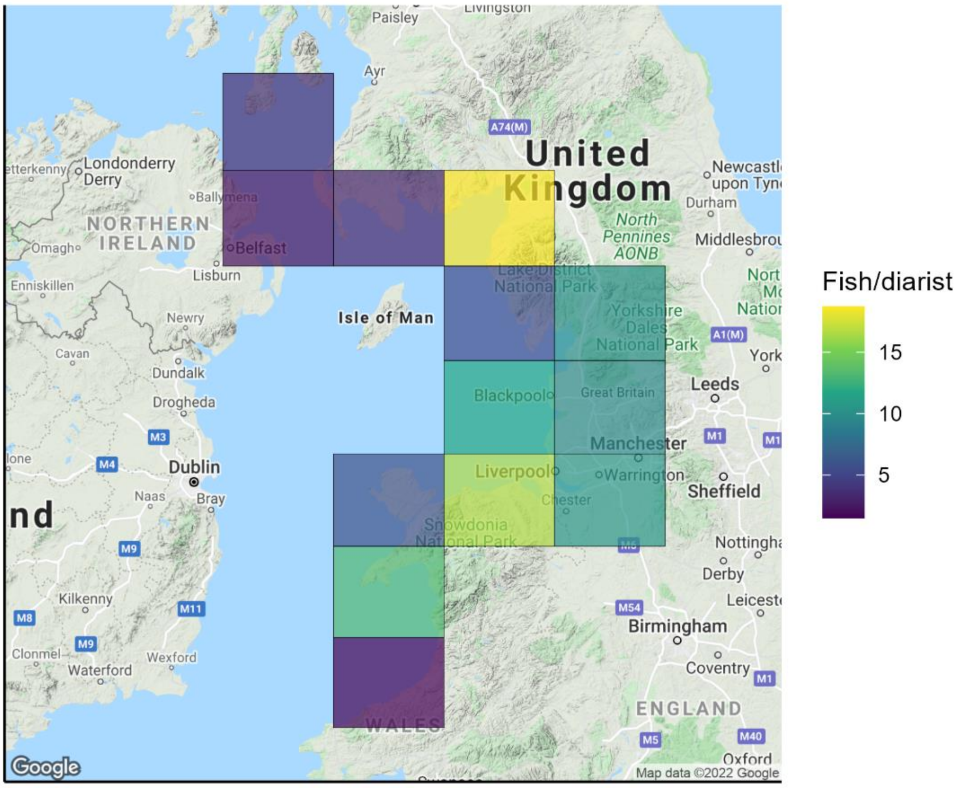
Fishery-specific MRF post-release mortality studies were not available so an assumption of 35.1% based on work by Capizzano *et al* (2016) was made. The released component of the catch makes up around 50% of the total weight caught, so changes in the post-release mortality can have a substantial impact on the total removals. Many factors can drive post-release mortality, including fishing platform (shore, boat, etc.) and method (bait, artificial lure) (Weltersbach and Strehlow, 2013), all of which vary between fisheries and countries due to varying fishing practices and motivations between anglers in different geographical regions. Consequently, the 35.1% post-release mortality used here is unlikely to represent the true recreational post-release mortality and should be treated as a precautionary value until further studies are conducted.


N. Diarists
0-10
11-20
21-30
50+
United Kingdom
Isle of Man
NORTHERN IRELAND
ENGLAND
WALES
Belfast
Dublin
Liverpool
Manchester
Blackpool
Birmingham
Map data ©2022 Google

a)


N. Fish
0-10
11-20
201-300
31-50
51-100
800+
United Kingdom
Isle of Man
NORTHERN IRELAND
ENGLAND
WALES
Belfast
Dublin
Liverpool
Manchester
Blackpool
Birmingham
Map data ©2022 Google

b)



c)

Figure 2.6. a) The number diarists fishing in the UK reporting catching Atlantic Cod in the Irish Sea within the sea angling diary project. b) The number of Atlantic Cod caught in the Irish Sea caught by UK sea anglers. c)The number of fish per diarists fishing in the UK reporting catching Atlantic Cod in the Irish Sea within the sea angling diary project. Figures created using the R package 'ggmap' (Kahle & Wickham, 2013)

2.3.4 Assessment model

A stock synthesis 3 model was used for the assessment. The model uses the following data

- Total catches (landings + discards) (1968-2020)
- Catch numbers at age (1968-2019, excluding 2003-2005, 2020 missing due to sampling issues related to covid-19 pandemic)
- Recreational removals (weight of all kept fish +35% of released fish weight assumed dead) (2016-2020), added to total catches
- Age 0 recruits (Q4 groundfish survey), 1995-2020
- Q1 groundfish survey (1995-2020)
- FSP survey (2004-2013, 2015-2020)

Initially three different natural mortality variants were considered (excluding the recreational data)

- M model estimated
- M following Lorenzen
- M estimated from tagging data

Only the best of the models was taken forward, multiple adaptations were performed afterwards.

Furthermore, 3 options including MIKNet and Q4 survey were tested

- Include Q4 survey as age 0 recruits
- Include Miknet as recruitment survey
- Include both surveys

Those three options were only applied to the best model for natural mortality above. Only the best fitting one was taken forward.

Regarding the recreational data, a number of tests were considered and investigated

- Include the recreational fishery as an additional fleet from 2016, however the data were not sufficient.
- Estimate recreational removals back in time to 1968 using a fixed F approach and then using estimated catches as an additional fleet with selectivity linked to the commercial selectivity. This was necessary as the available data for the recreational fishery were not able to provide a selectivity.
- Add the recreational removals to the total catches from 2016 onwards.

Those models were applied to the model with M estimated by tagging and the Q4 survey age-0 recruits.

A shift in recruitment was observed in 2002, and an additional recruitment block was added, estimating R0 for 1968-2001 and 2002-2020.

Table 2.6. Investigated model options.

	Model	description	Fit	notes
No recreational data, Q4 data year-0 recruits	Baseline 1	M estimated from tagging	Objective Function: 2226.7; good fit of all residuals except FSP survey ages, retrospective pattern/ Mohn's rho in ICES guidelines	This was a candidate for the final model, but it was agreed to include the recreational data.
	Baseline 2	M estimated by model	Objective Function:2221.7; good fit of all residuals, retrospective pattern/ Mohn's rho just in ICES guidelines	The estimated M for ages 2.5 + was 1.06, which is deemed too high
	Baseline 3	M estimated from Lorenzen	Objective function 2268.3; good fit of all residuals except FSP survey ages, retrospective pattern/ Mohn's rho not acceptable in ICES guidelines	Following the explorations into estimating M, the fit and retrospective pattern is considerably better with the tagging M.
M estimated by tagging	Recruitment 1	Include Miknet as recruitment survey (instead of Q4)		
	Recruitment 2	Include both surveys	Objective Function 2995.3; good fit of all residuals except FSP survey ages, large retrospective pattern/ Mohn's rho, 2015 peel did not converge	
Baseline 1	Recreational 1 (Final Model)	Add the recreational removals to the total catches from 2016	Objective Function: 1066.12; good fit of all residuals, retrospective pattern/ Mohn's rho in ICES guidelines	This was decided as the final model as it did include the recreational data without estimating back in time.
	Recreational 2	Estimate recreational removals back in time		This was discussed, but was discarded during the bench-

Model	description	Fit	notes
	to 1968 using a fixed F approach and then add estimated catches to catch fleet		mark meeting as not being the best approach since data were sparse and estimation back in time could not be justified

The Baseline 1 model was presented at the meeting as the working model. During the benchmark discussions regarding the inclusion of recreational data were held and the consensus was reached to include the five years of recreational removals to the total catches (Model Recreational 1). During the first two days of the benchmark the model was further tweaked to improve fit and the retrospective. This included a slight change in the blocks, in the phases and sample sizes. The other models were not further updated.

Recreational 1 (final agreed) model results and diagnostics:

The model consists of all catch data, and adds the recreational data to the final 4 years.

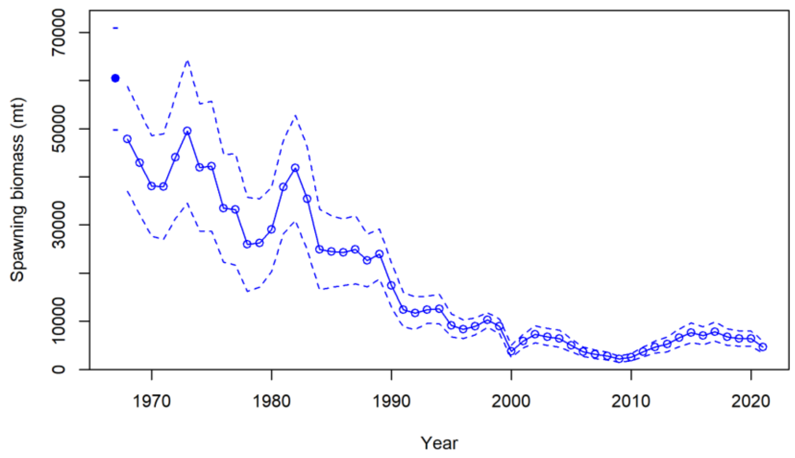


Figure 2.7. Estimated SSB including 95% confidence interval. The blue point in 1968 represents the virgin biomass.

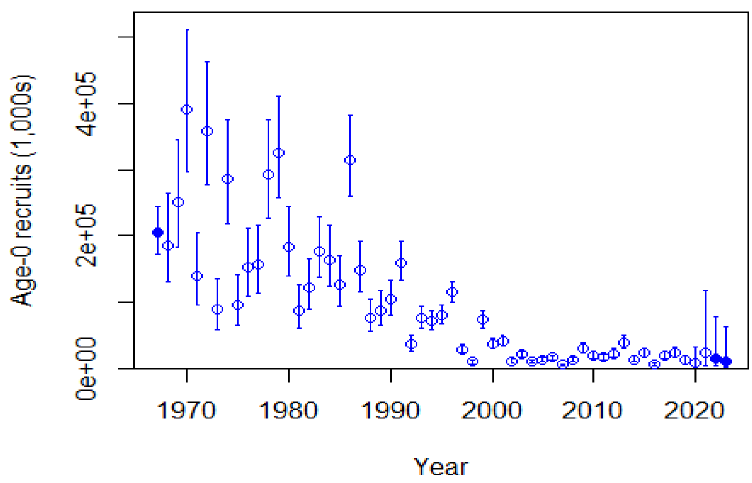


Figure 2.8. Recruits (in 1000s).

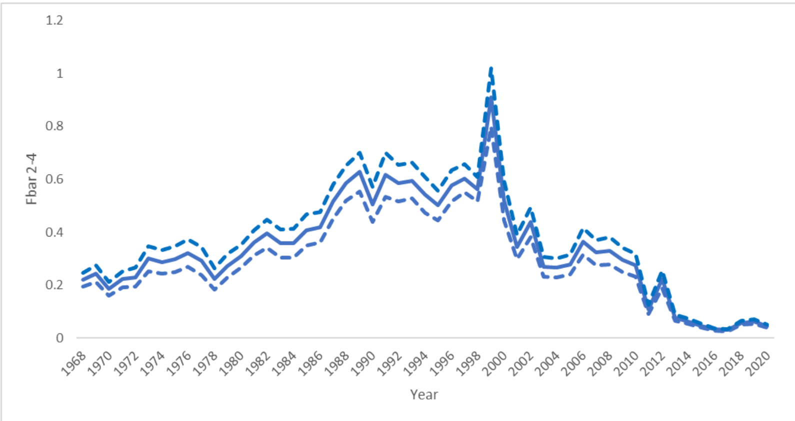


Figure 2.9. F average ages 2-4.

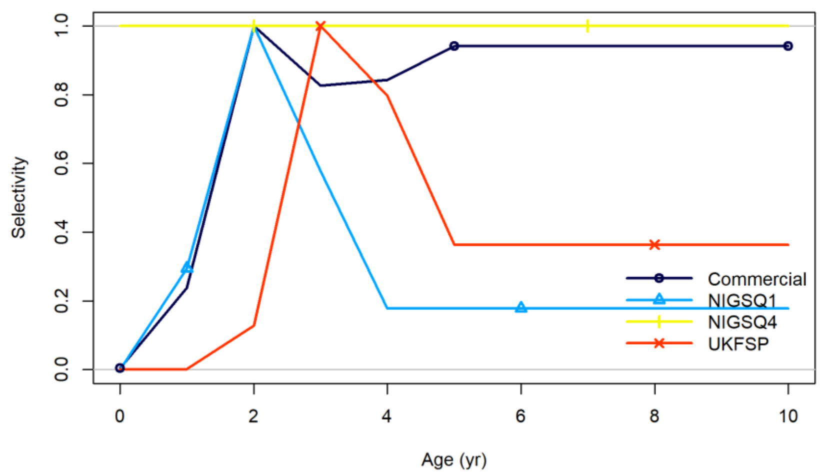


Figure 2.10. Selectivity by age and fleet in the final year (NIGFSQ4 is not estimated as it is recruitment age 0 only and plotted at 1). The commercial selectivity includes discards and recreational removals.

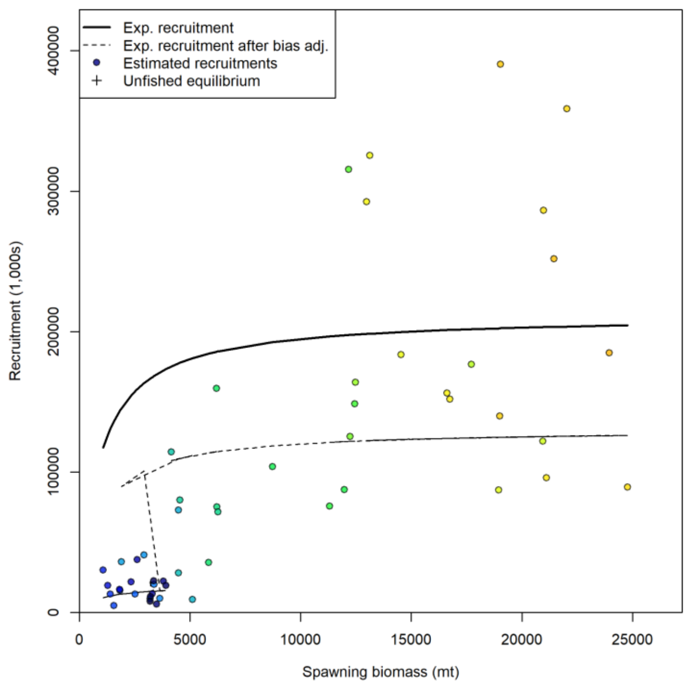


Figure 2.11. Spawner recruit relationship with bias adjustment.

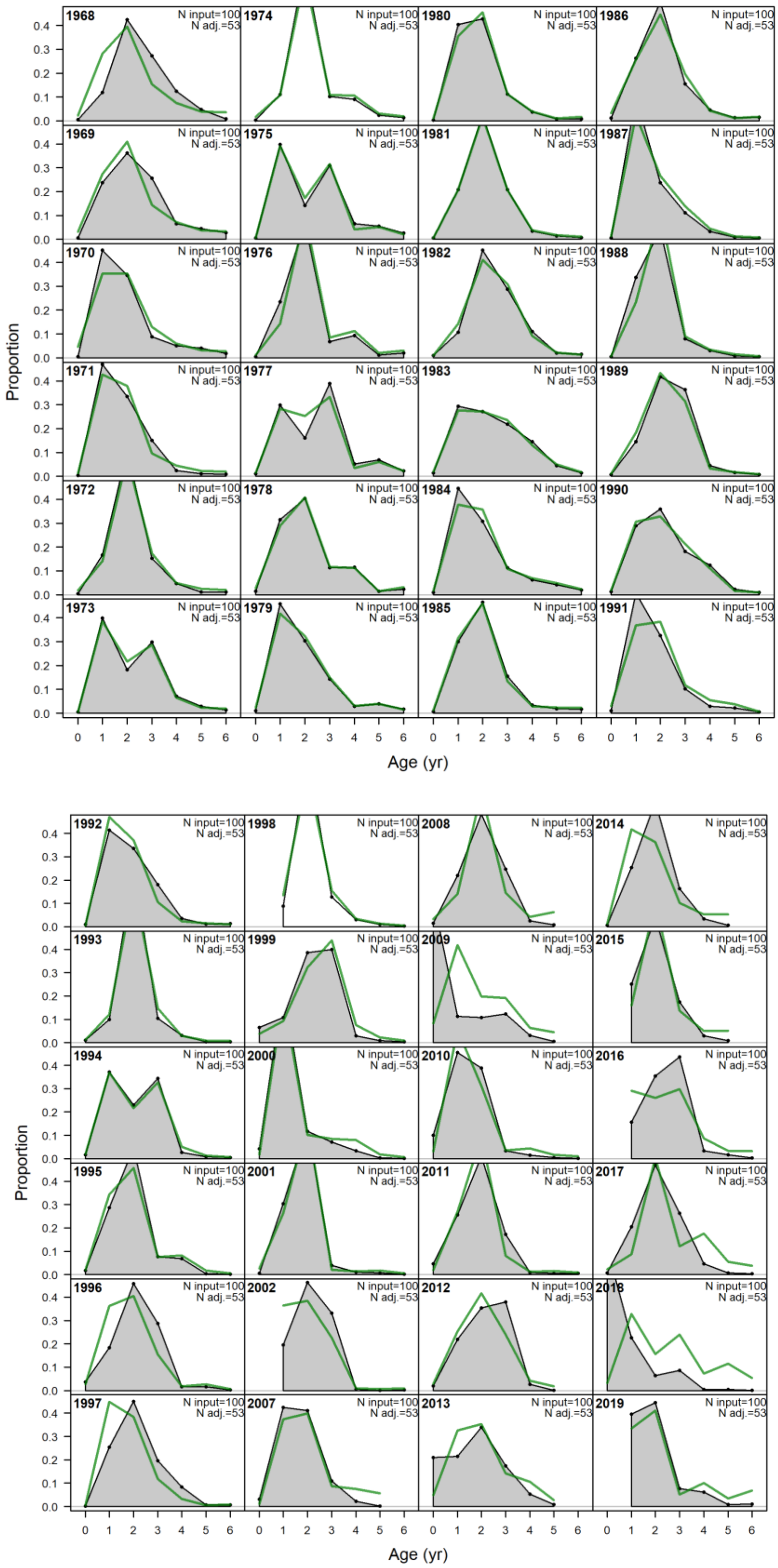


Figure 2.12. Length-at-age fit commercial data.

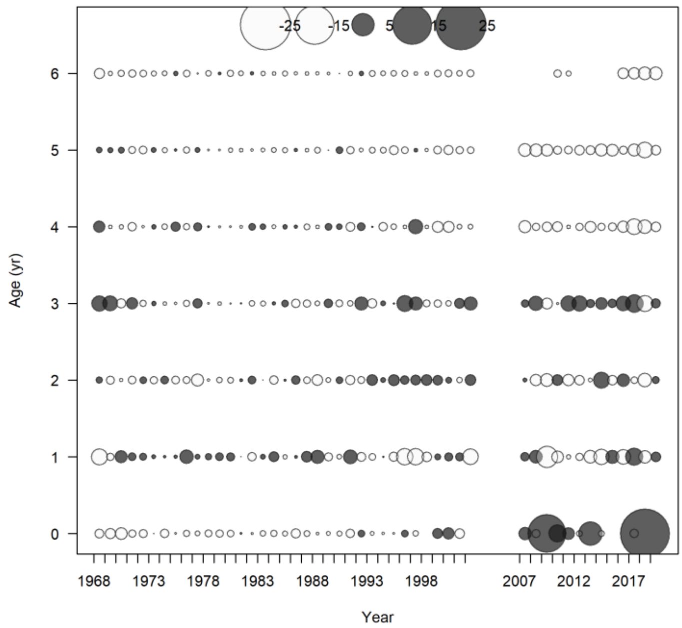
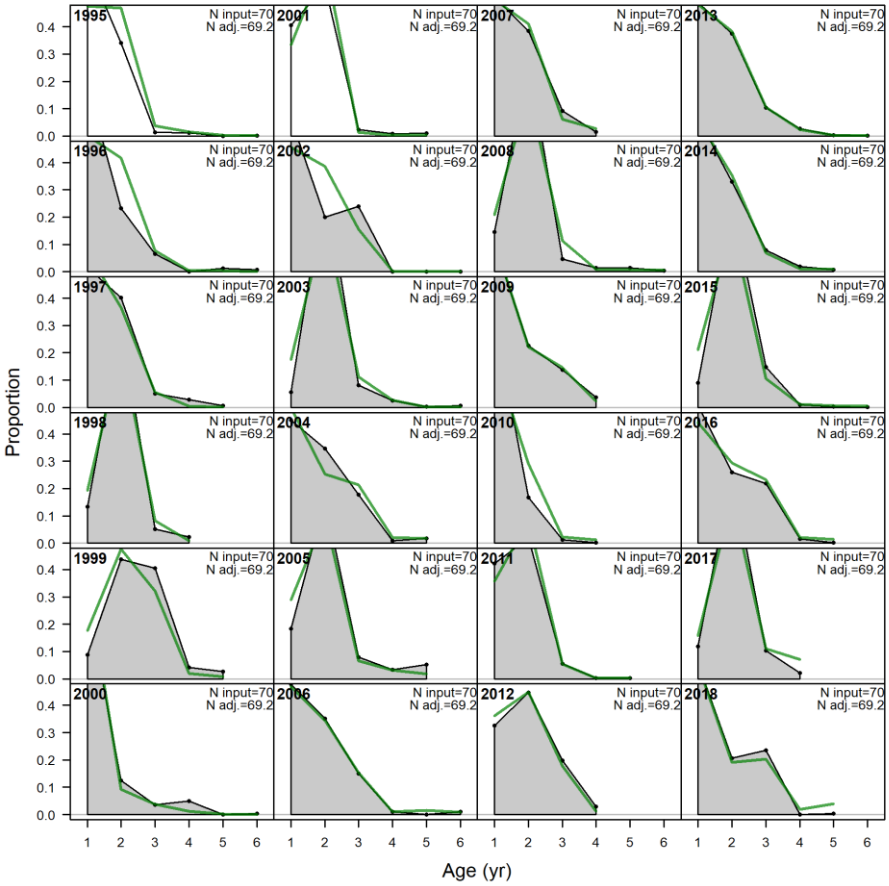
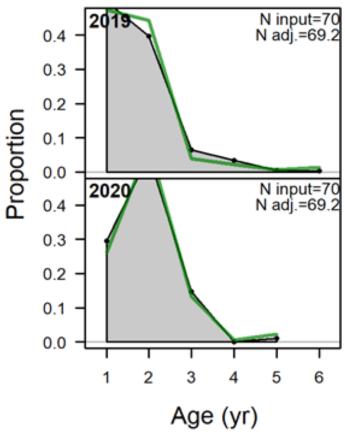


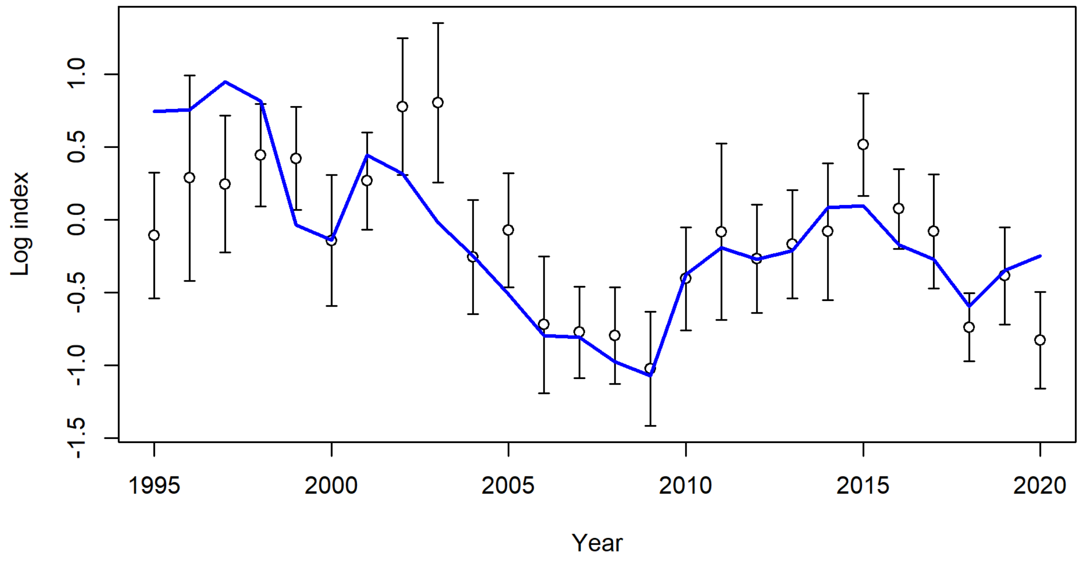
Figure 2.13. Residuals of commercial fleet. Years 2003-2005 and 2020 are missing as sampling effort was very poor. A number of years in more recent times have no age 0 catches.

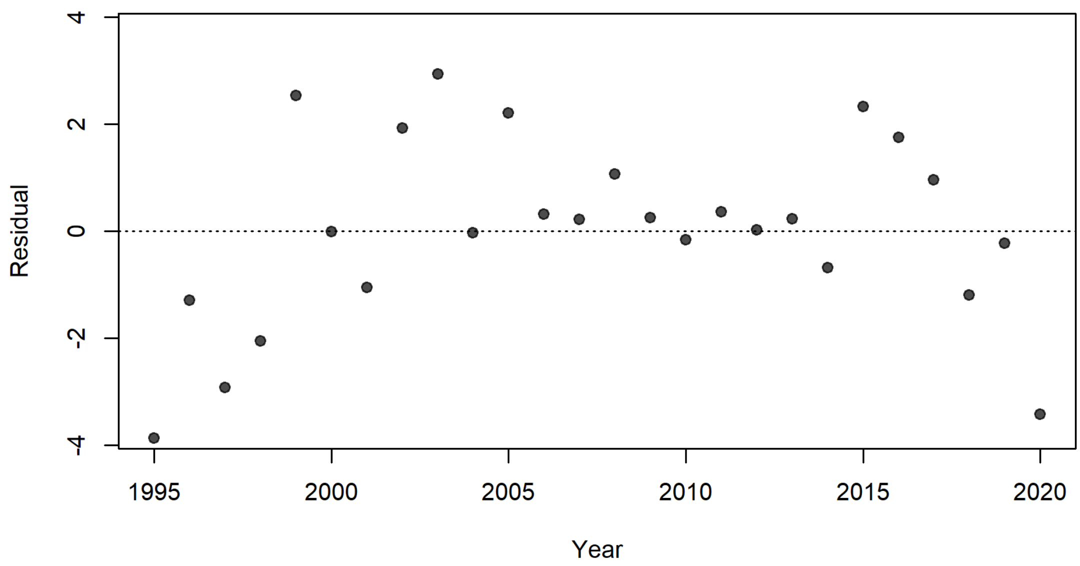


1995
2001
2007
2013
1996
2002
2008
2014
1997
2003
2009
2015
1998
2004
2010
2016
1999
2005
2011
2017
2000
2006
2012
2018
N input=70
N adj.=69.2
Proportion
Age (yr)



2019
2020
N input=70
N adj.=69.2
Proportion
Age (yr)


Log index
1.0
0.5
0.0
-0.5
-1.0
-1.5
1995
2000
2005
2010
2015
2020
Year


Residual
4
2
0
-2
-4
1995
2000
2005
2010
2015
2020
Year

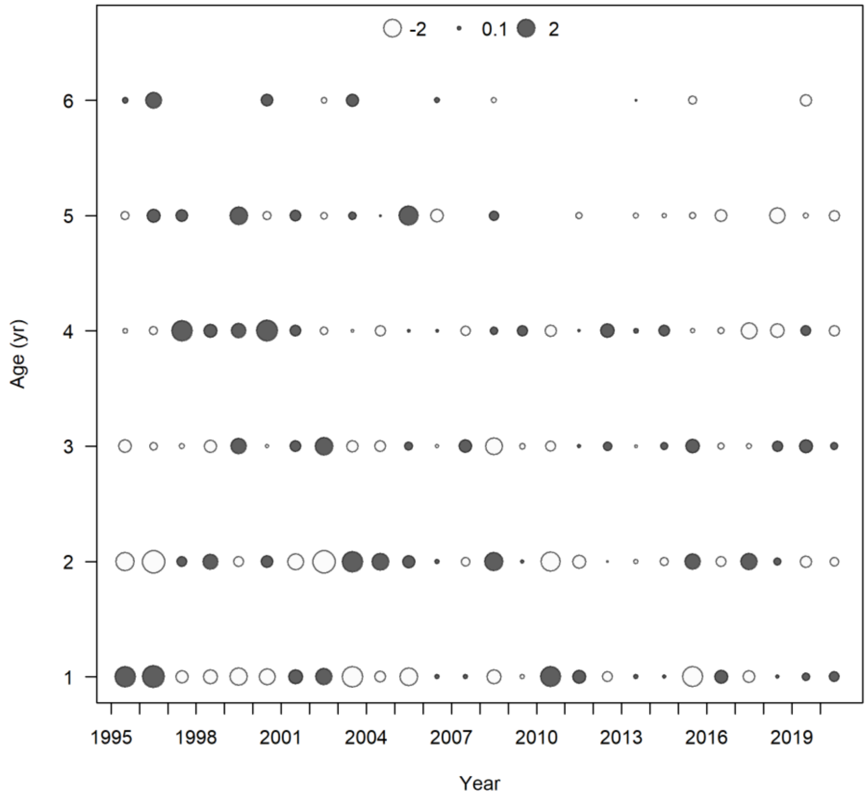
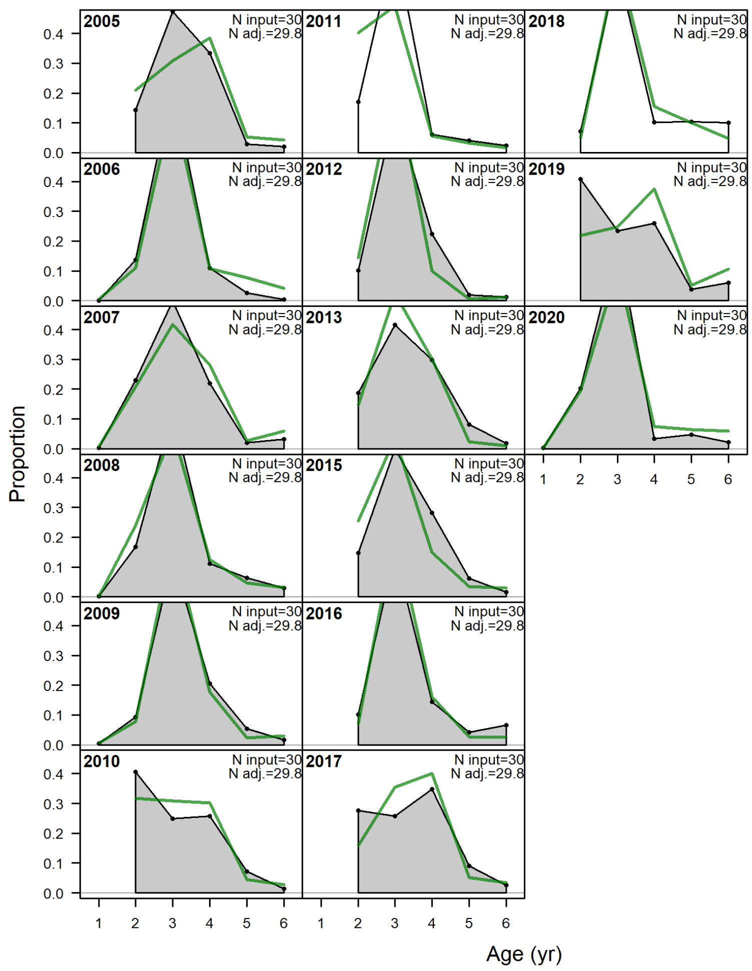
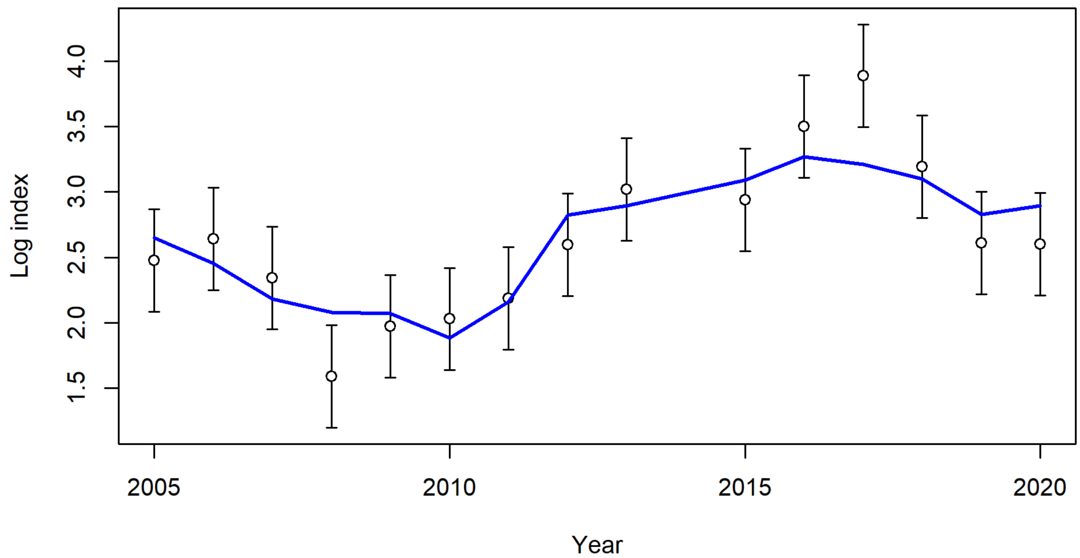
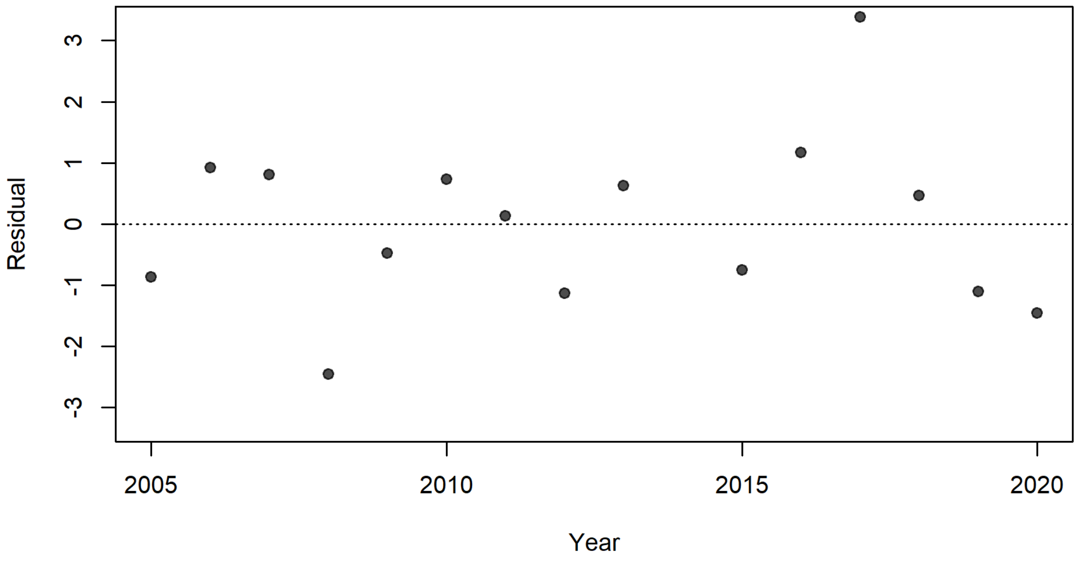


Figure 2.14. NIGFSQ1 from top to bottom: fit at age, log CPUE fit, index residuals, age residuals


2005
2006
2007
2008
2009
2010
2011
2012
2013
2015
2016
2017
2018
2019
2020
N input=30
N adj.=29.8
Proportion
Age (yr)


Log index
Year



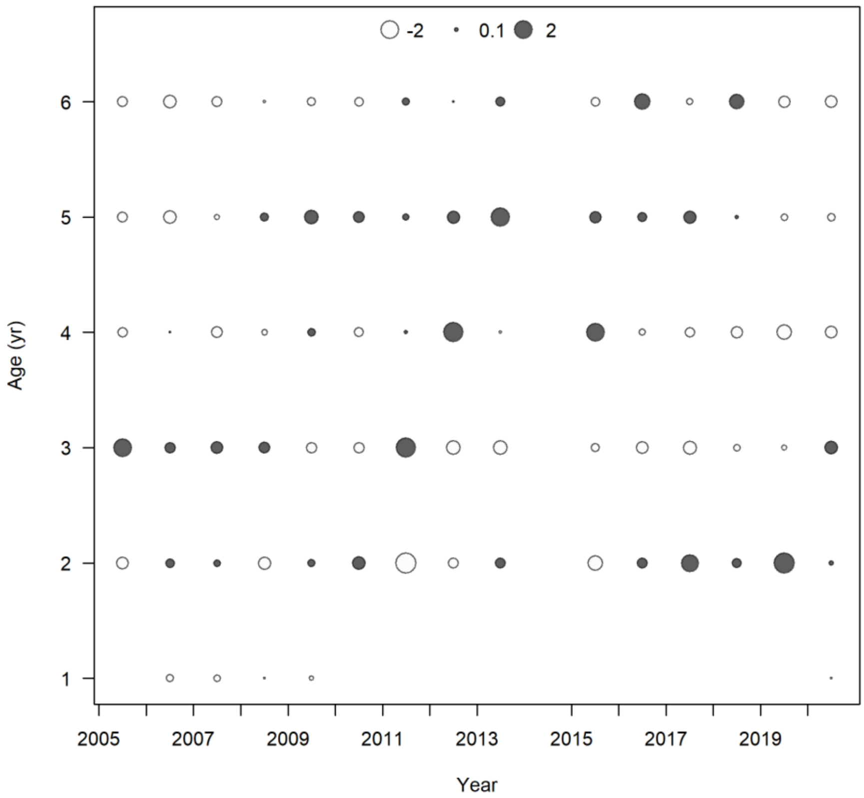


Figure 2.15. FSP survey. Fit at age, log CPUE fit, index residuals, age residuals

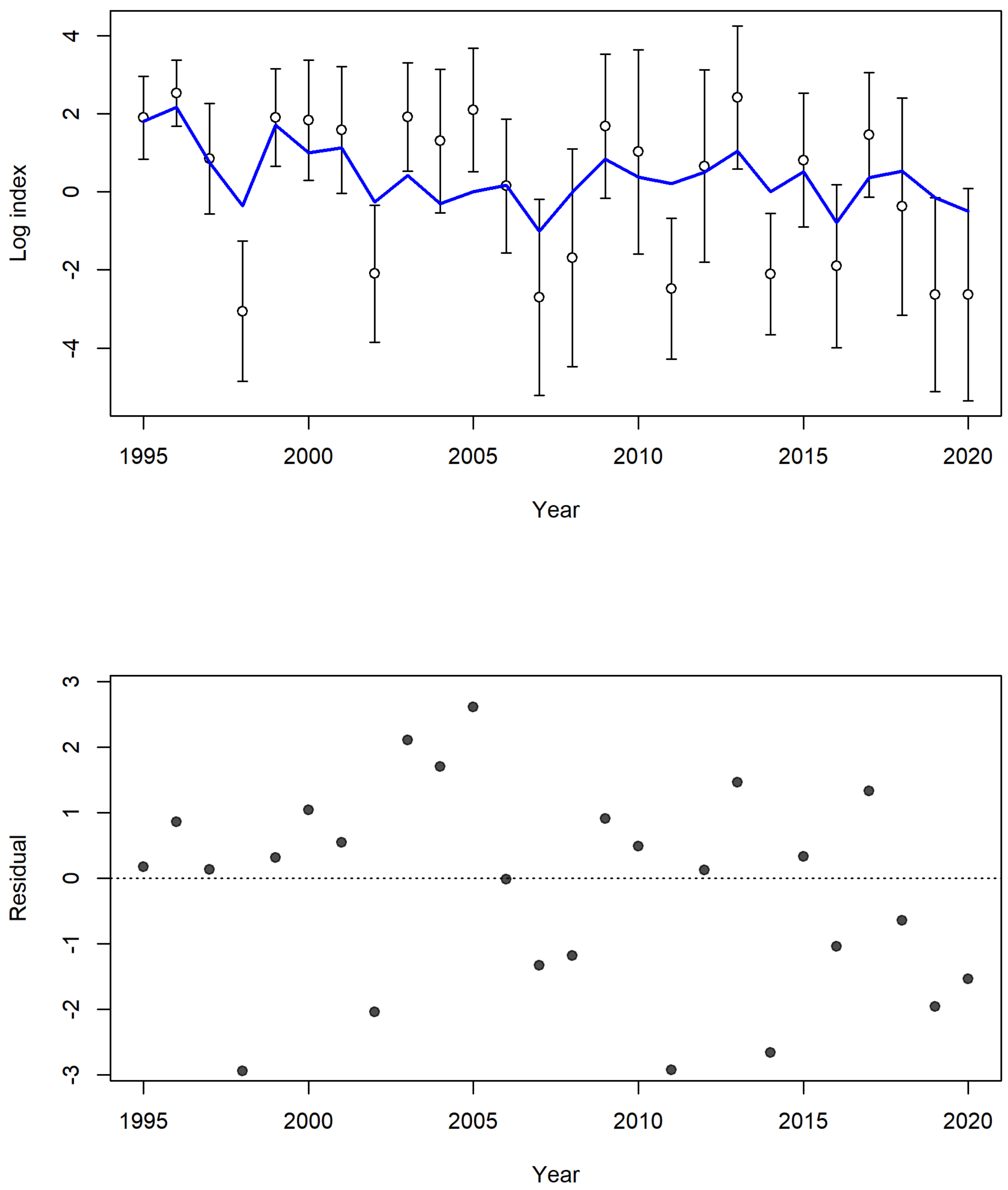


Figure 2.16. NIGFSQ4; log CPUE fit, index residuals.

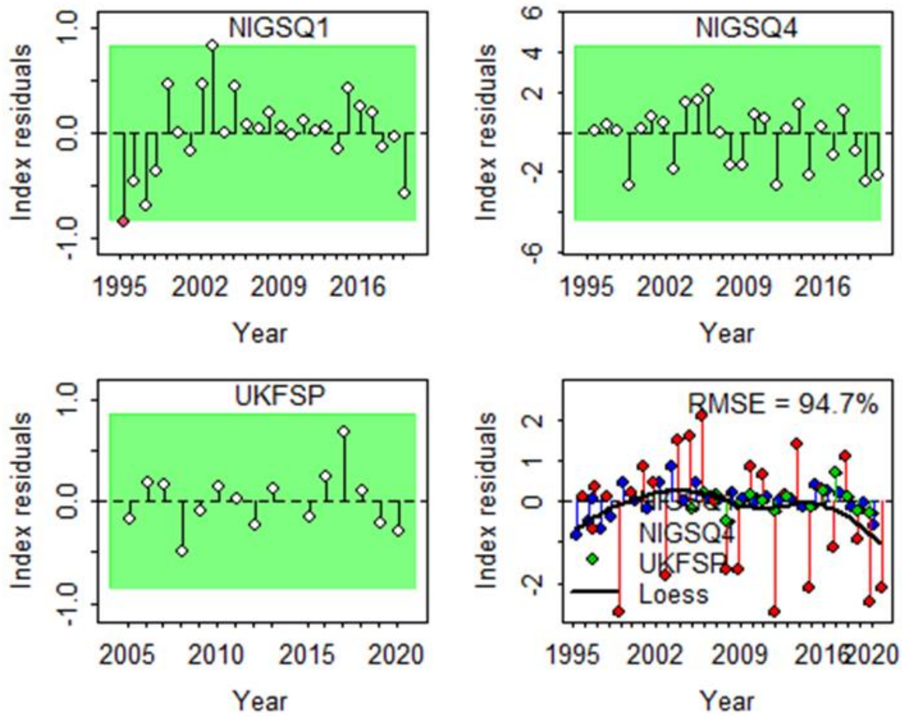


Figure 2.17. Runs test plot and Joint residual plot for fits to indices, where the vertical lines with points show the residuals, and solid black lines show loess smoother through all residuals. Green colour signals a good fit without patterns. Boxplots indicate the median and quantiles in cases where residuals from the multiple indices are available for any given year. Root-mean squared errors (RMSE) are included in the upper right-hand corner of the plot.

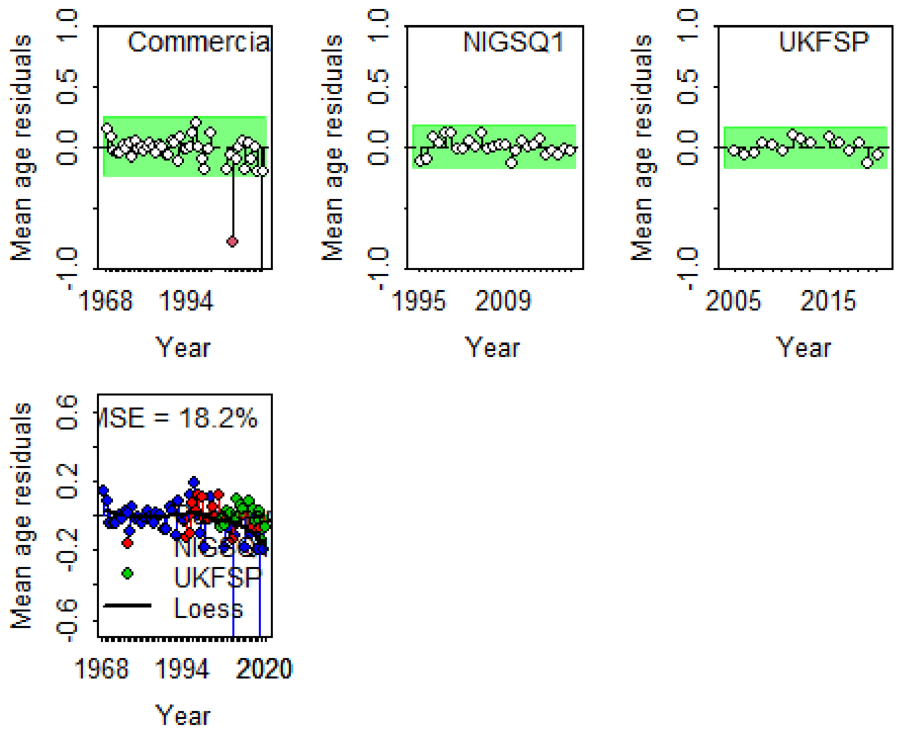


Figure 2.18. Runs test plot and Joint residual plot for mean ages from fits to surveys NIGFSQ1 and FSP and fisheries dependent age-composition data.

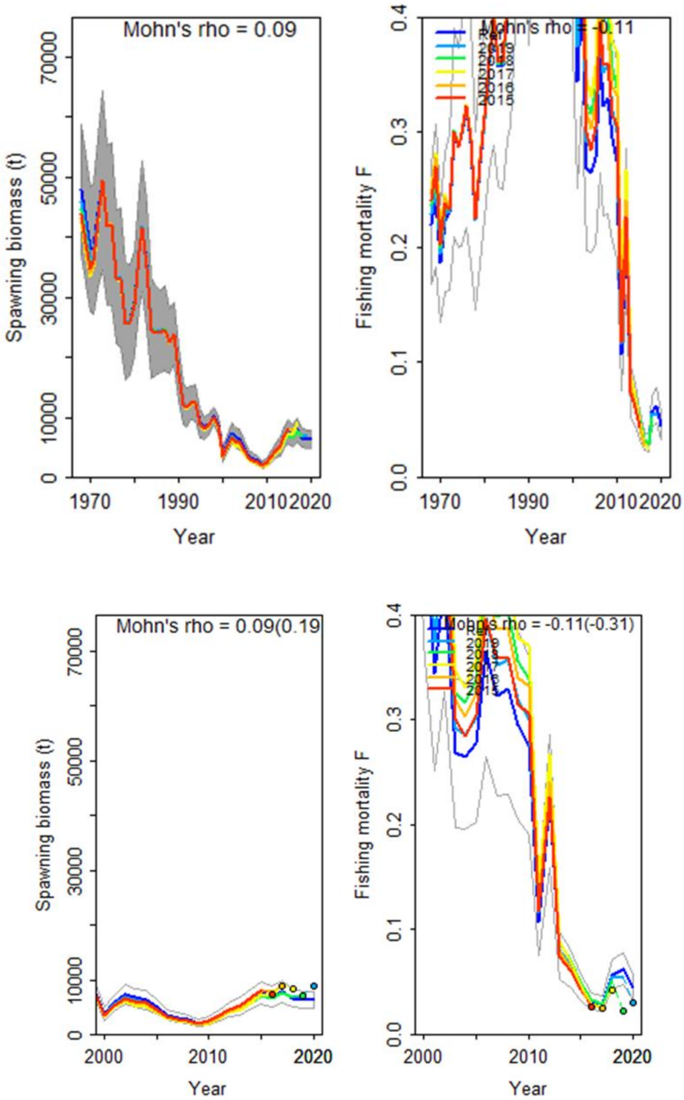


Figure 2.19 Retrospective plots with 5 peels and zoomed in retrospective plots. The envelope is in grey or white. Mohn's rho for SSB and F and in brackets one-year-ahead projections. Those are also denoted by color-coded dashed lines with terminal points shown for each model.

The overall fit of the model to indices, index ages and catch at age is good and Mohn's rho is at 0.09 (SSB) and -0.11 (F). A Mohn's rho for recruitment is not calculated as recruitment does not really follow a stock recruitment relationship.

2.3.5 Appropriate Reference Points (MSY)

At the benchmark discussion around reference points for Irish Sea cod it was agreed that the traditional ICES reference point framework does not really fit a stock like Irish Sea cod. To comply with the benchmark guidelines reference points were agreed in the following manner. An additional document exploring F_{ECO} as an additional reference point was created to be reviewed by an alternative set of reviewers as it was deemed to be outside the scope of WKNSCS.

Further issues with the use of the reference points in the traditional ICES way are outlined in the next section below.

The markdown script used to estimate the reference points is in **Error! Reference source not found.**. A working document outlining the peer reviewed and agreed (after the benchmark) F_{ECO} reference point is in **Error! Reference source not found.**.

Table 2.7. Agreed Reference Points

Reference Point	Value	Rationale
MSY $B_{trigger}$	11538t	B_{pa}
F_{MSY}	0.222	Median point estimates of (F_{MSY}) EqSim with combined SR
$F_{MSYLower}$	0.168	Median lower point estimates of (F_{MSY}) EqSim with combined SR
$F_{MSYUpper}$	0.273	Median upper point estimates of (F_{MSY}) EqSim with combined SR
B_{lim}	8303t	Lowest SBB with above-average recruitment (1998)
B_{pa}	11538t	B_{lim} combined with the assessment error
F_{lim}	0.43	F with 50% probability of SSB less than B_{lim}
F_{pa}	0.25	F_{05}
F_{ECO}	0.19	Ecosystem Indicator (I_s); FECO = F_{MSY} lower + ((FMSY upper - F_{MSY} lower)*I_s)

2.3.6 Future Research and data requirements

Future research into stock identification, stock area and mixture is needed and currently conducted. A project is on the way to investigate migratory behaviour of Irish Sea cod using DST tags and otolith trace element analysis. A project is currently under way.

Further investigation into the recreational fishery in Irish Sea waters, and in particular in the republic of Ireland is needed with the recreational fishery possibly becoming a more important part of the total removals. The research is under way.

It has become apparent that the current setting of ICES reference points might not be the best way to manage some stocks. The ICES reference point system tries to implement restrictions, such as F_{MSY} and $B_{trigger}$, to ensure that a stock that is fished at F_{MSY} will stay at safe SSB levels to ensure a sustainable level at which the stock can sustain itself. A stock that is below B_{lim}/ $B_{trigger}$ is supposed to return to SSB levels above the threshold when fishing is stopped or restricted to lower F values, estimated by a ratio of current SSB and $B_{trigger}$. However, this assumes that the stocks productivity has not changed.

Irish Sea stock has been under a strict cod recovery plan for 20 years, however, the stock failed to recover bar one cohort moving through the fishery. In particular we can see that the stock experienced a change in productivity throughout the last three decades which extremely impeded recruitment. Managing the stock by reducing the fishing pressure has not had the desired effect. This is partly due to a temperature impeded recruitment (Beggs *et al.*, 2014). One possibility is to include the temperature directly into the assessment and recruitment process, which is an opportunity with SS3, however was not possible within the timeframe of the benchmark. Alternatively, F_{ECO} (Bentley *et al.* 2021) could be used in the forecast and advice as an additional tool of the F_{MSY} procedure. The process is currently reviewed outside of the benchmark.

While the use of FECO will be in a step in the right direction, it remains to see if the ICES reference point framework is the right way to manage this stock with a shift in productivity. To further manage the stock it is essential to consider a time-varying dynamic estimation of B_0, "Dynamic B_0", the theoretical state the stock would be in each year if there had been no fishing (MacCall *et al.*, 1985)). This assumes all the biological states, especially the recruitment deviations and recruitment, but also M, growth would have been the same without fishing pressure as with fishing pressure. Figure 2.20 shows the theoretical development of the Irish Sea cod stock without fishing in relation to the stock development calculated from the stock assessment under fishing conditions.

A strong decline in SSB in the absence of fishery can be seen in between the early 1990s until 2004 where it looks as if a new equilibrium state might have been reached at around 10 000 t.

This leads to the question as to where one should set adequate reference points.

One suggestion rather than using the ICES procedure would be to explore a management strategy evaluation (MSE) to investigate the future management of the stock.

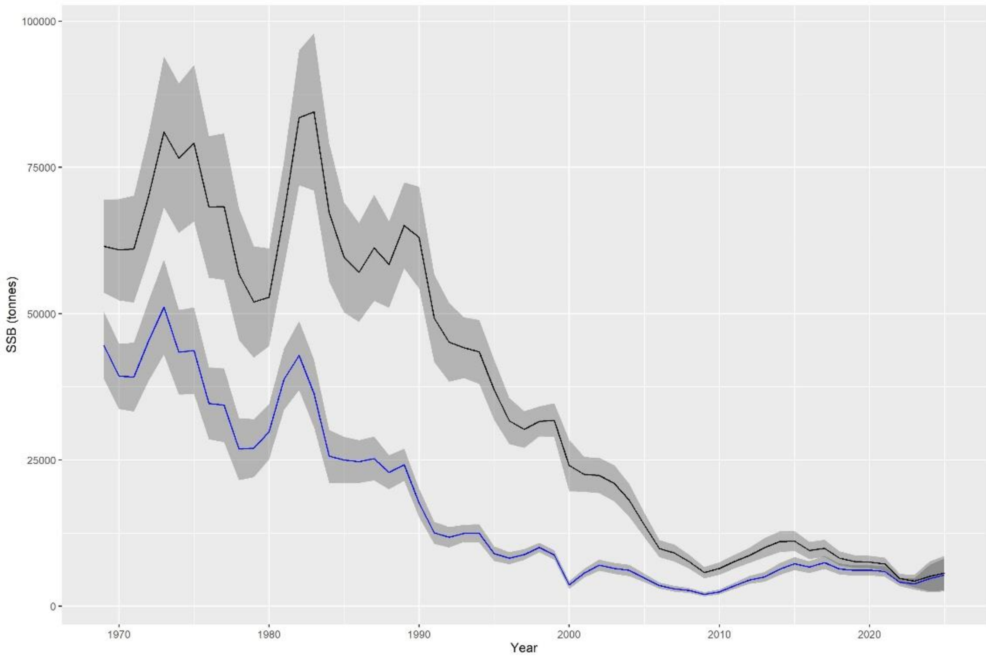


Figure 2.20. Dynamic B_0- black (i.e. the expected SSB without fishery removals) and SSB estimated by SS3-blue.

Comparing the SSB estimate from the current assessment with the one from the previous benchmark (WKIRISH 2017) ASAP model shows a stark difference in the historic stock development: While SSB trend of the two assessments is the same, the initial stock size in the older model was considerably lower (Figure 2.21). The more recent SSB development, since the early 1990s, on the other hand is very similar. Additionally, there are large confidence intervals around the earlier years SSB estimation (Figure 2.7) in the current assessment. The large confidence intervals are likely due to the absence of any tuning series prior to 1995 and the assessment is purely driven by the commercial catches. The stark change in the earlier years from the previous assessment could origin in the increased natural mortality M. It is possible that the stock did not only experience a change of productivity but also a change in M over the years, with a chance of having been exposed to a lower M in the earlier years. On the other hand, the earlier years assessment are purely based on catches and F estimated from catches. An increase in M will considerably increase the total mortality Z, which then inevitably leads to the estimation of a higher SSB. This in turn leads to higher values of B_{lim} and $B_{trigger}$ when considering the full time-series, making a point to only include the SSB estimates, F and recruitment from 1995 onwards into the estimation of the reference points.

This should be further investigated in the future, in combination with the dynamic B_0.

Figure 2.21 shows not only the estimated assessment SSB, but also the SSB level estimated from an independent egg survey conducted in 5 years (blue dots), which are in close agreement with the most recent assessment.

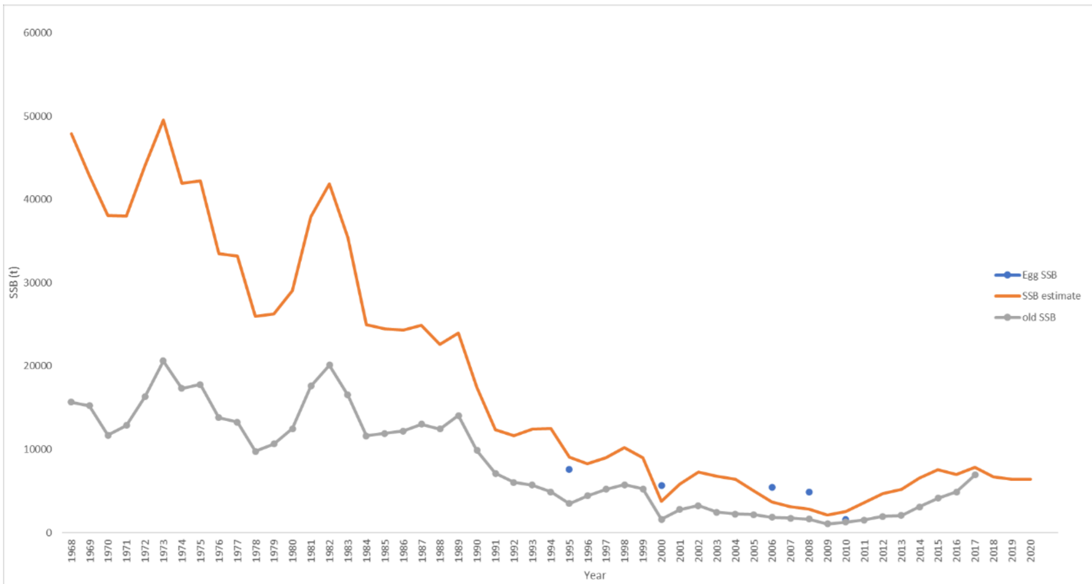


Figure 2.21: Estimate of SSB over time from the old model fitting, the current model and from the egg survey back calculated SSB.

2.4 References

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2.5 Steps to derive reference points

We describe the steps involved in estimating PA and MSY reference points including the R-code for Irish Sea Cod as part of WKNSCS benchmark. The outputs of individual Eqsim runs can have small variations at the 3rd decimal place.

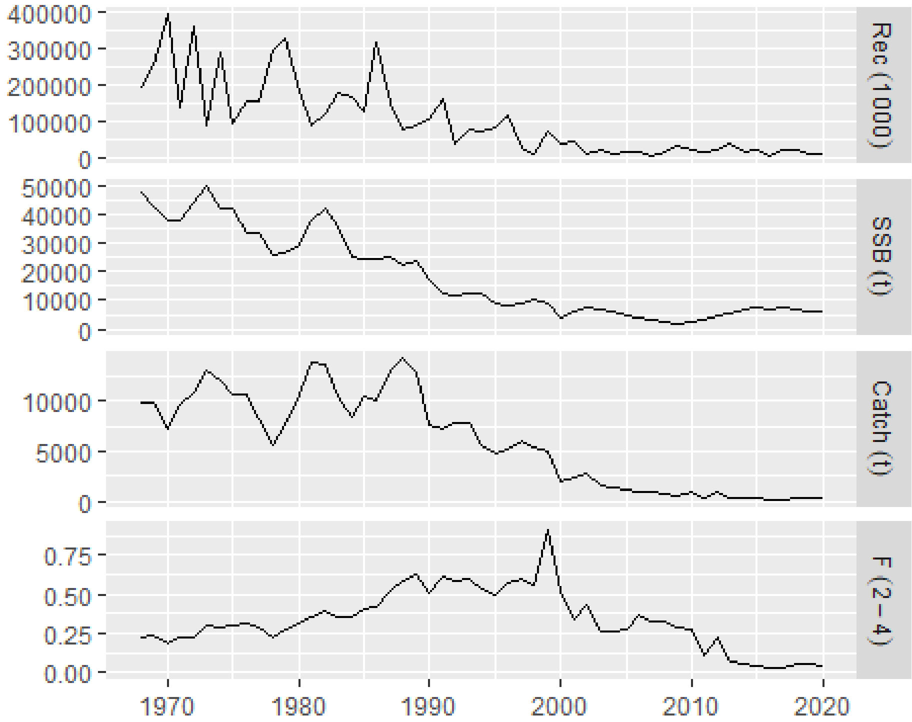

Figure 2.22. Stock Recruitment, SSB, Catch and F over the time-series

```
#stock<-window(stock,start=1996)
```

SSB summary and recruitment summary

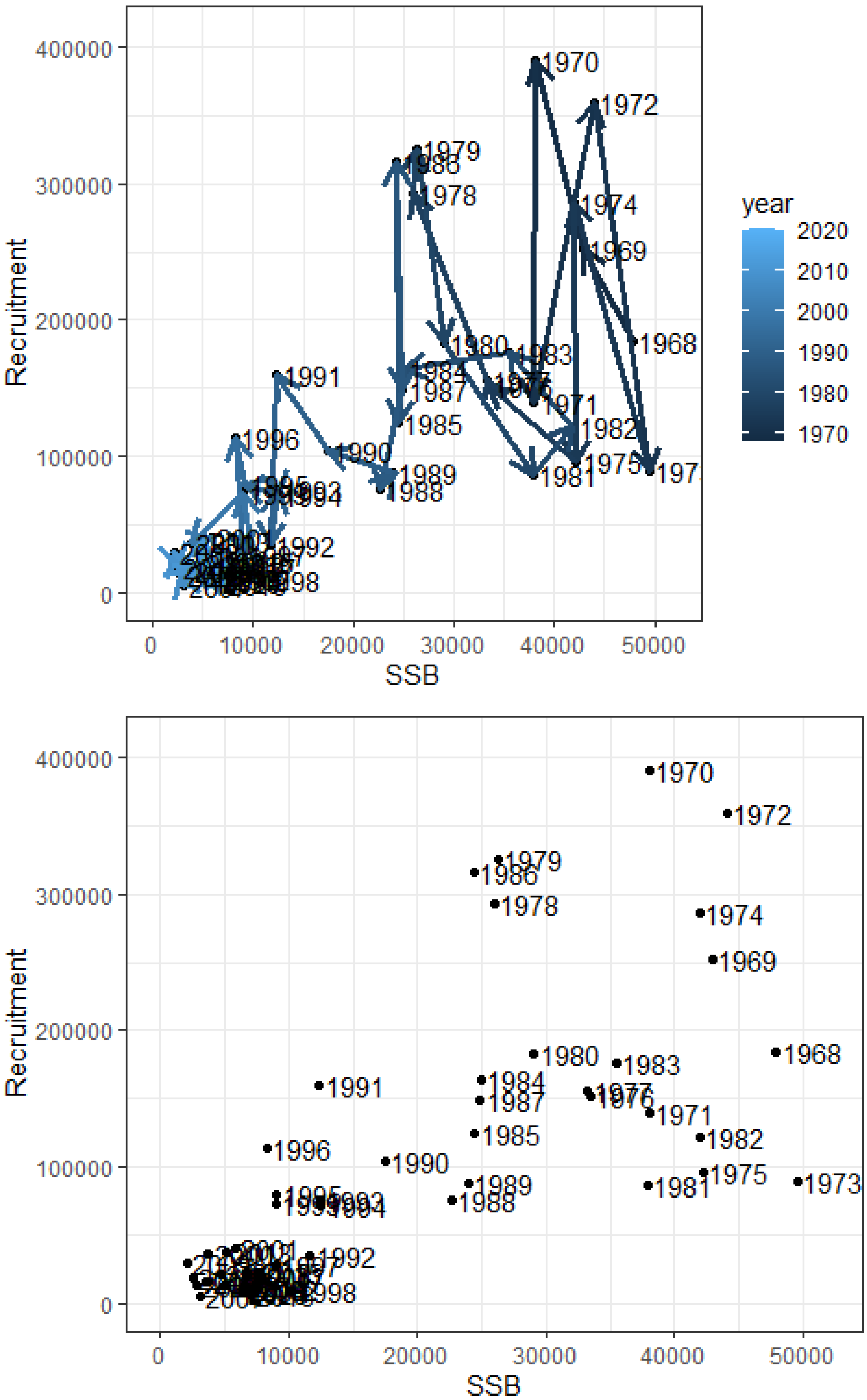

Figure 2.23. recruitment and SSB pair by year.

```
## [1] 8303.458
```

The first step in the process is to examine the stock and recruit pairs and decide on a Blim value.

For Irish Sea Cod: Stock type Type 1 Spasmodic stocks stocks with occasional large year classes. Blim is based on the lowest SSB where above average recruitment is observed resulting in a Blim of 8303t

Table 1. Summary of values for SSB and recruitment

SSB ref value	SSB Estimate
Terminal SSB	6386t
Min observed	2151t
50th Percentile	11674t
75th Percentile	29061t
Max observed	49538t
Blim	8303t

ICES defines yield to be catch above the minimum catch/conservation size (ICES technical guidelines for setting reference points for cat1 and 2: http://ices.dk/sites/pub/Publication%20Reports/Guidelines%20and%20Policies/12.04.03.01_Reference_points_for_category_1_and_2.pdf).

Fix for zeros

```
# get rid of 0-group (shouldnt affect outcome)
#stock <- trim(stock,age=1:6)

stock@catch.n <- ifelse(stock@catch.n==0,0.001,stock@catch.n)
stock@catch.wt <- ifelse(stock@catch.wt==0,0.001,stock@catch.wt)
stock@landings.n <- ifelse(stock@landings.n==0,0.001,stock@landings.n
)
stock@landings.wt <- ifelse(stock@catch.wt==0,0.001,stock@catch.wt)

SetBlim<- blim
FixedBlim <- function (ab, ssb)
{log(ifelse(ssb >= SetBlim, ab$a * SetBlim, ab$a * ssb))}{Beggs, 2014
#225}

fit <- eqsr_fit(stock, nsamp = 1000, models = c("FixedBlim", "Segreg"
))
eqsr_plot(fit,ggPlot=FALSE)
```

In the ICES approach Bpa is the estimated SSB which ensures that the true SSB has less than 5% probability of being below Blim. In practice this requires an estimate of sigma, the standard deviation of ln(SSB) at the start of the year following the terminal year of the assessment. Here sigma is set to 0.3 as is suggested for “short lived species”.

The default SSBcv is used as 0.2.Fcv is 0.212 with F_{phi} = 0.423 as default values from WKMsyRef4.

Refernce Point	Estimate
Blim	8303t
Bpa	11538t

Estimating F_{MSY} using segmented regression stock recruit relationship

The base Eqsim analysis largely uses default settings for the input parameters: Selection pattern is the default 10-year range. Biological parameters is the default of 10 years. The scan sequence is fairly granular to have more consistent interpolations. The uncertainties are as specified above.

In the case of the Irish Sea cod we use a model averaged stock recruit relationship of segmented regression, Ricker and Beverton Holt. The approach is applied to the full time-series. Blim and Bpa are set from the analysis above with Blim from the stock recruit pairs as 8303t.

```
fit <- eqsr_fit(stock, nsamp = 1000, models = c( "Ricker", "Bevholt",
"Segreg"))
eqsr_plot(fit,ggPlot=FALSE)
```

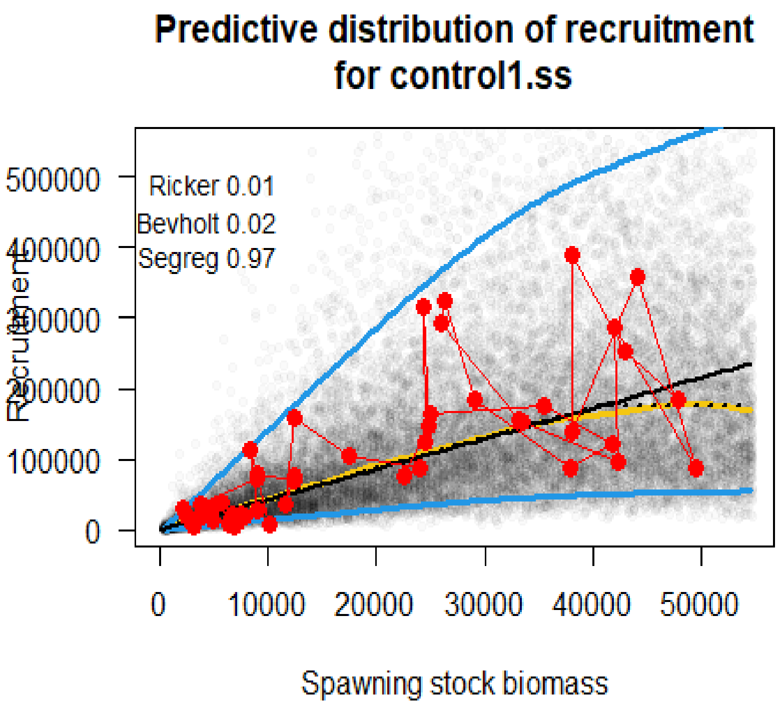

Figure 2.24 Modelled stock recruit relationship

Now run with with Blim as 8303t, error and model averaged regression stock recruit relationship Step 1

```
setup <- list(data = stock,
             bio.years = c(2011, 2020),  # last 5 yrs
             bio.const = FALSE,
             sel.years = c(2011, 2020),  # last 5 yrs
```

```
              sel.const = FALSE,
              Fscan = seq(0,1.5,by=0.05),
              Fcv = 0.212,    # ICES default 0.212
              Fphi = 0.423,   # ICES default 0.423
              Blim = blim,
              Bpa = bpa,
              Btrigger = NA,
              extreme.trim=c(0.05,0.95)
)


res <- within(setup,
              {
                fit <- eqsr_fit(stock, nsamp = 999, models = c("Segre
g","Ricker","Bevholt"))
                sim <- eqsim_run(fit, bio.years = bio.years, bio.cons
t = bio.const,
                                   sel.years = sel.years, sel.const = s
el.const, Fscan = Fscan, rhologRec = TRUE,
                                   Fcv = Fcv, Fphi = Fphi, Blim = Blim,
Bpa = Bpa,
                                   extreme.trim = extreme.trim, verbose
= FALSE)
              })

knitr::kable(t(res$sim$Refs2), digits=c(3,3,0,0,0,0))
```

F_{MSY} is initially calculated as the F that maximizes median long-term yield in stochastic simulation under constant F exploitation (i.e. without MSY $B_{trigger}$).In figure 3 below we see that the median estimate of F_{MSY} is 0.2 which is expected to generate median catches of 7840.418 t.

```
fmsy<-round((res$sim$Refs2["lanF", "medianMSY"]),3)
fmsyL<-round((res$sim$Refs2["lanF", "Medlower"]),3)
fmsyU<-round((res$sim$Refs2["lanF", "Medupper"]),3)
eqsim_plot_range(res$sim, type="median")
```

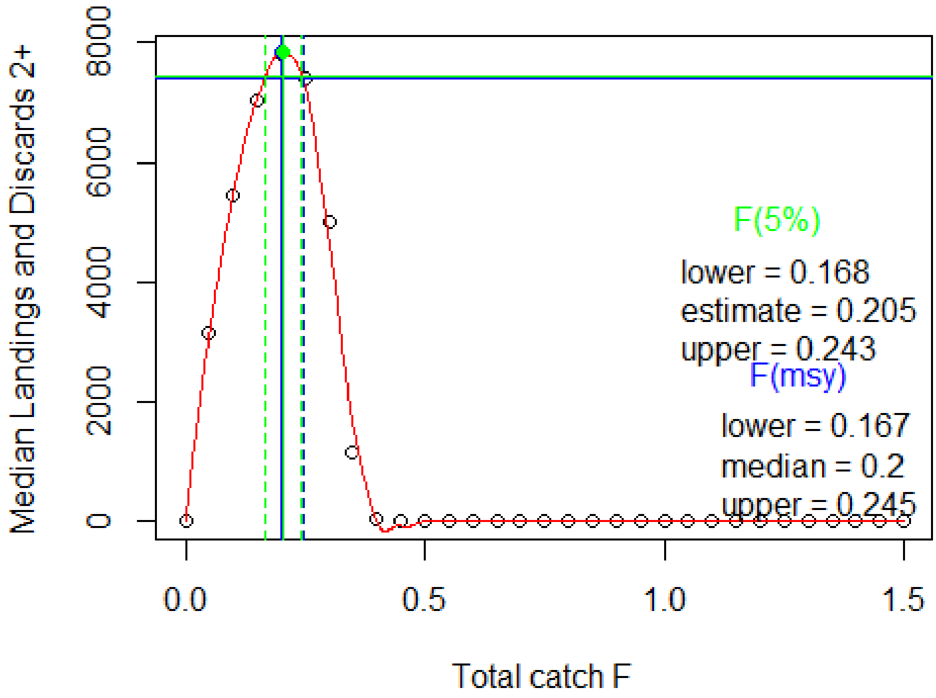

Figure 2.25 Yield curve and FMSY upper and lower ranges (vertical blue lines) and Flim upper and lower ranges (vertical green lines) for the segmented regression recruit model. Fmsy median point estimates and upper and lower bound are given. The value for median SSB corresponding to the lower and upper Fmsy bounds are also shown on the plot.

Flim & Fpa (Segmented regression stock recruit relationship) Following the ICES procedure we need to calculate the Fpa. If FMSY is greater than Fpa then we reduce FMSY to Fpa.Eqsim is run with no error (Btrigger = 0, Fcv = 0 & Fphi = 0) to estimate Flim with segmented regression with breakpoint at BLim.

To calculate Flim we use a loess smoother to predict the F that has a 50% probability of bringing the stock to Blim. The sigma for the buffer is 0.2 default from guidelines.

```
setup <- list(data = stock,
              bio.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              bio.const = FALSE,
              sel.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              sel.const = FALSE,
              Fscan = seq(0,1.5,by=0.05),
                Fcv  = 0.0,     # ICES default 0.212, was 0.30
                Fphi = 0.0,    # ICES default 0.423, was 0.28
              Blim = blim,    # min.SSB (Bloss) was = 6669.75 at last
benchmark 2015
              Btrigger = 0,
              Bpa = bpa,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95)
             )
SetBlim<- blim
FixedBlim <- function (ab, ssb)
{log(ifelse(ssb >= SetBlim, ab$a * SetBlim, ab$a * ssb))}
```

```
res <- within(setup,
              {
                fit <- eqsr_fit(stock, nsamp = 999, models = c("Fixed
Blim"))
                sim <- eqsim_run(fit, bio.years = bio.years, bio.cons
t = bio.const,
                                 sel.years = sel.years, sel.const = s
el.const, rhologRec = TRUE ,Fscan = Fscan,
                                 Fcv = Fcv, Fphi = Fphi, Blim = Blim,
Bpa = Bpa,
                                 extreme.trim = extreme.trim, verbose
= FALSE)
              })

eqsim_plot_range(res$sim, type="median")
```

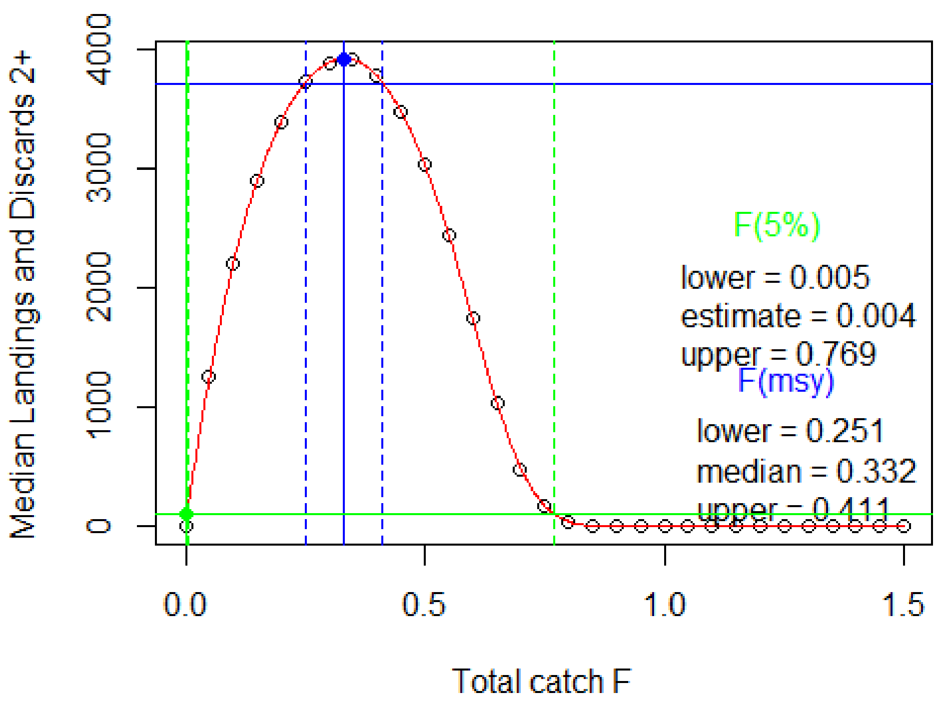

Figure 2.26.

```
data.95<-res$sim$rbp
x.95<-data.95[data.95$variable == "Spawning stock biomass",]$Ftarget
b.95<-data.95[data.95$variable == "Spawning stock biomass",]$p50
b.lm<-loess(x.95~b.95)
flim<-predict(b.lm, blim)
fpa<-Fpa(flim, .2)
fmsy_old <- fmsy
fmsy<-ifelse(fmsy>fpa,fpa,fmsy)
```

The lower of the F_{MSY} estimate 0.2 and Fpa 0.3119592 values should be used as F_{MSY}: 0.2.

Running the code with no error gives an estimate of Flim = 0.433, and estimate of Fpa = 0.312.

##MSY Btrigger without error and model averaged stock recruit relationships Following the ICES procedure we calculate, with no assessment/advice error and Btrigger = 0 A similar approach is used to estimate the MSYBtrigger that you would get from the analysis to test if this is higher than Bpa.

```
setup <- list(data = stock,

              bio.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              bio.const = FALSE,
              sel.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              sel.const = FALSE,
              Fscan = seq(0,1.5,by=0.05),
                Fcv  = 0.0,    # ICES default 0.212, was 0.30
                Fphi = 0.0,   # ICES default 0.423, was 0.28
              Blim = blim,    # min.SSB (Bloss) was = 6669.75 at last
benchmark 2015
              Bpa = bpa,
              Btrigger = 0,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95)

)

res <- within(setup,
              {
                fit <- eqsr_fit(stock, nsamp = 999, models = c("Fixed
Blim"))
                sim <- eqsim_run(fit, bio.years = bio.years, bio.cons
t = bio.const,
                                 sel.years = sel.years, sel.const = s
el.const, rhologRec = TRUE, Fscan = Fscan,
                                 Fcv = Fcv, Fphi = Fphi, Blim = Blim,
Bpa = Bpa, Btrigger = 0,
                                 extreme.trim = extreme.trim, verbose
= FALSE)
              })


data.05<-res$sim$rbp
x.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$Ftarg
et
b.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$p05
plot(b.05~x.05, ylab="SSB", xlab="F")
```

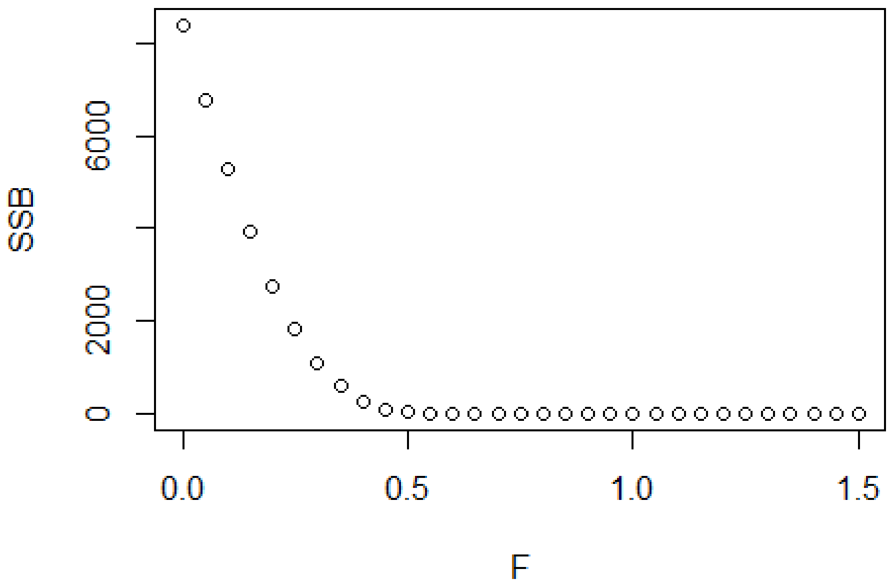

Figure 2.27.

```
b.lm <- loess(b.05 ~ x.05)
(msybtrig <- predict(b.lm, fmsy))

## [1] 3212.342

msybtrig<-ifelse(msybtrig<bpa,bpa,msybtrig)
msybtrig

## [1] 11538
```

MsyBrigger based on above is 11538. Taking the largest of the two gives MSYBtrigger of 11538t.

###ICES Advice rule - assessment error and Btrigger and model segmented regression stock recruit relationship.

The next step is to evaluate the ICES advice run via the stochastic simulation with these values of FMSY and MSY Btrigger. If the F5% in this run is smaller than the candidate F_{MSY} the initial F_{MSY} is reduced to F5%. So EqSim is run again this time including the selected MSY Btrigger value and error.

```
setup <- list(data = stock,
              bio.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              bio.const = FALSE,
              sel.years = c(2011, 2020),  # last 5 yrs  # c(2014, 201
8),  updated 25-July-2020
              sel.const = FALSE,
              Fscan = seq(0,1.5,by=0.05),
              Fcv = 0.212,  # ICES default 0.212
              Fphi = 0.423, # ICES default 0.423
              Blim = blim,    #
```

```
                Bpa = bpa,
                Btrigger = msybtrig,
                extreme.trim=c(0.05,0.95)
                )

res <- within(setup,
                {
                  fit <- eqsr_fit(stock, nsamp = 999, models = c("Segre
g"))
                  sim <- eqsim_run(fit, bio.years = bio.years, bio.cons
t = bio.const,
                                   sel.years = sel.years, sel.const = s
el.const, rhologRec = TRUE, Fscan = Fscan,
                                   Fcv = Fcv, Fphi = Fphi, Blim = Blim,
Bpa = Bpa,Btrigger = Btrigger,
                                   extreme.trim = extreme.trim, verbose
= FALSE)
                })

eqsim_plot_range(res$sim, type="median")
```

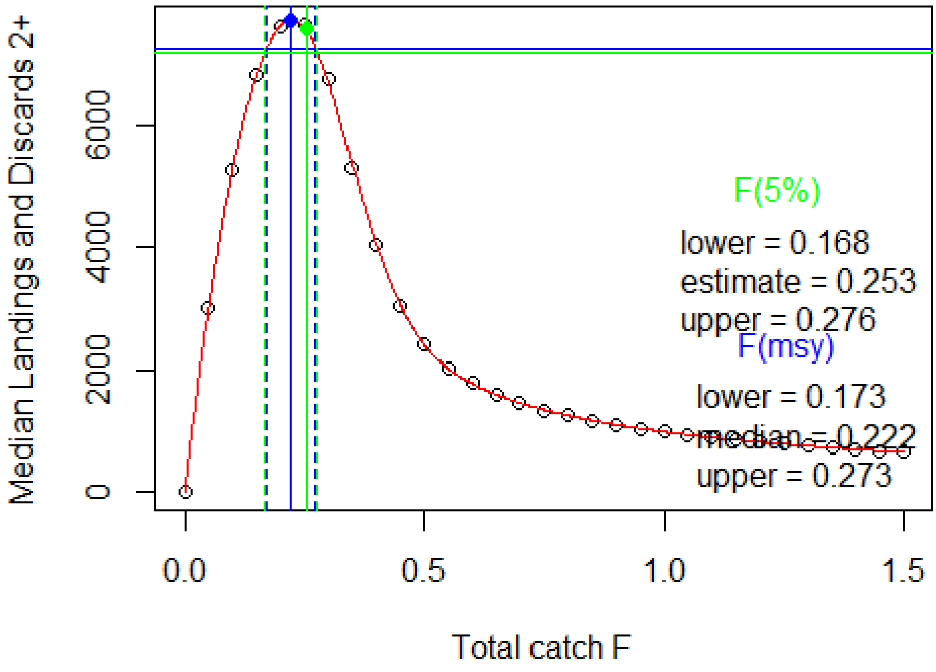

Figure 2.28.

```
eqsim_plot_range(res$sim, type="ssb")
```

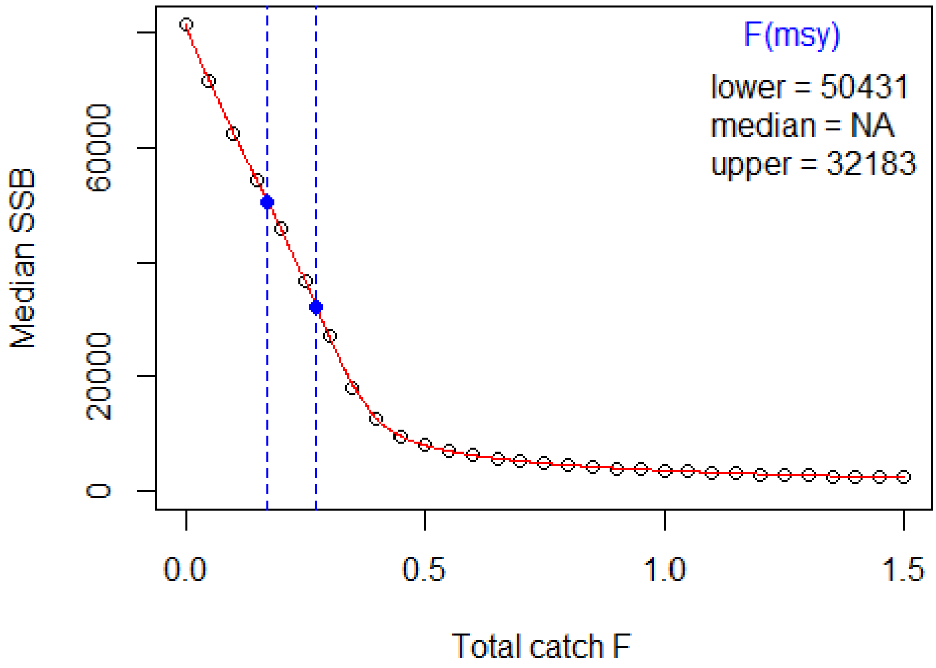

Figure 2.29.

```
ffmsy<-round((res$sim$Refs2[2,4]),3)
ff5<-round((res$sim$Refs["catF", "F05"]),3)
fmsy<-ifelse(ff5>fmsy,fmsy, ff5)

  data.95 <- res$sim$rbp
  x.95 <- data.95[data.95$variable == "Catch", ]$Ftarget
  y.95 <- data.95[data.95$variable == "Catch", ]$p50
  lm.pred <- data.frame(x = seq(min(x.95), max(x.95), length = 1000),
y = rep(NA, 1000))
  x.lm <- loess(y.95 ~ x.95, span = 0.2)
  interval = 0.95

  f05 <- res$sim$Refs["catF", "F05"]
  yield.f05 <- predict(x.lm, newdata = f05)
  yield.f05.95 <- interval * yield.f05
  lm.pred$y <- stats::predict(x.lm, newdata = lm.pred$x)
  lm.pred.f05.95 <- lm.pred[lm.pred$y >= yield.f05.95,]
  f05.lower <- min(lm.pred.f05.95$x)
  f05.upper <- max(lm.pred.f05.95$x)
  ff5<-round((res$sim$Refs2["lanF", "F05"]),3)

fmsyU <- res$sim$Refs2["lanF", "Medupper"]
fmsyL <- res$sim$Refs2["lanF", "Medlower"]
fmsy <- res$sim$Refs2["lanF", "medianMSY"]

FMSYL<-ifelse(f05.lower<fmsyL,f05.lower,fmsyL)
FMSYU<-ifelse(f05.upper<fmsyU,f05.upper,fmsyU)
FMSY<-ifelse(f05<fmsy,f05,fmsy)
```

```
eqsim_plot_range(res$sim, type="median")
```

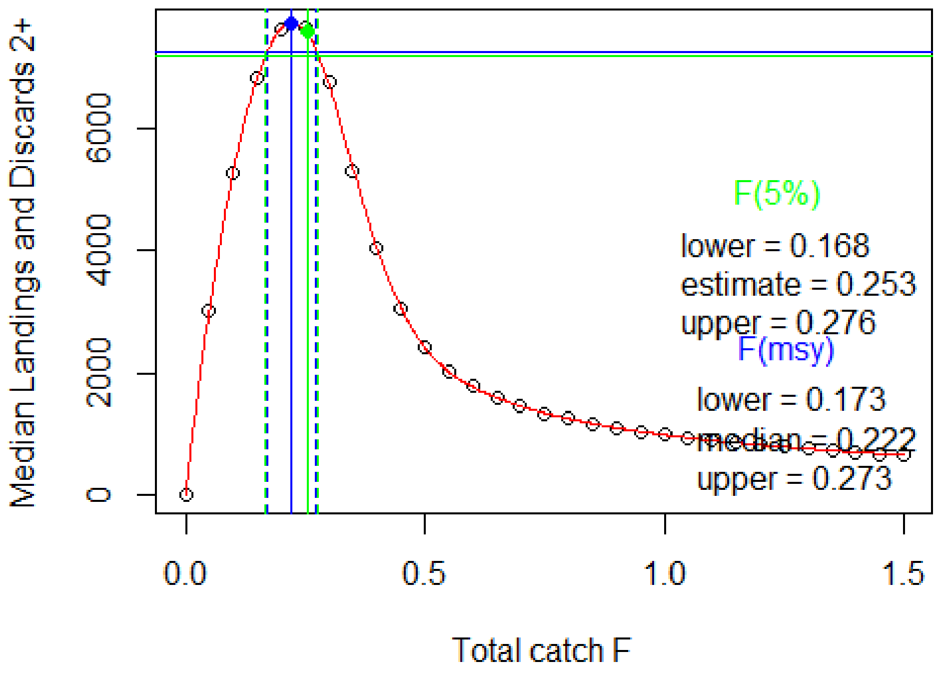

Figure 2.30

```
x.95 <- data.95[data.95$variable == "Landings", ]$Ftarget
y.95 <- data.95[data.95$variable == "Landings", ]$p50

eqsim_plot(res$sim,catch=F)
```

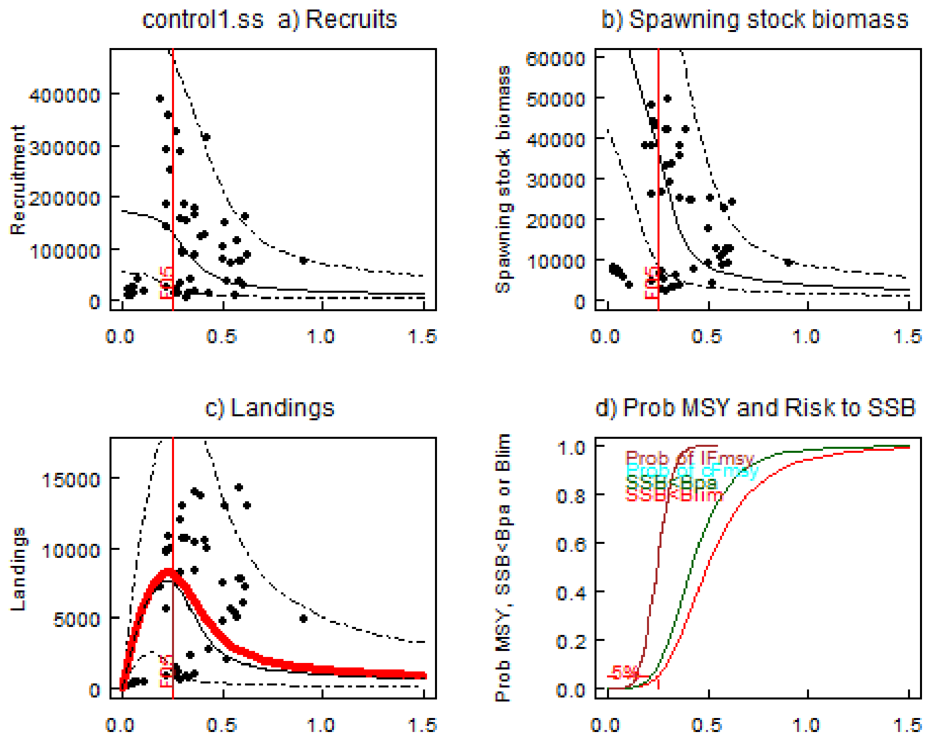

Figure 2.31. F_{MSY} **estimated as to 0.222**

Table 2.8. Reference points.

Reference Point	Value	Rationale
$B_{MSY\ Btrigger}$	11538t	B_{pa}
F_{msy}	0.222	Median point estimates of (FMSY) EqSim with combined SR
$F_{msyLower}$	0.168	Median lower point estimates of (FMSY) EqSim with combined SR
$F_{msyUpper}$	0.273	Median upper point estimates of (FMSY) EqSim with combined SR
B_{lim}	8303t	Lowest SBB with above-average recruitment
B_{pa}	11538t	B_{lim} combined with the assessment error
F_{lim}	0.43	F with 50% probability of SSB less than B_{lim}
F_{pa}	0.25	$F_{.05}$

2.6 F_{ECO} for Irish Sea cod

2.6.1 Summary

- Based the on-going benchmark of Irish Sea cod (WKNSCS 2022) reference points are being updated.
- F_{ECO} for advice in 2023 will be based on Sea Surface Temperature from 2021 using an indicator derived 1973 to 2020.
- F_{MSY} is in the range of 0.168 and 0.273.
- F_{ECO} is calculated as 0.19.

2.6.2 Introduction

The single species stock assessment model for Irish Sea cod is undergoing benchmark at WKNSCS in February 2022. At this time a new assessment model has been proposed and associated management reference points calculated.

ICES WKIrish (Workshop on an Ecosystem Based Approach to Fishery Management for the Irish Sea) (ICES, 2019a) proposed greater integration of ecosystem understanding within the ICES single stock benchmark process (Figure 2.32). WKIrish identified a route by which ecosystem information could be incorporated into the current single species assessment process through providing modification of the F_{MSY} target value used for advice. WKIrish also suggested how ecosystem understanding and the assessment process could be developed further to work toward a more complete Ecosystem Based Fishery Management (EBFM) process (Figure 2.32). A soft framework was proposed that would use ecosystem indicators to inform decision making within current assessment benchmarking processes. It was suggested that this may involve, but would not be limited to: exploring productivity change across the assessment time-series, examining trends in aspects of population dynamics such as natural mortality and recruitment success, and input into the definition of reference points. At WKNSCS these process were considered for the Irish Sea cod stock through discussion and review of supporting data, in particular this was discussed with regard to the selection of management reference points. This working document outlines the approach.

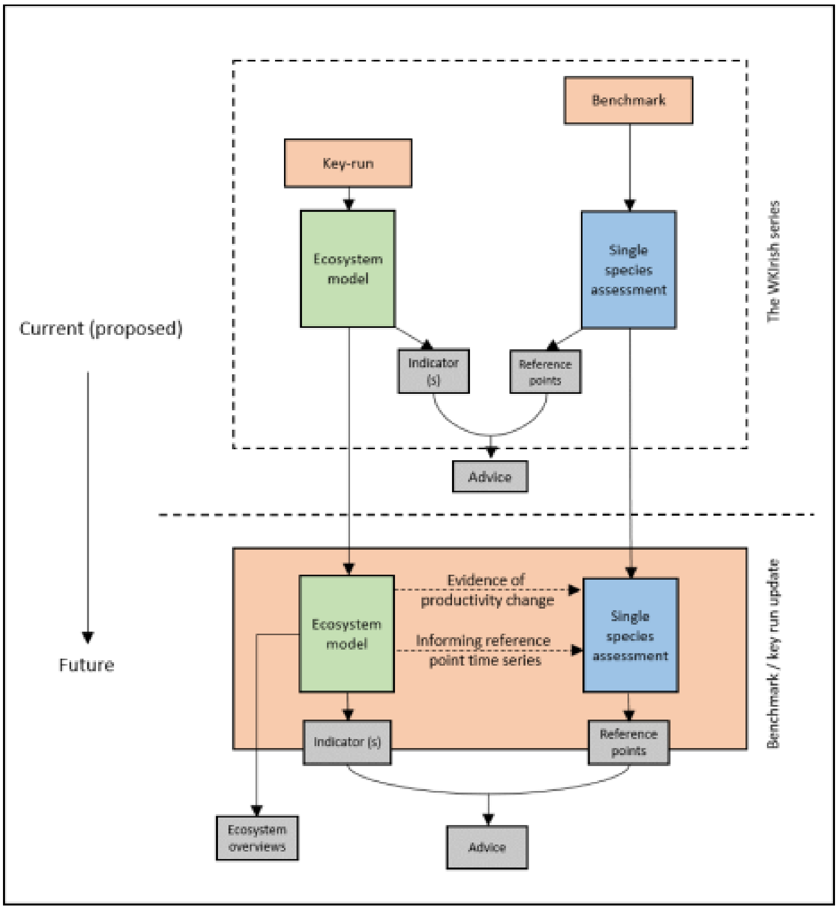

Figure 2.32. Framework for the interlinkage and interdependency of the WKIrish proposed approach to Ecosystem Based Fishery Management. The framework outlined the use ecosystem indicators to define the F target (F_{ECO}) within the F ranges and the future development of a holistic EBFM approach within single-species stock assessment benchmarking exercises.

2.6.3 FECO Concept and Calculation

Ecosystem advised F, for a given stock, which we refer to as F_{ECO}, is a precautionary F within the predefined F_{MSY} range based on the strategic understanding available from ecosystem models (Bentley *et al.*, 2021).

This approach does not require additional complexity in stock assessment models, therefore maintaining their robustness for short-term forecasting of stock trajectories. F_{ECO} achieves

EAFM and facilitates a move toward EBFM, providing an important step to bring ecosystem information into the advice process (Bentley *et al.,* 2021)

The proposed approach for calculating F_{ECO} in a given year takes the status of the selected ecosystem indicator for that year (*Is*) relative to its long-term range. Where I_{YR} is the ecosystem indicator value in year *YR*, min(I_{YR}) is the minimum value in the time-series and max(I_{YR}) is the maximum value.

The calculation thus provides a scaling between zero (relatively poor status) and one (relatively good status), ranking the current status of the indicator relative to previous years (Bentley *et al.,* 2021).In the case of a negative relationship with the ecosystem indicator the scaling is inverted so high indicator values return low *Is* values, as shown (Equation 1):

$$Is = 1- ((I_{YR} - \min(I_{YR}^{0-n})) / (\max(I_{YR}^{0-n}) - \min(I_{YR}^{0-n}))) \quad (1)$$

This scaling is then used to select F_{ECO} within the bounds of F_{lower} and F_{upper}. (Equation 2):

$$F_{ECO} = F_{Lower} + ((F_{Upper}-F_{Lower})*Is) \quad (2)$$

The values of the indicator can be updated annually when derived from environmental time-series or in the case of an ecosystem model (e.g. EwE) derived metrics, should be updated after benchmark re-evaluation of the ecosystem models. F_{ECO} is considered precautionary given utilization of the existing F_{MSY} range. The application of F_{ECO} is also demonstrated to fit within the current advice rule, with regard to $MSY_{BTrigger}$ (Figure 2.33). When SSB is below MSY $B_{Trigger}$ F_{ECO} is applied to the linear reduced F_{MSY} following the ICES advice rule (Equation 3):

$$F_{ECO} = Is*(F_{MSY} \times SSB_{YEAR+1}/MSY\ B_{Trigger}) \quad (3)$$

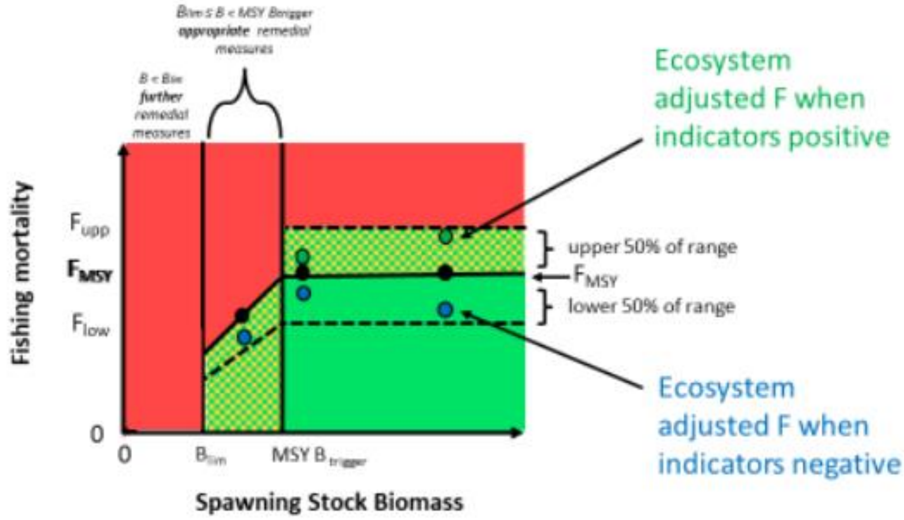

Figure 2.33. Scenarios of the application of the ICES MSY advice rule when incorporating ecosystem indicators within the F_{MSY} ranges.

F_{ECO} is devised to increase precautionary fishing behavior in the context of EAFM. Retrospective simulations conducted demonstrate that fishing at F_{ECO} led to a more precautionary approach with fishing mortality reduced during poor environmental conditions resulting in a higher SSB and resulting catches(Bentley *et al* 2021).

Review of Irish Sea Surface Temperature as an Indicator for Irish Sea cod

WKIrish (2019) identified SST as a potential ecosystem indicator for changes in productivity of Irish Sea cod. Ecosystem indicators to inform F_{ECO} should be selected based on a biological understanding of the stock and the likely mechanism behind the indicator-stock relationship (Bentley *et al.*, 2020). There is a strong body of evidence for a negative relationship between cod abundance and temperature in stocks at the southern range of the species thermal limits. Direct impacts on recruitment (Clark, Fox, Viner, & Livermore, 2003; O'Brien *et al.*, 2000; Planque & Fox, 1998; Rindorf, Cadigan, Howell, Eero, & Gislason, 2020), consumption rates (Peck, Buckley, Caldarone, & Bengtson, 2003), growth (Brander, 1995) and mortality (Akimova, Hufnagl, Kreus, & Peck, 2016) have all been observed.

A negative relationship between Irish Sea cod recruitment and temperature (Figure 2.34) is well documented (Planque and Fox, 1998; Planque and Fredou, 1999, Beggs *et al.*, 2014).

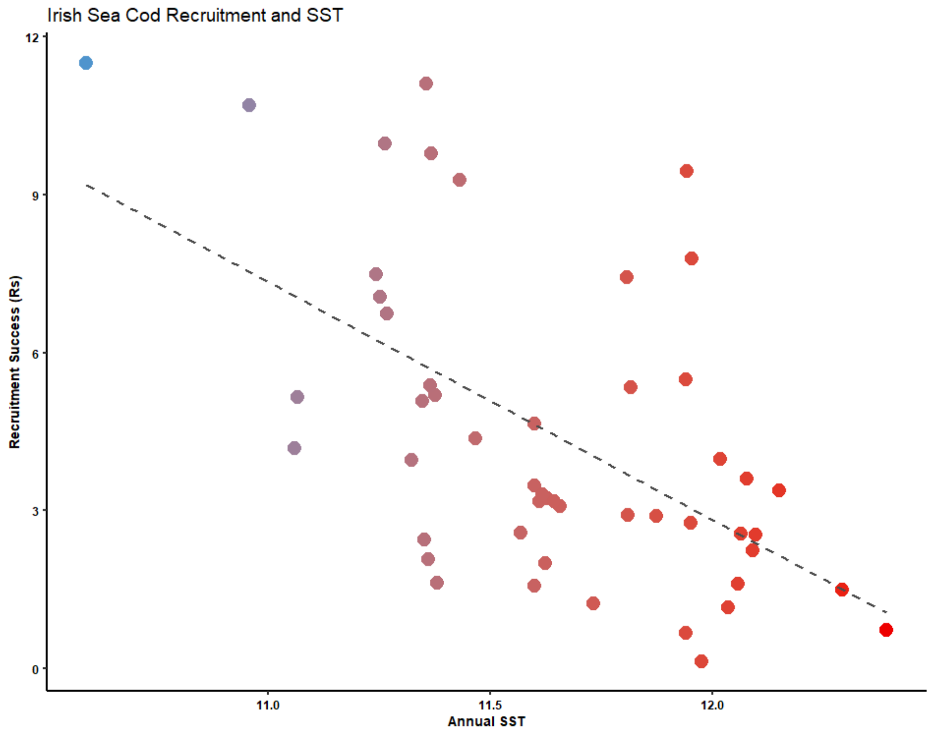

Figure 2.34. Mean annual SST and recruitment success (Rs) (Rec/SBB) of Irish Sea cod. Values of SSB and R taken from 2017 assessment estimates.

The link between temperature and recruitment is further strengthened by the correlations in abundance between early life history stages and subsequent life history stages (Figure 2.35).

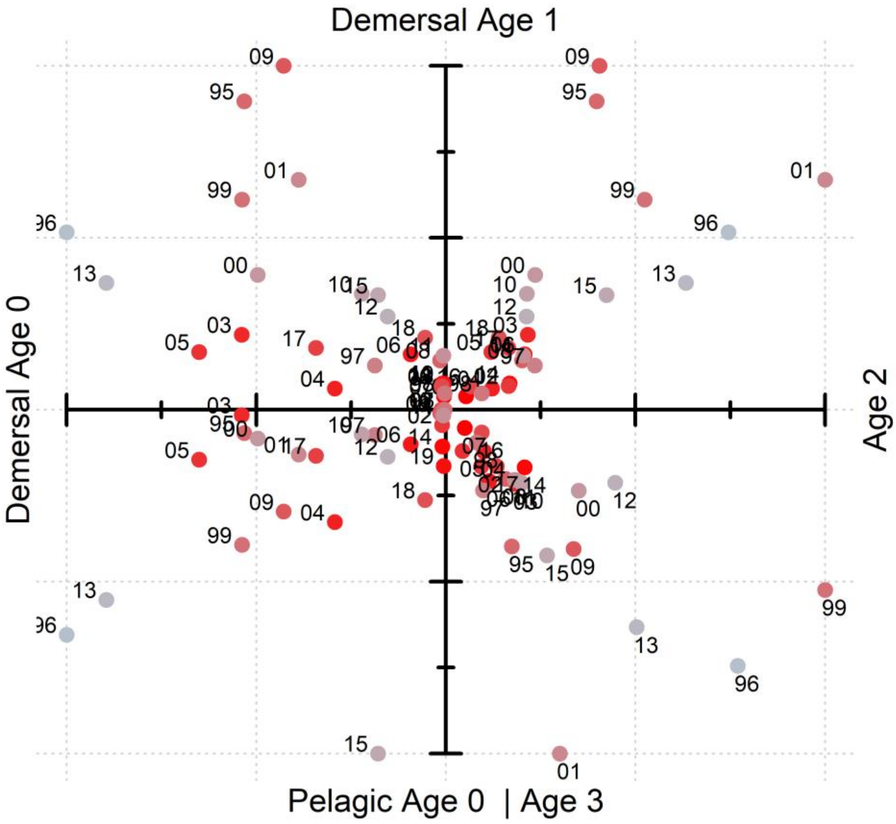

Figure 2.35. Paulik diagram for Irish Sea cod. Significant correlations between life history stages. Pelagic Age 0 abundance indices from NI_MIK net survey, Demersal Age 0-3, abundance indices from NI_GFS. All data (1994-2019) standardised by mean. Axis values are index values and are for illustrative purposes only, therefore no numbers given. Years donate year class and colours represent mean annual temperature, blue cooler and red warmer.

The SST changes in the Irish Sea follow the generally patterns observed in all waters surrounding the UK (Tinker and Howes, 2020). Over the beginning of the time-series the conditions are generally cooler with shorter periods of warm conditions. Since the mid 1990s there has been a shift to predominantly warm conditions (Figure 5).

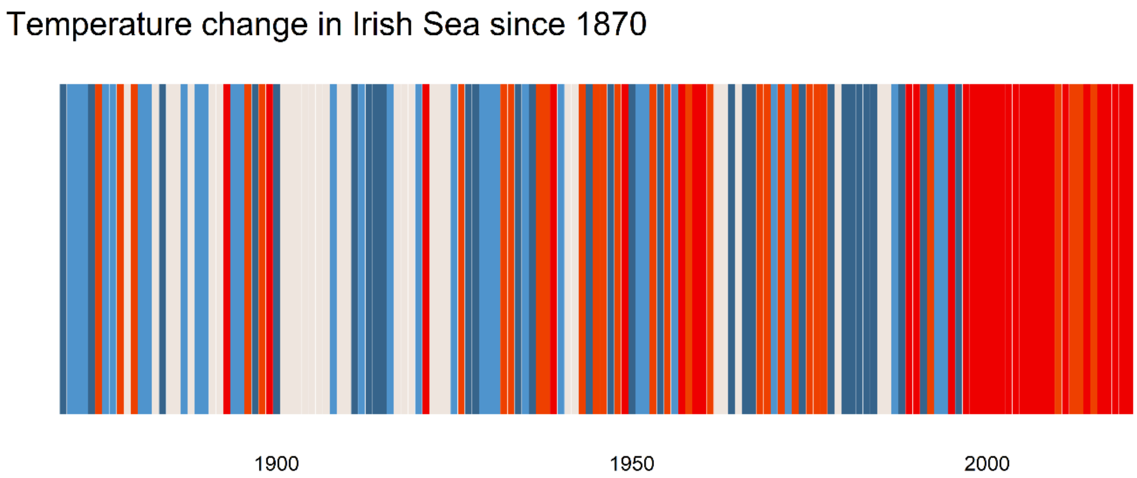

Figure 2.36. Anomaly plot for annual mean sea surface temperature anomaly (°C) calculated from HADISST dataset for period 1870 – 2020. Colour intervals based on quintiles (red=higher/warmer values, blue = lower/cooler values).

Modelling Environmental impacts on Irish Sea Cod

To further test impact of the environment on cod in the Irish Sea the Ecopath with Ecosim (EwE) software (version 6.6 beta) was used by WKIrish to construct a food web model of the Irish Sea (Bentley, Serpetti, Fox, Reid, & Heymans, 2018; ICES, 2019b).

Food web model simulations were compared with and without environmental drivers to identify the key drivers of commercial stocks and understand how the environment might have retrospectively influenced fishing opportunities in the Irish Sea (Figure 2.37). Model simulations identified environmental drivers as one of the primary causes for the stock's slow response to the cod long-term recovery plan. When excluding environmental drivers from the model's simulation, the cod stock recovered after 1990 in response to reductions in fishing effort (Bentley *et al.*, 2020).

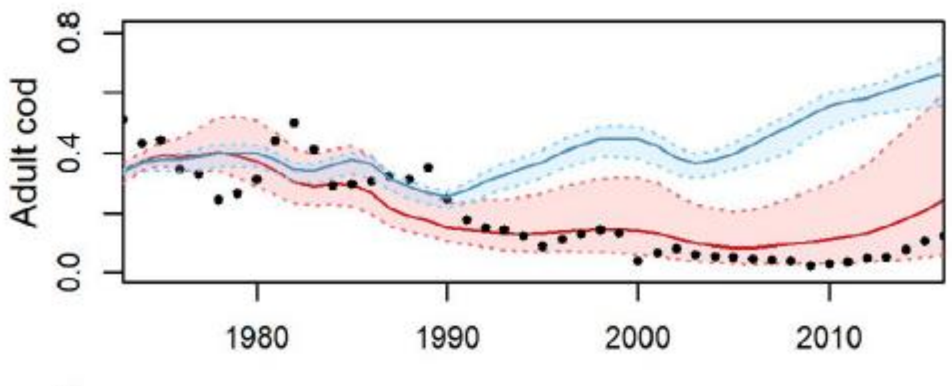

Figure 2.37. Biomass simulations for Irish Sea cod from 1973 to 2016. Simulations were generated by fitting model with environmental drivers (red) and without (blue). Solid lines indicate baseline mode simulations, shaded areas indicate 95% confidence intervals based on input uncertainty, and points indicate observed data trends (redrawn from Bentley *et al.*, 2020).

Irish Sea F_{eco} in 2022

For the calculation of I_S and F_{ECO} SST data from the Met Office Hadley Centre's sea ice and sea surface temperature (SST) data set, HadISST1 data set was extracted (www.metoffice.gov.uk/hadobs/hadisst/data/download.html) for the Irish Sea region. Mean annual SST from 1970 to 2020 was used as the time-series for calculating $min(I_{YR}{}^{0\text{-}n})$ *and* $max(I_{YR}{}^{0\text{-}n})$. A 3 year lag was introduced as this improved the relationship between SST and cod biomass (Bentley *et al.*, 2021). It also has the added benefit of allowing advice to be based on retrospective environmental data which often is not updated sufficiently to provide current year advice.

Therefore the SST in 2020 is used for providing advice in 2023.

The F_{MSY} reference points for Irish Sea cod are estimated from the recent benchmark process to be in the range 0.168 to 0.273, with F_{MSY} of 0.222. Figure 2.38 shows the times-series of I_S and derivation of F_{ECO}.

Calculation of F_{ECO} is:

SST Indicator value:

$$I = 1 - ((I_{YR} - min(I_{YR}^{0-n})) / (max(I_{YR}^{0-n}) - min(I_{YR}^{0-n})))$$

Where:

$I_{YR} = 12.01$,

$min(I_{YR}^{0-n})) = 10.59$,

$max(I_{YR}^{0-n})) = 12.39$;

$I = 0.209$

$F_{ECO} = F_{Lower} + ((F_{Upper}-F_{Lower})*I)$

Where:

$F_{Lower} = 0.168$,

$F_{Upper} = 0.273$;

$F_{ECO} = 0.19$

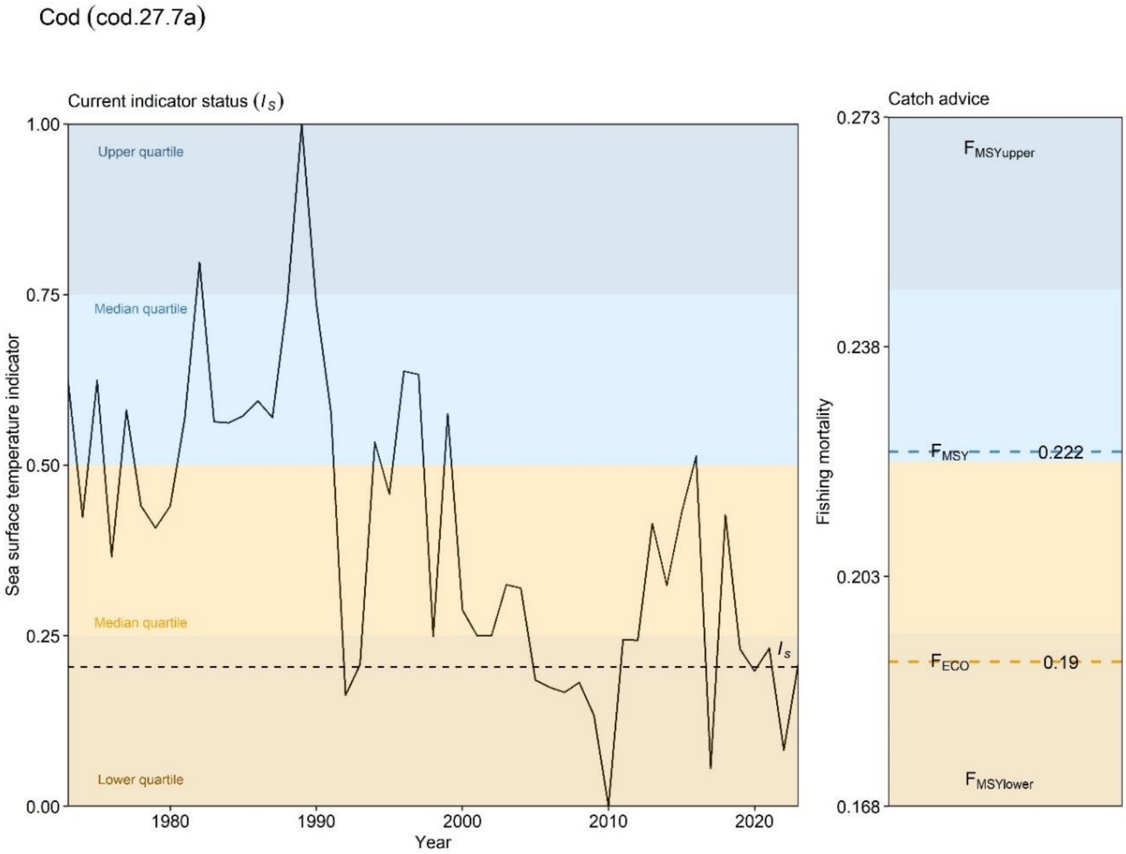

Figure 2.38. Derivation of F_{ECO} for Irish Sea cod. On the left: time-series of inverted SST (3-yr lag) (*Is*) for years 1970 – 2020 rescaled between zero and one to provide a percentile value which ranks the status of the indicator (*Is*) in 2023 compared with previous years. On the right, the status of the indicator determines the placement of the F_{ECO} reference point within F_{MSY} ranges.

2.6.4 References

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3 Herring (*Clupea harengus*) in Division 6.a North (North of 56°00’N and East of 07°00’W), autumn spawners (West of Scotland) – her.27.6aN

Introduction

Atlantic herring, *Clupea harengus L.* to the west of Scotland and north-west of Ireland consist of spring, autumn and winter spawning components. The first assessment for herring in division 6.a was carried out in 1974, although the fishery was closed from 1978 to 1981. Despite a substantial fishery for herring in division 7.b, no assessment took place in this area and catches were taken under a precautionary total allowable catch (TAC). A review by the ICES Herring Assessment Working Group (HAWG) in 1981 reviewed biological information from herring in 6.aN and 6.aS,7.b-c (Figure 3.32). This review concluded that the populations exploited to the north and west of Ireland were biologically different from those off the west coast of Scotland (ICES, 1982). Separate assessments were conducted for these two stocks from 1981 until 2015.

In 2015, ICES carried out a benchmark of these two stocks to resolve issues surrounding the splitting of the acoustic survey data (ICES, 2015). It was not possible to split the Malin Shelf acoustic index into separate tuning indices for the two stocks, and a combined assessment was adopted that used the acoustic survey as one of its tuning indices. This combined assessment took the form of a multifleet SAM model that assessed the 6.aN autumn spawning herring and 6.aS,7.b-c winter spawning herring as a single stock (ICES, 2015). Since this benchmark, zero TAC advice has been in place for the combined stock with an agreed monitoring TAC in place for each area to continue the collection of scientific samples (ICES 2016).

Work to address stock identity issues continued. In 2017 an EASME (European Commission’s Executive Agency for Small and Medium-sized Enterprises) funded project began, with work completed in 2020. This project aimed to assess the identity of herring stocks using genetic analysis, with the result that genetic profiles for the northern (6.aN) and southern (6.aS,7.b-c) herring stocks were developed which could be used to differentiate between the two stocks at times of mixing (Farrell *et al.*, 2021). These results have been reviewed and supported by the Stock Identification Methods Working Group (ICES, 2021a) and the Working Group of International Pelagic Surveys (ICES, 2021b), and have been used to genetically split the Malin shelf acoustic survey index to enable exploration of separate assessments for the two components.

Examination of assessment options for the two stocks were conducted separately by Marine Scotland Science (6.aN) and the Marine Institute (6.aS,7.b-c). The goal was to produce two assessments that would provide separate advice for the split stocks. In this report we discuss the approaches and outcomes for the 6.aN stock.

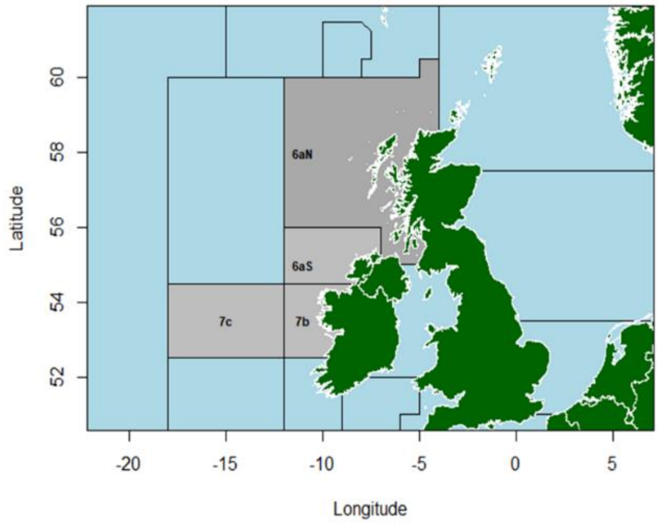

Figure 3.32. Assessment and management units for herring in 6.a and 7.b-c.

3.1 Stock ID and sub-stock structure

Stock structure for herring in subarea 6.aN is complex, with two spawning components (autumn and spring) in the north that mix with herring in 6.aS. Over the past four decades, various reviews of biological information been undertaken to further understand herring population structure in this area (ICES, 1982; Hatfield *et al.*, 2003; Farrell *et al.*, 2021).

The latest genetic work (Farrell *et al.*, 2021) provides indices of biomass and abundance for 6.aN autumn spawning and 6.aS,7.b-c winter spawning populations from the Malin Shelf Herring Acoustic Survey, and has allowed separate assessments for the two components to be developed. It should be noted that this project was not able to split out the 6.aN spring spawning population, and this is no longer being assessed (was previously a part of the combined assessment).

3.2 Issue List

The issue list in the table below outlines the issues that are relevant to herring in 6.aN.

Issue	Problem/ Aim	Work needed/ possible direction of solution
1. Fisheries data	1.1 Catches in 6.aN contain an unknown proportion of components of geographic and biological components over the time-series.	Document the changes in the fishery over the time-series and consider how these may have changed the proportion of mixes in the catch historically. Investigate splitting commercial catches to stock components.
	1.2 6.aN Historical data – how far back in time can we comfortably assume accurate catch records, considering area misreporting between area 4.a and 6.a.	Revisit catch data and WG allocations revised in WKWEST and WKREDNOSE. Investigate how far back in time this can be done. Investigate catches around the 4 degree line
2. Tuning series	2.1 Surveys contain an unknown mix of stock components.	The 6.a summer acoustic survey (HERAS/WESPAS) to be split by component as far back as possible using stock splitting methodologies developed in WESTHER and EASME.

Issue	Problem/ Aim	Work needed/ possible direction of solution
		Develop methods in the survey estimation software StoX to handle 2 survey inputs and split index outputs
	2.2 New data from annual 6aSPAWN survey started in 2016 available. 6.aN industry acoustic survey	Develop index of abundance at age and biomass from industry survey in 6.aN (2016-2020) Investigate whether index can be used in assessment
	2.3 Compare survey signals across all available surveys	Both in numbers at age or overall biomass
	2.4 Absence of older ages in catch and surveys in 6.aN	Consider link to North Sea
3. Biological parameters	3.1 Review updated M values from WGSAM	Examine new M values provided by WGSAM and compare with previously used values
4. Assessment method	4.1 Investigate assessment methods that are sensitive to issues of stock mixing (6.aS, 6.aN, autumn spawners and spring spawner + other potential components.) Explore separate assessments for 6.aS and 6.aN	Consider results from genetic stock structure work (EASME) that will be completed towards the end of 2020. (See 2.1) Consider assessment model types and parameterisations, including SAM, ASAP, SPiCT (building on inter-benchmark work). Explore a range of model settings and different input data combinations
5. Biological Reference Points	5.1 Investigate reference points using EqSIM and other available packages	Revise reference points with updated assessment Examine sensitivity of reference points to potential changes in productivity over time and assumptions due to model configuration.
6. Environmental data	6.1 Declines of Western herring have occurred in spite of reductions in fishing pressure. The same is true for Celtic Sea herring and other fish stocks on the Western shelf.	Information on changes in the environment should be considered in the assessment. Learn from work in WKIRISH? Review literature. Benchmark guidelines state 'Task 1. Review all available data for use in the assessment with the aim to improve integration of environmental information into the assessment'

3.3 Scorecard on data quality

No major biases are considered to occur in the data for the 6.aN herring stock. See text table below:

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				
2. Species misreporting				
3. Taxonomic change				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
4. Grouping statistics				
5. Identification Key				
Final indicator				
B. LANDINGS WEIGHT				
1. Missing part				
2. Area misreporting				Misreporting suspected with adjacent areas
3. Quantity misreporting				
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed stock components in the landings				Unknown level of mixing, varies over the historical record
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				
1. Sampling allocation scheme				
2. Raising variable				
3. Size of the catch effect				
4. Damaged fish discarded				
5. Non response rate				
6. Temporal coverage				
7. Spatial coverage				
8. High grading				
9. Slipping behaviour				
10. Management measures leading to				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
discarding behaviour				
11. Working conditions	NA			
12. Species replacement	NA			
Final indicator				
D. EFFORT				
1. Unit definition	NA			
2. Area misreporting	NA			
3. Effort misreporting	NA			
4. Source of information	NA			
Final indicator				
E. LENGTH STRUCTURE				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
1. Quality assurance protocol				
2. Conventional/actual age validity				
3. Calibration work-				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
shop				
4. International exchange				Last workshop was held in 2005, last exchange 2015
5. International reference set				
6. Species/stock reading easiness				
7. Staff trained for age readings				
8. Age reading method				
9. Statistical processing				
10. Temporal coverage				
11. Spatial coverage				
12. Plus group				
13. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
Final indicator				
H. SEX RATIO				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
4. Staff trained				
5.Size/maturity effect NA				
6. Catchability effect NA				
Final indicator				
I. MATURITY STAGE				
1. Sampling protocol				
2. Appropriate time period all along the year				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity				
7. Histological reference				
8. Skipped spawning				
Final indicator				**Green as for assessment of maturity only data collected during appropriate period and using appropriate scale**

3.4 Multispecies and mixed fisheries issues

The targeted fishery for herring in 6.aN is considered to be clean, with little bycatch of other fish (ICES, 2021c).

3.5 Ecosystem drivers

The Atlantic herring, *Clupea harengus*, is numerically one of the most important pelagic species in North Atlantic ecosystems, with a widespread distribution around the Scottish coast. As well as being a commercially important species, herring represent an important prey species in the ecosystem west of the British Isles and are one of the dominant planktivorous fish in 6.aN (ICES, 2021c).

Thermal stratification and tidal mixing generate a northwards running current that runs northwards along the west coast of Scotland (ICES, 2007). In this area the main oceanographic features are the Islay and Irish Shelf fronts. These fronts create turbulence and this may bring nutrients from deep waters to the surface, promoting the growth of phytoplankton and dinoflagellates in areas of increased stratification. Aggregations of fish are associated with these areas of increased productivity. The Islay front persists throughout the winter due to the stratification of water masses at different salinities (ICES, 2006). These fronts play an important role in the transport of herring when at the larval and juvenile stages.

Temperatures in this area have been increasing over the past few decades (Baxter *et al.* 2008), and there are indications that salinity is also increasing (ICES, 2006). Changes in environmental conditions can have significant impacts for a variety of marine fish species. A study in 1980 found west coast herring catches correlated strongly with temperature and salinity at a constant lag of three to four years. Oceanographic variation associated with temperature and salinity fluctuations appears to impact herring in the first year of life, possibly during the winter larval drift (Grainger, 1980). In addition, temperature increases and a positive AMO (Atlantic multi-decadal oscillation) index are thought to be related to drops in weight-at-age in Celtic Sea herring (Lyashevska, 2020). With environmental changes predicted to continue, the impacts on herring in 6.aN could be substantial.

3.6 Stock Assessment

3.6.1 Catch – quality, misreporting, discards

Landings

A time-series of landings data for herring in 6.aN extends back to 1957 and runs until 2020. There have been fluctuations in landings over time (Figure 3.33). Landings peaked in 1973 with over 210,000 tonnes landed. Landings were high throughout the 1970s, but dropped to below 100 000 tonnes from 1980. Since then landings have continuously decreased, and have not been higher than 25 000 tonnes since 2008. Since implementation of the combined assessment in 2016 catch advice has been set to zero and a monitoring TAC has been in place and a monitoring TAC applied at 4170 tonnes for 6.aN, reducing to 3480 in 2020. Landings have been lower that the monitoring TAC since 2019, in part due to the industry decision to minimise fishing pressure in the face of decreasing abundance.

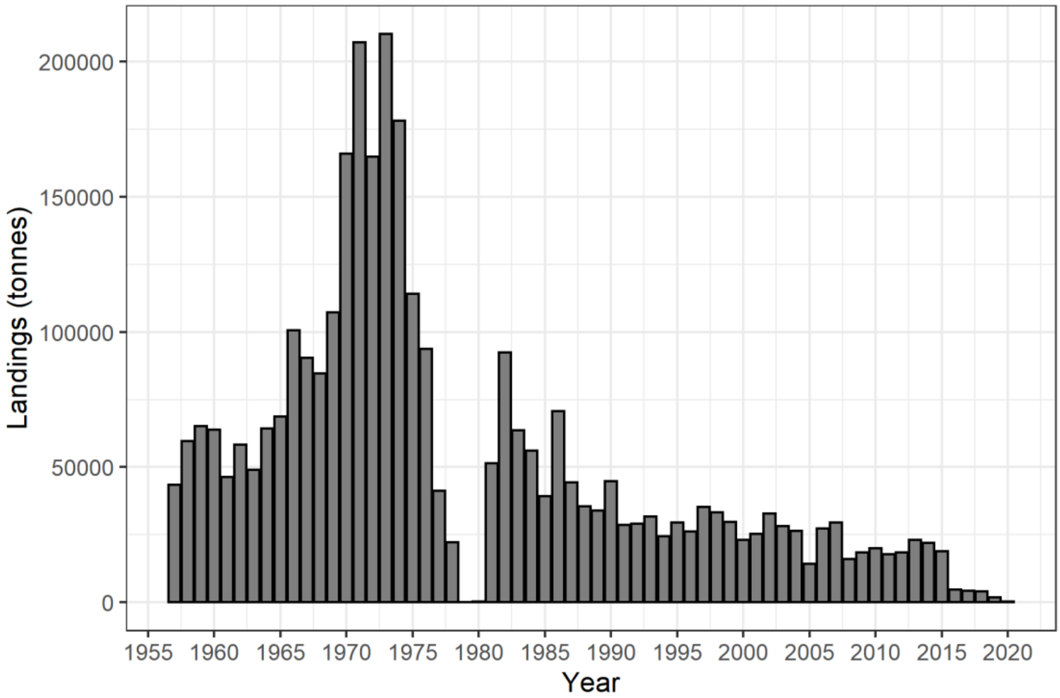

Figure 3.33. Landings in 6.aN from 1957 to 2020. Note that a monitoring TAC has been in place since 2016.

In the 1970s when landings were high, the fishery was dominated by landings from the winter and spring fishery. Since then the proportion of landings in these seasons has reduced, but they continued to constitute a significant proportion until 2000 (Figure 3.34). From then the fishery has been almost entirely dominated by landings in quarter three.

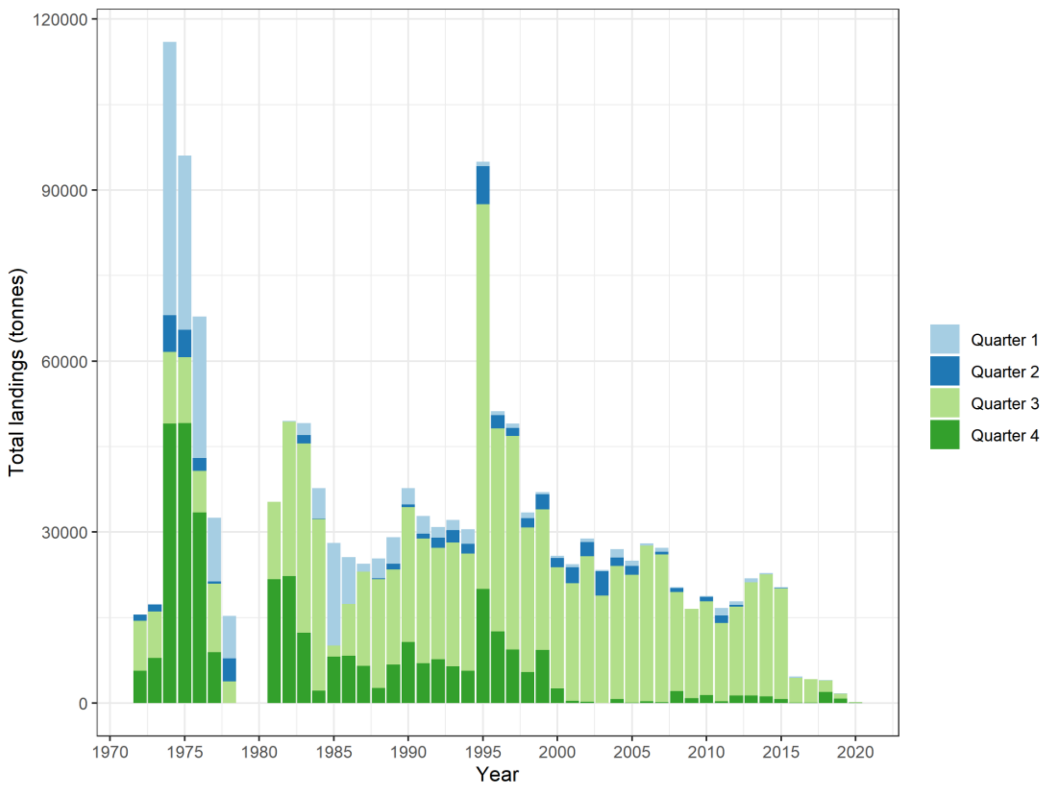

Figure 3.34. 6.aN landings by quarter 1972-2020.

Since the fishery has become focused on pre-spawning and spawning aggregation in quarter three and landings have reduced in magnitude, the fishery has been concentrated around Cape Wrath, targeting spawning aggregations of herring (Figure 3.35). Landings have become more spatially limited as they have declined, and tend to be highest next to the boundary with the North Sea herring stock (Figure 3.35).

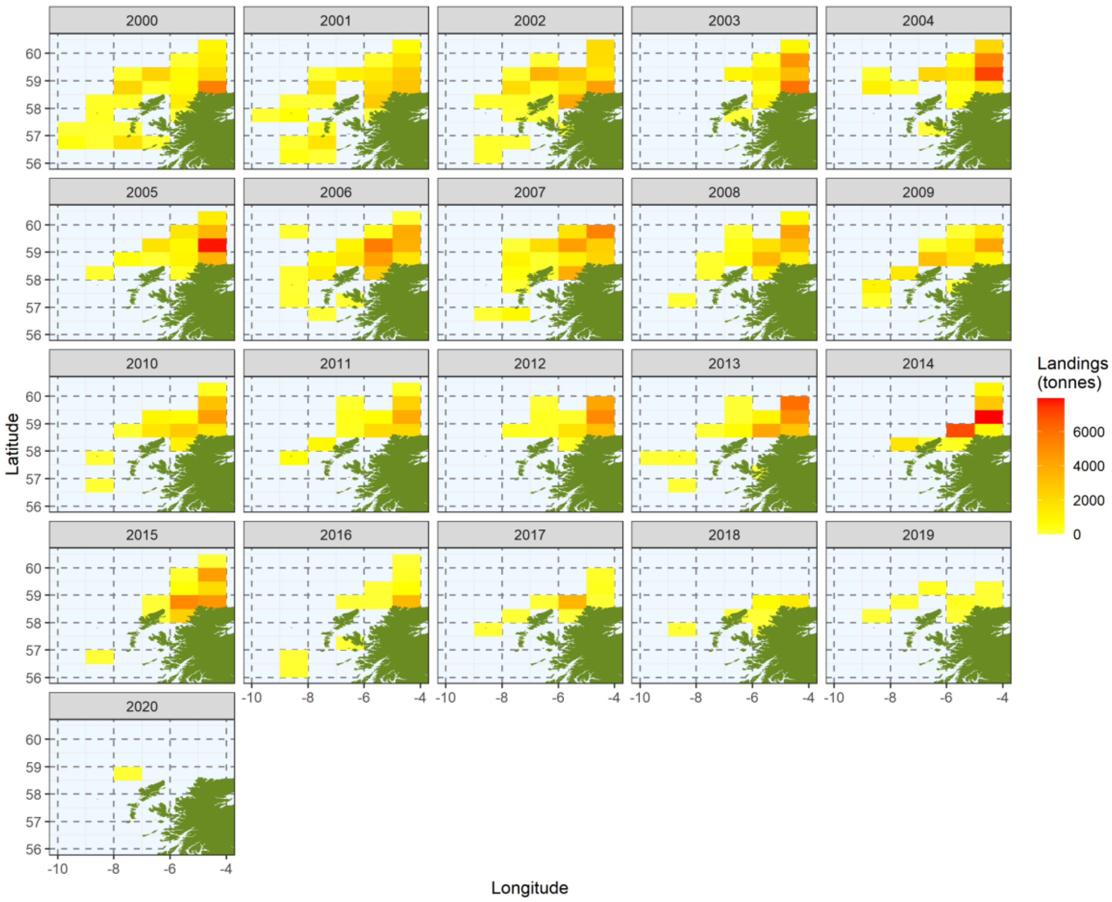

Figure 3.35. Spatial distribution of 6.aN herring landings in quarter three. Note since 2016 landings have come from the monitoring fishery only.

Quality of the catch data

The fishery in 6.aN has had misreporting issues prior to 2000, but this problem has reduced in recent years. In the past, a shortfall between the TAC and the catch were thought to have been used to misreport catches from subarea 4.a to the east, with fishery-independent data confirming large catches of herring reported from areas with low abundances of fish. Improved information allowed the reallocation of many of the misreported catches. In 2004 a fishery regulation preventing fishers from holding licences for herring in both the North Sea and the West of Scotland was rescinded, leading to a temporary increase in misreporting between the two areas (although not to levels seen prior to 2000). New sources of information on catch misreporting from UK vessels became available in 2006 which may be responsible for the lack of misreporting from vessels since this year.

Catch numbers-at-age

Catch numbers at age are updated annually, with sampling carried out by Marine Scotland Science. Since the zero TAC advice in 2016 sampling has continued through the monitoring TAC.

Figure 3.36 shows the catch numbers at age since 1957. Particularly strong year classes can be observed in 1964 and 1970 (Figure 3.36). Strong year classes are often picked up in the fishery as 2 wr (winter ring) fish rather than at 1wr. There have been no strong year classes in recent years compared to historical values (Figure 3.36). The current assessment uses catch numbers at age up to 9+, and herring in this area appear to survive well up to this age.

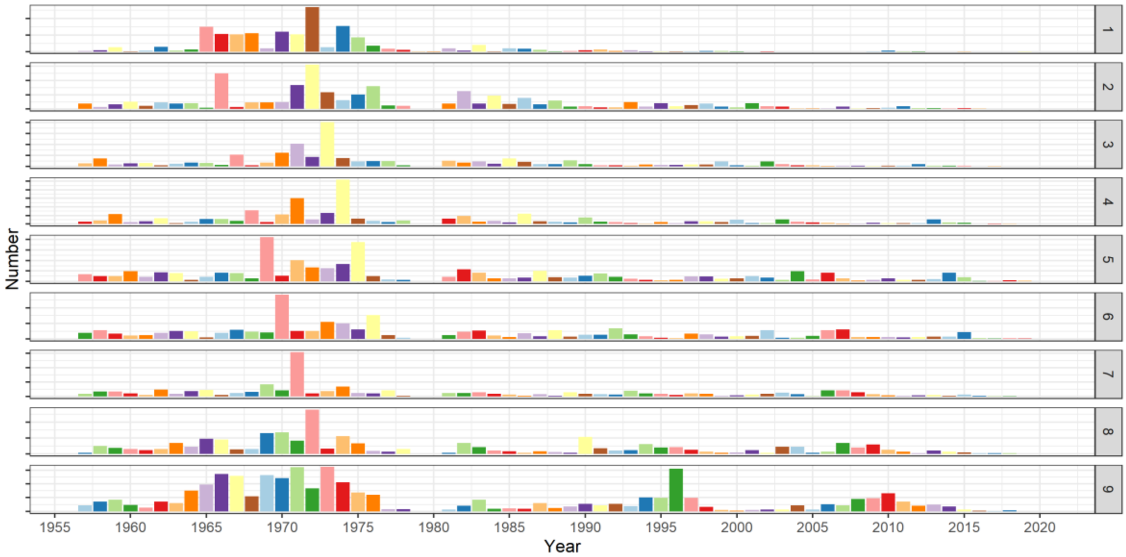

Figure 3.36. Catch numbers at age for the 6.aN fishery.

Since 2000, catches have been dominated by herring between ages 3-6 (Figure 3.37). Since 2010 the proportion of older herring in the catches has dropped. Although some year class tracking can be observed in this period, levels in terms of numbers are still very low compared to historical values.

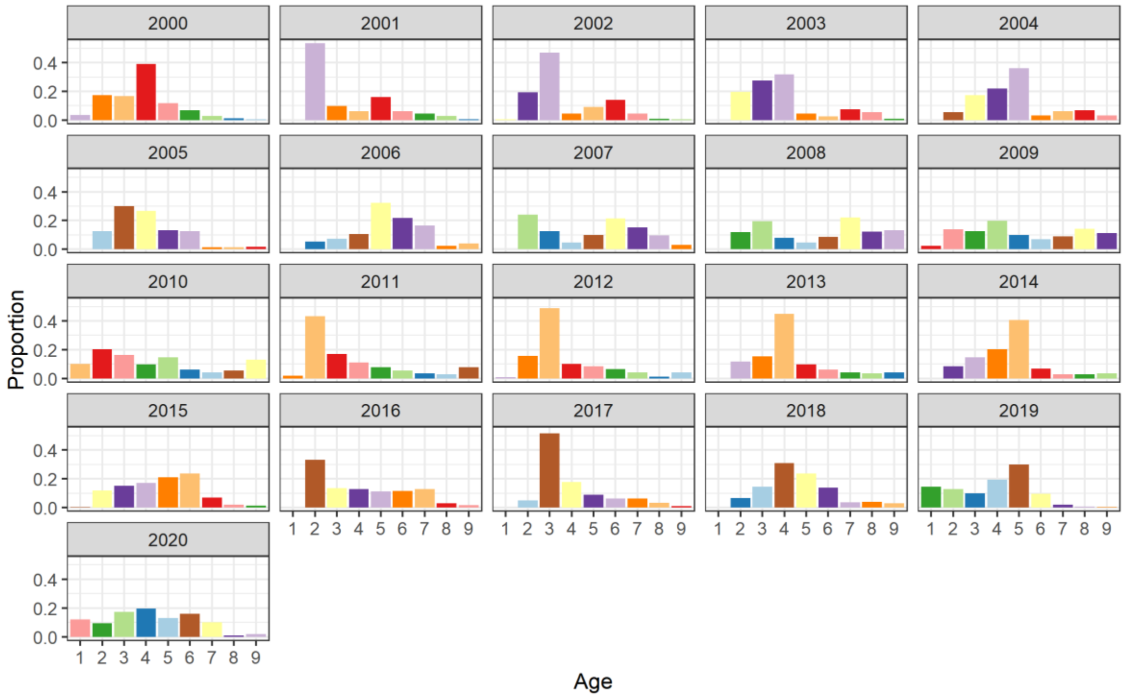

Figure 3.37. Proportions of catch numbers at age since 2000. Colours represent the year class.

Discards

Discard estimates were previously considered negligible for the 6.aN fishery in the multifleet SAM model previously used for the joint 6.a,7.b-c assessment. Estimates of discarding for this area have not previously been submitted to ICES, but are now available from 2017-2020.

With the monitoring TAC in place, the quantity of herring discards in 6.aN (~177 tonnes in 2020) is significant. The west coast of Scotland is home to a significant demersal fishery, with juvenile herring discarded from the TR2 (*Nephrops* trawl) fleet. Herring are primarily discarded from the Minch area and are therefore unlikely to be part of the Cape Wrath autumn spawning component. Consequently it was decided that discards would not be considered in the 6.aN assessment.

Length Frequency data

Length frequency data for herring in 6.aN are available since 2014. From 2014-2015 when catches were higher these data have come from commercial catch samples. Since 2016 a monitoring TAC has been in place, and length frequency data have come from the commercial portion of the monitoring fishery (Figure 3.38). In 2018 length frequency data from Dutch vessels were only collected to 1 cm bins, so all data were binned to this resolution for this year, and in 2020 no length samples were taken from commercial hauls (Figure 3.38).

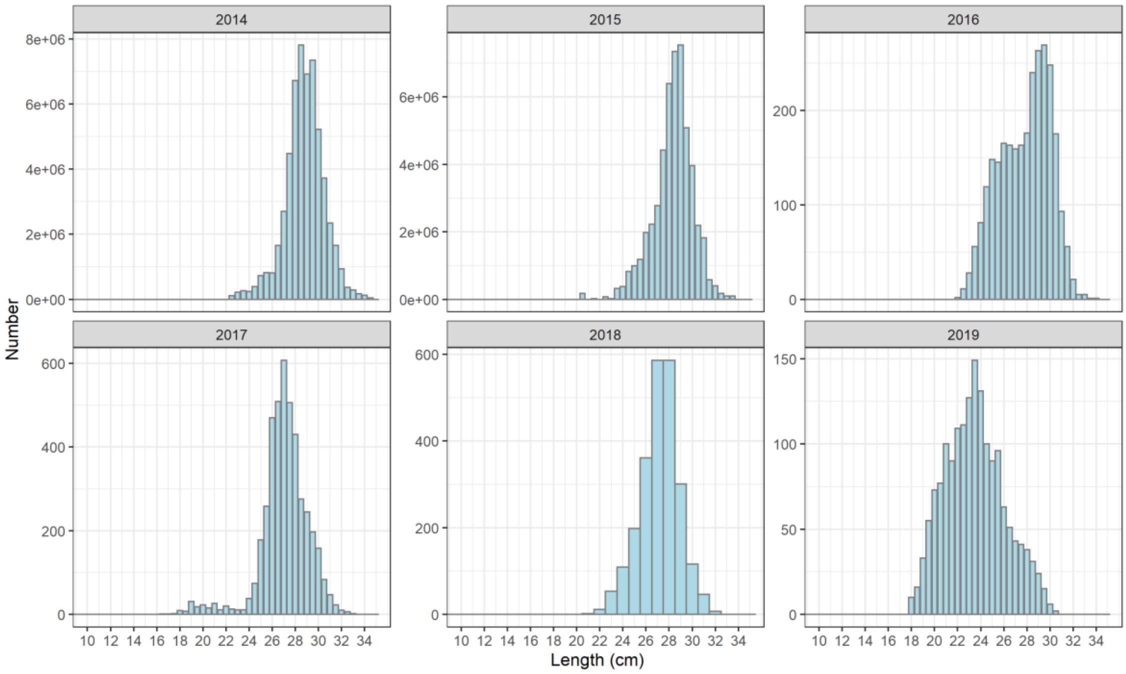

Figure 3.38. Length frequency data for herring in 6.aN. Note that since 2016 a monitoring TAC has been in place. Some data in 2018 were only reported to a 1 cm resolution, and therefore all data have been binned to this level in this year. No length data from commercial hauls are available for 2020.

3.6.2 Surveys

Split Malin Shelf Herring Acoustic Survey

Prior to genetic studies, StoX estimates were produced for the 6.aN component of the combined multifleet SAM using a geographical split, but were not used in the assessment. Following the EASME project (Farrell, *et al.* 2021), genetic sampling has enabled the calculation of abundance and biomass estimates in StoX for 6.aN autumn spawning herring caught in the Malin Shelf herring acoustic survey (Table 3.9; ICES,2021b). The Malin shelf herring acoustic survey provides survey estimates back to 1990, but the genetic sampling has only been in place since 2014, so split estimates are only available from this year. The SSB and abundance estimate in 2015 was considerably higher than 2014 and from 2016 onward. (figures 3.8 and 3.9). Estimates of abundance of age 0-1 herring are variable, being difficult to sample.

Table 3.9. Abundance estimates at age (TSN x10^6) for 6.aN autumn spawning herring with cvs.

Year	1	2	3	4	5	6	7	8	9+	CV
2014	0	2.75	13.50	21.36	85.13	20.39	5.35	2.41	6.65	0.35
2015	0	35.56	139.03	127.40	97.37	106.38	24.68	3.81	5.76	0.30
2016	0	5.81	15.50	13.62	11.15	8.83	5.22	0.06	0.73	0.26
2017	0	0.71	35.74	25.40	26.44	11.41	9.93	2.45	1.86	0.37
2018	92.9576	41.07	14.27	48.31	16.67	3.34	10.05	5.49	2.28	0.59
2019	0	17.17	17.32	15.80	20.17	4.64	0.16	0	0.51	0.28
2020	59.05	103.81	49.5056	14.964	12.44	28.21	11.01	0	0	0.26

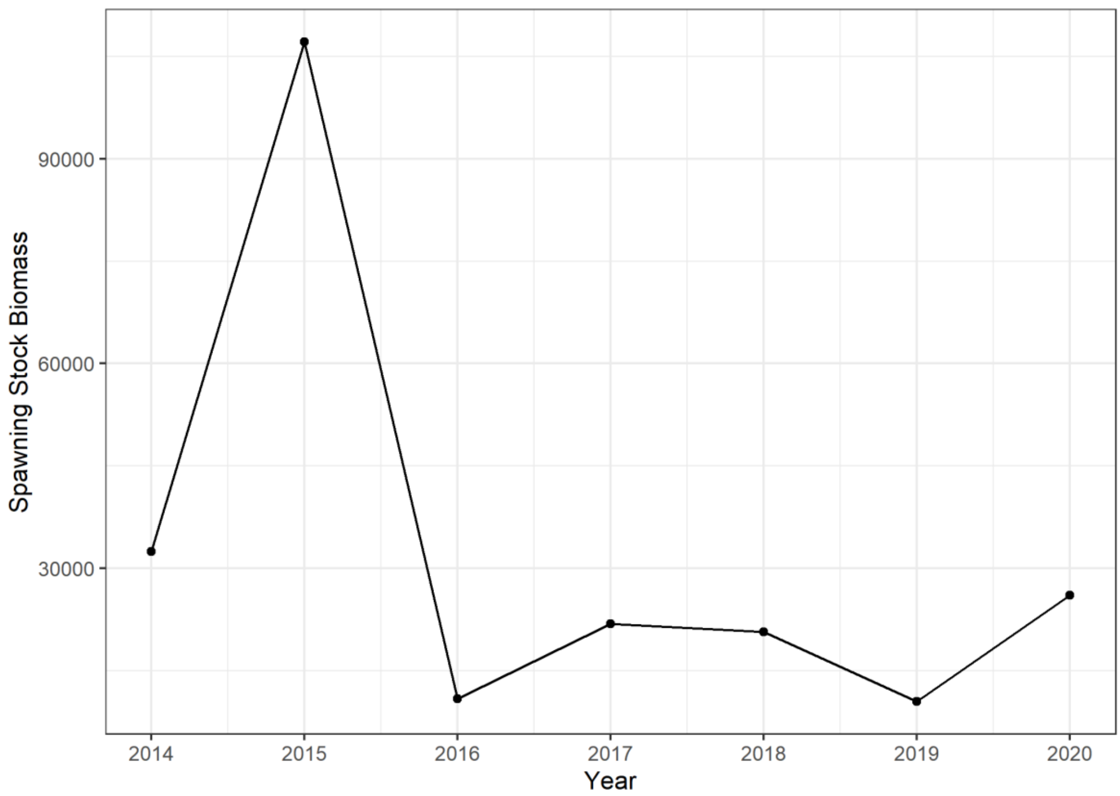

Figure 3.39. SSB estimates produced from the Malin Shelf Herring acoustic survey for 6.aN autumn spawning herring.

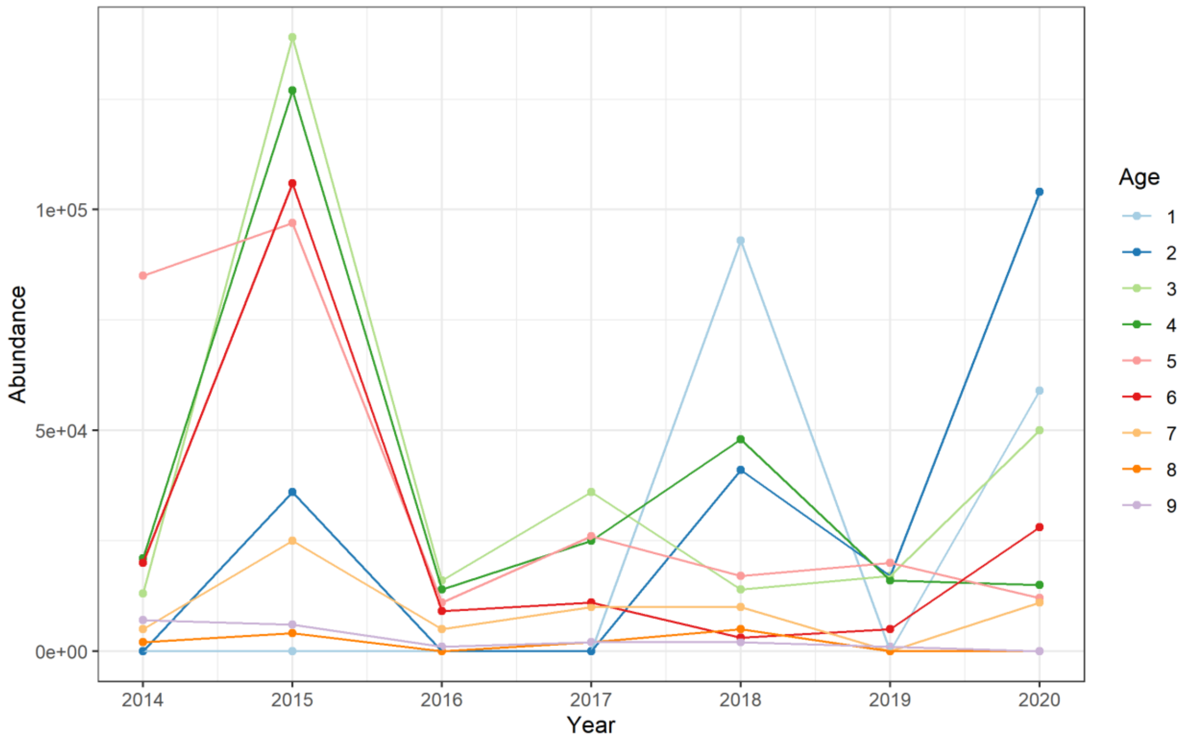

Figure 3.40. Abundance at age of 6.aN autumn spawning herring from the genetically split Malin Shelf survey.

Correlation between ages from the genetically split indices are relatively poor (Figure 3.41).

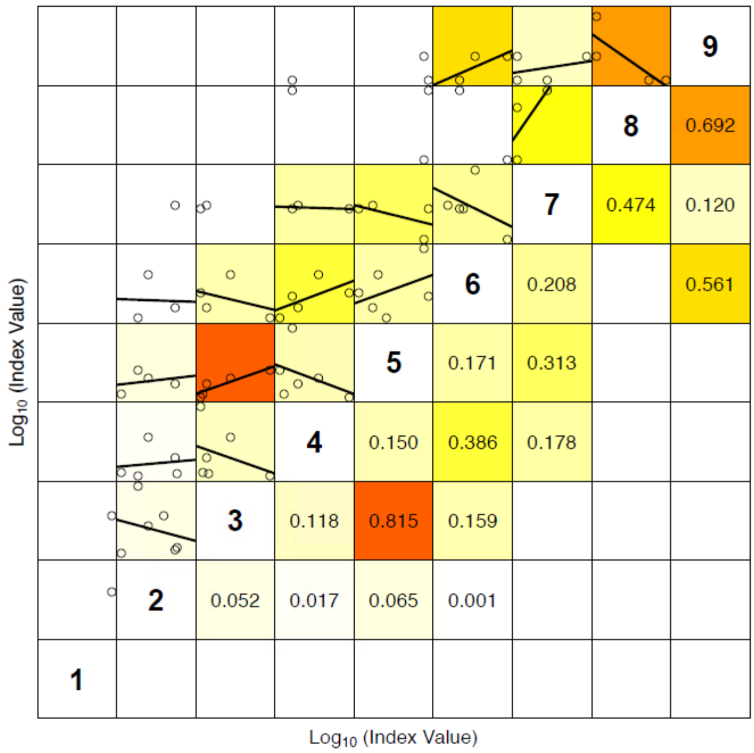

Figure 3.41. Correlation matrix at age for the 6.aN autumn spawning herring genetic split from the Malin Shelf survey since 2014.

6.aN Industry survey

Industry-led surveys of herring have taken place in 6.aN and 6.aS,7.b-c since 2016, targeting spawning aggregations in 6.aN and 6.aS,7.b-c (ICES, 2021b, Mackinson *et al.*, 2017). The acoustic index used in the benchmark for the 6.aN portion of this survey focuses on known spawning areas around Cape Wrath (Figure 3.42) and provides estimates of herring at the location of the fishery itself. This survey offers estimates on abundance, SSB, proportion mature at age and weights at age, but the time-series is short. It is assumed this index relates to the 6.aN autumn spawning herring because of the timing and location of the survey, but limited evidence from ageing and genetics indicates that a fraction of 6.aN spring spawning and 6.aS fish may be included in these estimates. Indices have been variable over time, especially for younger ages (Figure 3.43). Estimates for 2021 indicate a considerable decline in herring across all ages.

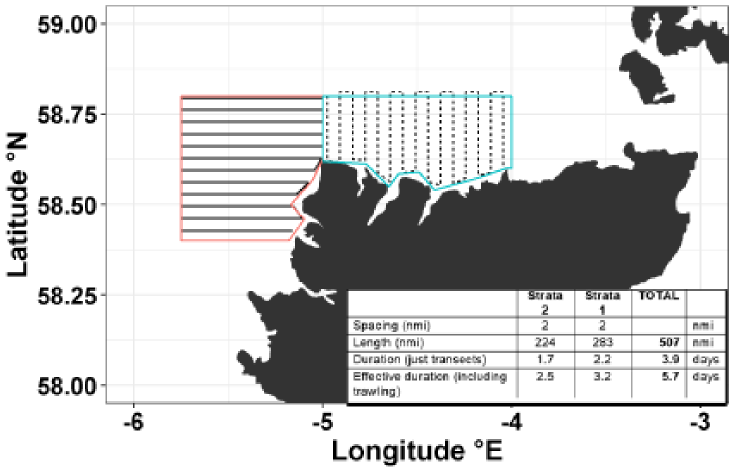

Figure 3.42. Area covered by the 6.aN industry survey in 2020. From ICES, 2021b

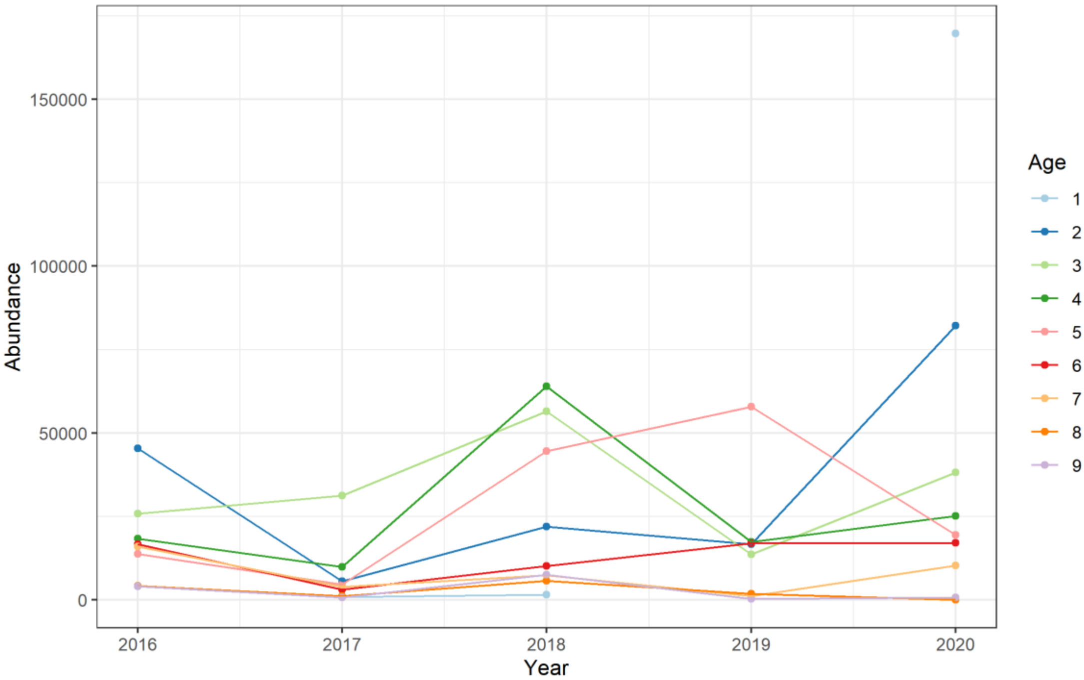

Figure 3.43. Abundance at age from the 6.aN industry survey.

The correlation between ages from the genetically split indices are very poor at present. Abundance of age 0-1 fish are not well generally well represented by this survey because of the focus on pre-spawning and spawning aggregations.

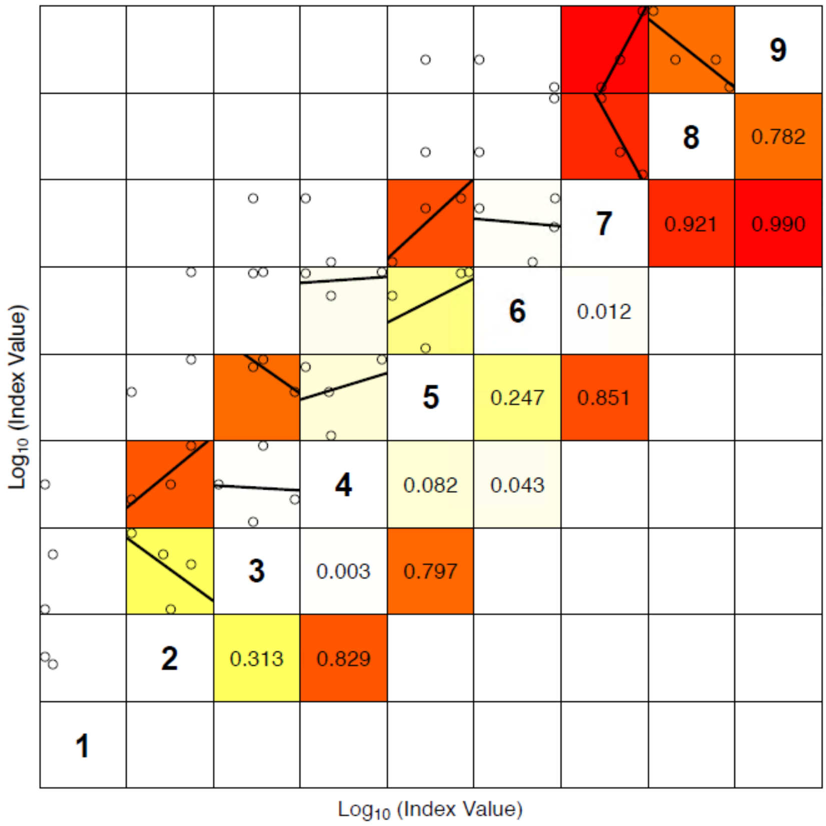

Figure 3.44. Correlation matrix at age of herring caught in the 6.aN industry survey since 2016.

International Bottom Trawl Surveys

Indices for herring from international bottom trawl surveys (IBTS) are available for quarter 1 and quarter 4. These indices are calculated using a delta lognormal GAM (Berg *et al.*, 2014) and provide the longest time-series of tuning data available for herring to the west of Scotland (since 1996/1997). These data provide relatively stable indices of abundance (Figure 3.45, Figure 3.46). A geographic split at 56˚N was applied to these indices, assuming that herring belonging to the 6.aS, 7.b-c stock would mostly be further south spawning during winter and spring. The model produces lower and upper values for each index, which indicate that estimates are less variable after 2010 and at older ages.

The proportion mature at age from both of these surveys was calculated following ICES guidelines (ICES, 2008), but estimates are poorly timed with the fishery and were not used in the assessment. It should be noted that the 2022 IBTS quarter 1 survey in this area will not yield any data because the survey had to be abandoned early due to operational difficulties.

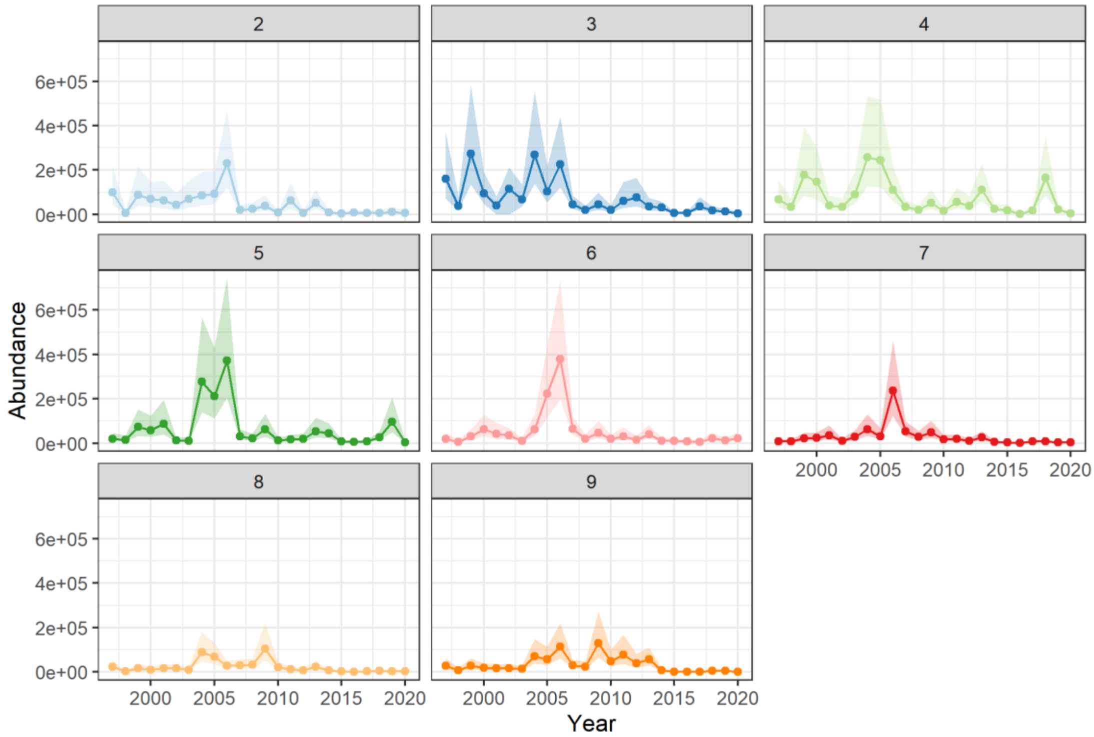

Figure 3.45. Survey indices of herring by age from IBTS Quarter 1 hauls north of 56 degrees calculated using a delta gam model.

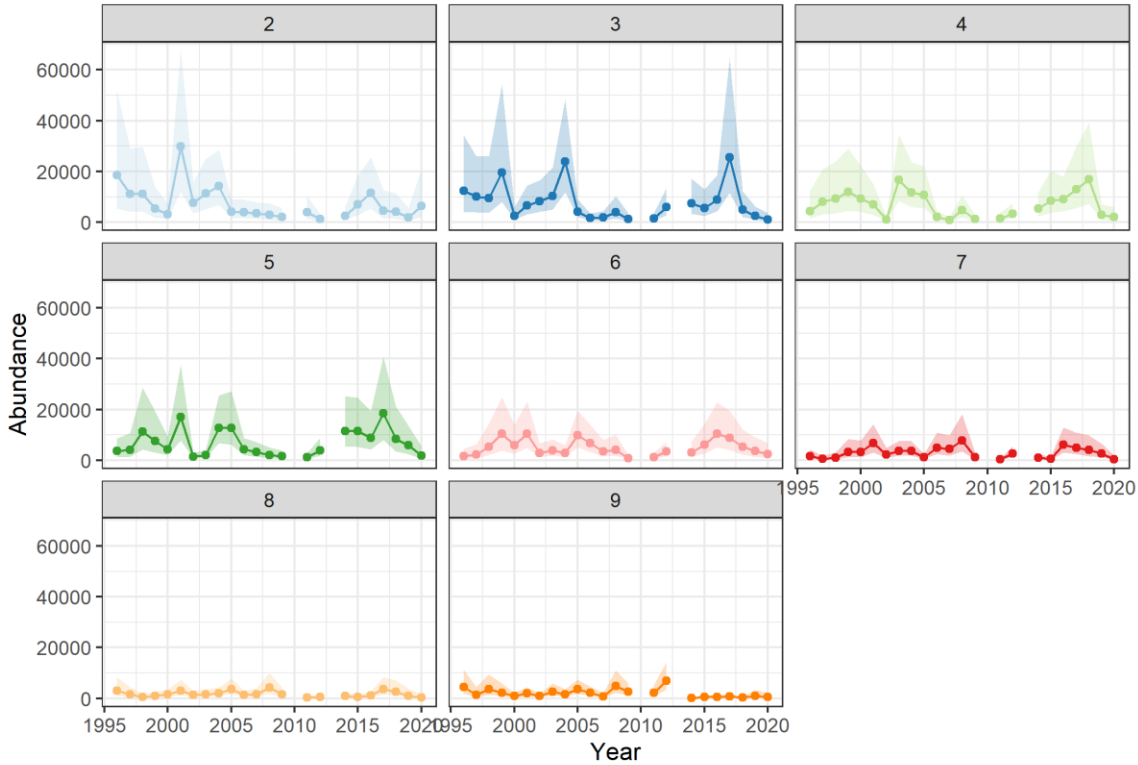

Figure 3.46. Survey indices by age of herring from IBTS Quarter 4 hauls north of 56 degrees calculated using a delta gam model.

Internal consistency plots from IBTS data showed greater consistency than those produced from the acoustic datasets (Figure 3.41, Figure 3.44) from ages 2 to 9.

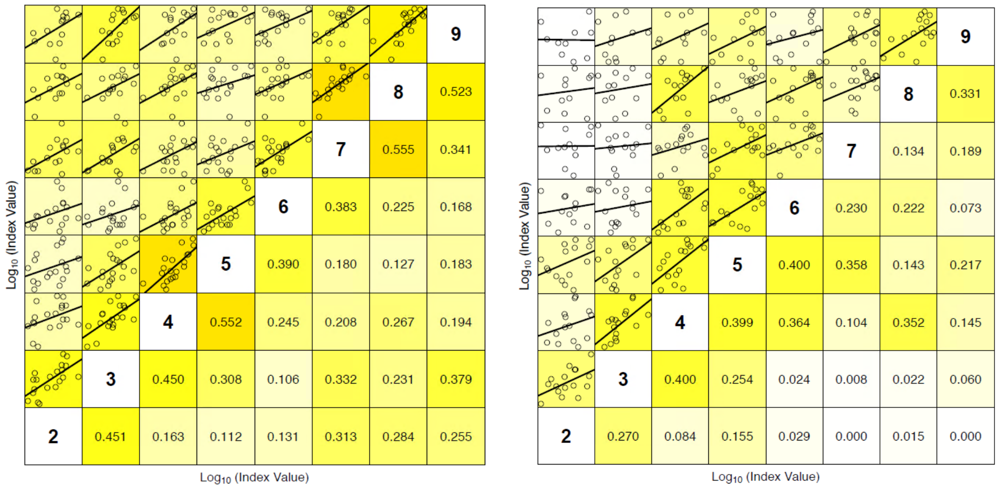

Figure 3.47. Internal consistency plots groundfish surveys north of 56 degrees north in 6.a: Left; IBTS Q1 Right; IBTS Q4.

Some initial genetic work has indicated that mixing of herring populations in these surveys occurs more than previously thought, and a geographic split of 56 degrees is not a meaningful stock delineator. Maturity stage of herring from the 6.aN autumn spawning population would be expected to be spent/ recovering at this time of year, and so the proportion of herring at maturity stage 7-8 on the Scottish 9 pt scale (5-6 on the ICES 6pt scale) north of 56 degrees from the IBTS surveys was examined. It should be noted that winter spawning 6.aS,7.b-c herring would also be spent/recovering at this time of year, and therefore it cannot be assumed that all spent fish are 6.aN autumn spawners. Herring at immature and developing maturity stages are also found in these surveys (Figure 3.48), demonstrating that populations of late winter/spring spawning fish (or undetermined origin) are mixing north of the geographic split.

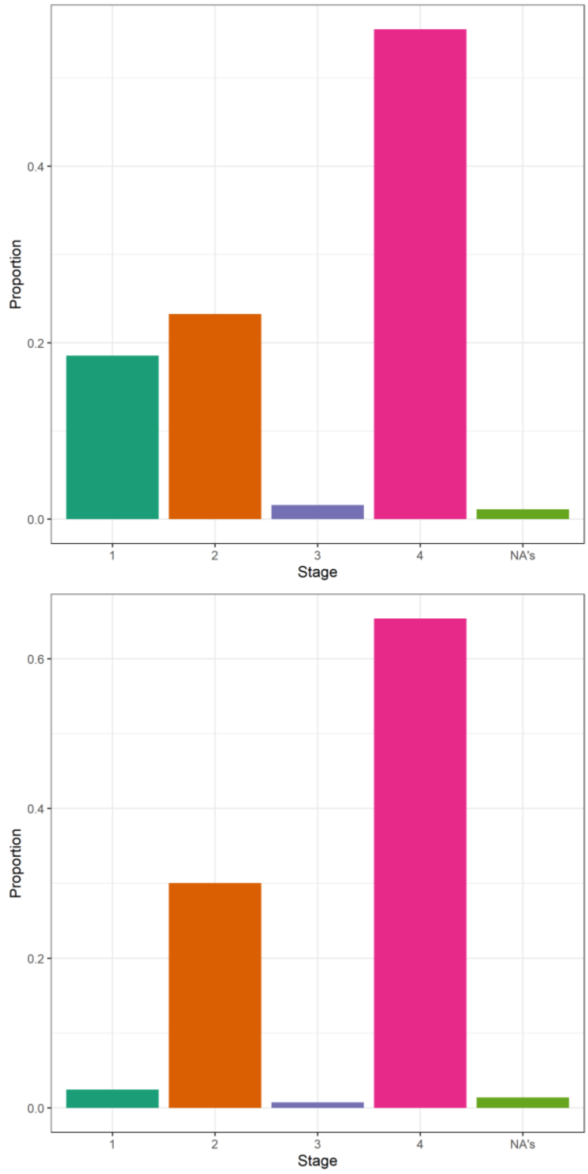

Figure 3.48. Proportion of maturity stages of herring caught in the IBTS Quarter 1 and Quarter 4 surveys north of 56 degrees. 1 = immature, 2 = developing, 3 = spawning , 4 = spent.

3.7 Weights, Maturities, Growth, Mortality

Mean weights in the catch

Weights-at-age from catch data are available for the 6.aN fishery from 1957–2020, and are updated annually from sampling carried out by Marine Science Scotland. Since 2016 a monitoring TAC has been in place and gaps in the sampling of catches from Scottish vessels have appeared at older and younger ages in some years. In these instances, weight-at-age estimates have been taken from samples collected by the Dutch fleet.

Mean weights were stable from the 1980s up to the late 2000s. Since then mean weights have declined across all ages, and numbers of samples for 1 wr herring have become reduced, increasing variability in the weight at age estimates (Figure 3.49). Decreases in mean weight have also been observed for other herring stocks around the Celtic Seas (ICES, 2021c).

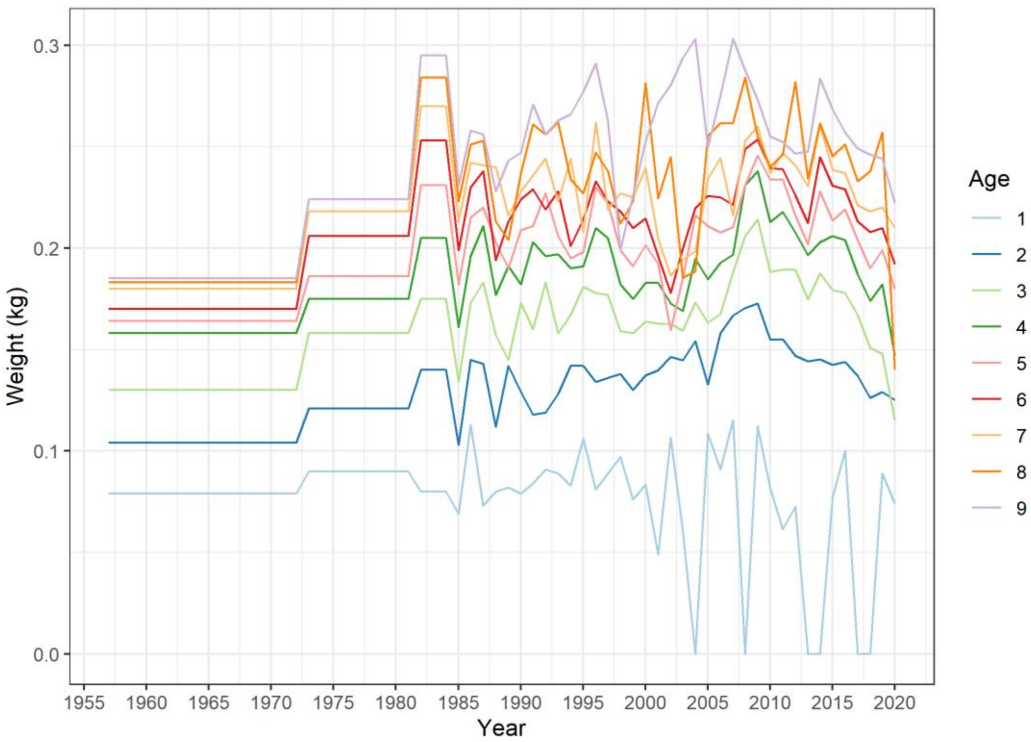

Figure 3.49. Herring in 6.aN. Mean weights in the catch.

Mean weights in the stock

Weights-at-age for the stock were taken from the Malin shelf survey genetic split and are shown in Figure 3.50. An average value is used prior to 2014. These fish are confirmed as 6.aN autumn spawners and provide the most accurate estimate of weights in the stock of this population. As with the mean weights in the catch, there is a downward trend since 2015, but estimates are more variable, especially at older ages (Figure 3.50). In some years there were no 1 wr fish found on the survey. In these years a three-year running average is used.

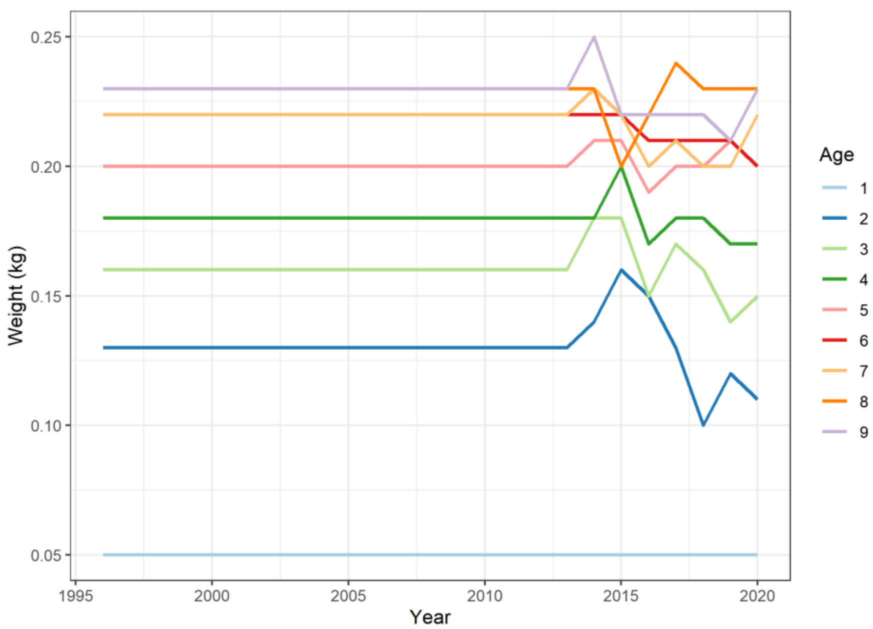

Figure 3.50. Herring in 6.aN. Mean weights in the catch

Maturity Ogive

Various sources were considered for the proportion mature in 6.aN. Maturity ogives were calculated using GLM modelling from both IBTS surveys, but these were discounted due to mistiming with the fishery. StoX estimates of the proportion mature from the Malin Shelf genetic split and the 6.aN industry survey were compared to estimates previously used in the combined assessment from the Malin Shelf acoustic survey. The proportion mature from the genetically split data were known to be 6.aN autumn spawning herring and estimates were less volatile than values from the industry survey (Figure 3.51); it was decided that these were most appropriate values for the 6.aN herring stock.

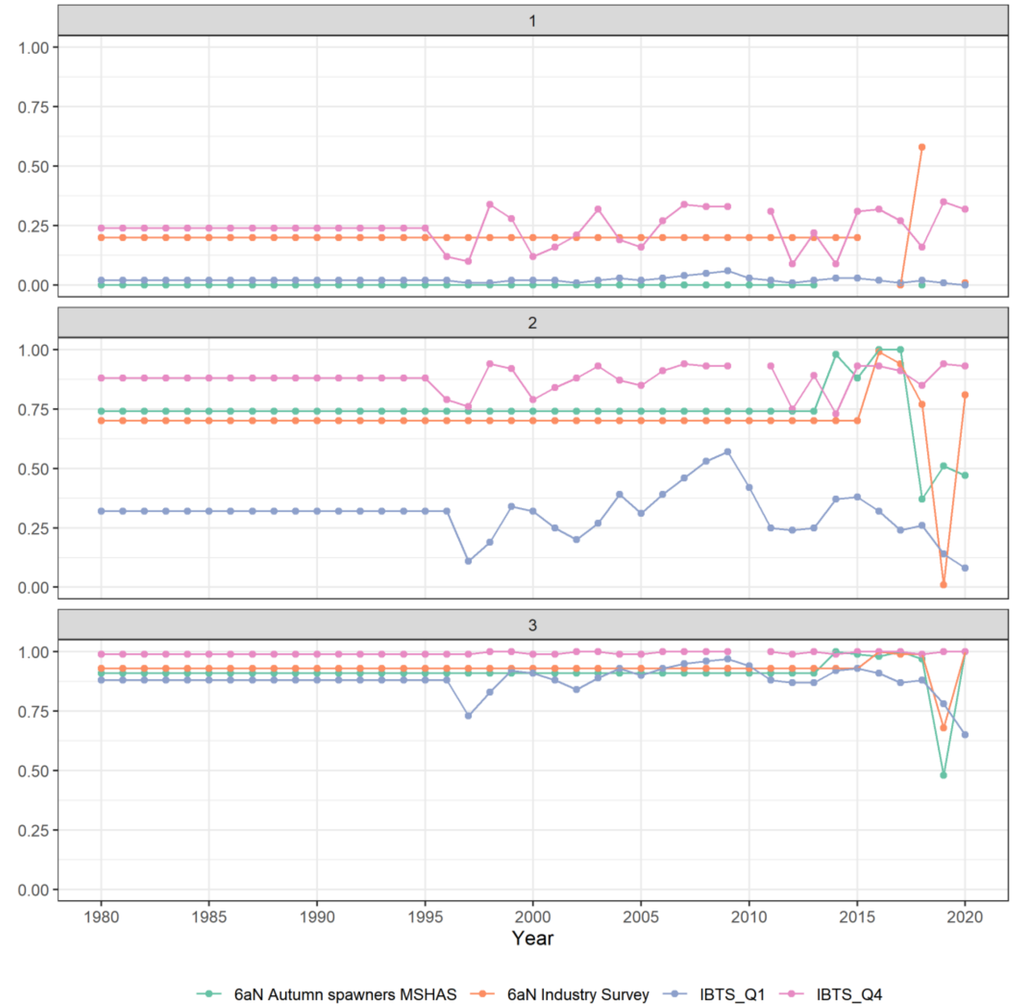

Figure 3.51. Proportion mature at age for ages 1-3 from survey indices over time.

Natural Mortality Estimates

Natural mortality of herring in this area were examined at WKWEST (ICES, 2015). Prior to this benchmark natural mortality was fixed over time but varied by age, but it was decided that using values based on updated information from the North Sea was more appropriate. These values came from the 2011 North Sea multispecies SMS key run, with an average value for each age from 1974-2013 taken. This value varies with age but is time invariant.

Since the benchmark there have been various updates to this SMS key run by the Working group on multispecies assessment methods (WGSAM). Following the procedure that had been agreed at WKWEST, the natural mortality values for the assessment were updated using data from the 2020 SMS key run (ICES, 2021d). The updated values show a lower natural mortality across all ages (Figure 3.52).

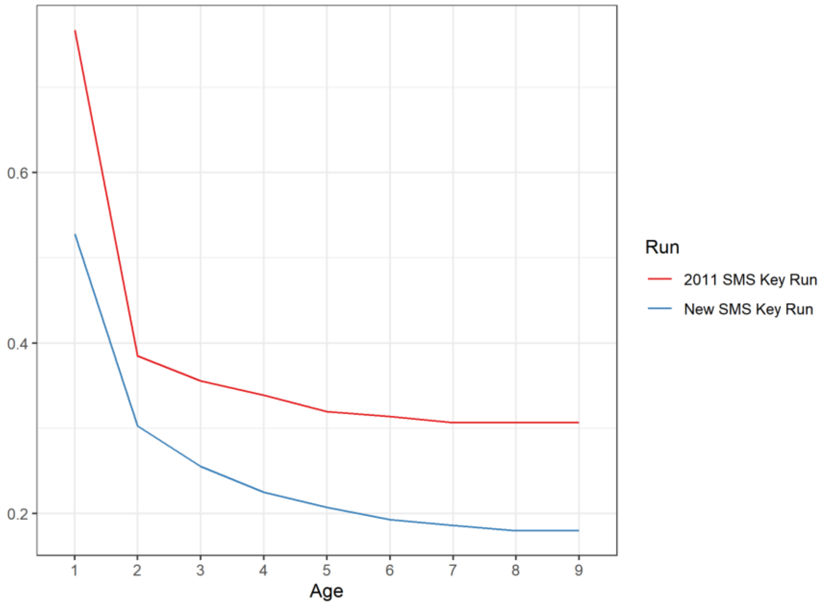

Figure 3.52. Comparisons between the 2011 SMS key run values and 2020 SMS key run values.

For category three assessments, the value of M were taken from ages 3-6 from the SMS key run (Table 3.10).

Table 3.10. Average M (1974-2019) at age for herring from the North Sea multispecies model (SMS) key run 2020 used in the assessment of 6.aN herring.

Age (winter rings)	1	2	3	4	5	6	7	8	9	Ages 3-6
M value	0.528	0.303	0.255	0.225	0.207	0.193	0.186	0.180	0.180	0.220

3.7.1 Assessment Model

SAM assessment

A number of exploratory models were developed in stockassessment.org (Nielsen and Berg, 2014), using different configurations of survey inputs, time spans and model settings. Weights, maturity and natural mortality data inputs are described in the section above.

The genetically split acoustic survey data was retained in all model runs because of the confidence that the abundance index refers specifically to the 6.aN autumn spawning stock and because the survey is dedicated to estimating the abundance of herring. Submitting an assessment using only demersal survey data was not deemed suitable.

All data inputs were truncated to exclude years before 1996. From this date there are survey data available, catch data are more reliable, and the timing of the fishery in this time period is analogous (Figure 3.34).

The acoustic survey estimates for age 1 are very variable (Figure 3.40, Figure 3.43), so assessment runs with age 1 herring removed from this survey and from the catch data were tested. These runs did not converge, and age 1 herring were retained in the model.

Estimates of survey variance were calculated for the IBTS datasets from the upper and lower values calculated as part of the delta-lognormal model outputs (Figure 3.45, Figure 3.46). These were included as a weighting on the IBTS survey datasets in the SAM assessment runs, and improved the model fit when used.

For each series of survey data tested in the modelling process, several model configuration settings were examined. Settings of the covariance structure options, various coupling values in the configuration of the survey catchabilities, the age-dependent observation error for all datasets and the corF value were all tweaked during this process (Table 3.13).

Decisions on which survey inputs worked best were made based on model AIC, residual patterns in the assessment, confidence intervals from the models and outputs from the retrospective runs generated. Removing the IBTS quarter four estimates dramatically improved all of these characteristics (Table 3.11). The exclusion of the IBTS quarter four dataset had a dramatic effect on the SSB, Fbar and Recruitment estimates from the models (Figure 3.53, Figure 3.54, Figure 3.55). When data from the IBTS quarter four survey were removed, inclusion of the 6aSPAWN industry acoustic survey data did not affect the performance of the model in either way.

Table 3.11. Retrospective bias for model runs including a range of survey inputs and run names used in comparison plots. NAs show where the retrospectives would not run.

Different configurations of Survey inputs	Run Number	Recruitment	SSB	Fbar (3-6)
IBTS Q1, IBTS Q4, genetically split acoustic survey and industry survey	Run 1	NA	NA	NA
IBTS Q1, IBTS Q4 and genetically split acoustic survey	Run 2	0.129	0.079	-0.077
IBTS Q4, genetically split acoustic survey and industry survey	Run 3	NA	NA	NA
IBTS Q1, genetically split acoustic survey and industry survey	Run 4	0.054	0.002	-0.066
IBTS Q1 and genetically split acoustic survey	Run 5	0.052	-0.035	0.093
Genetically split acoustic survey and industry survey	Run 6	1.262	0.914	-0.287

The final SAM run was developed for 6.aN herring using the data inputs outlined above and are summarised below in Table 3.12 (Run 5 in Table 3.11).

Table 3.12. Data inputs for the final SAM configuration

Data Input	Source
Catch numbers	Catches in 6.aN 1996-2020
Catch mean weights	Sample data, has been some infilling in recent years 1996-2020
Survey indices	Genetically assigned 6.aN fish from MSHAS 2014-2020
	IBTS Q1 calculated using delta-lognormal gam 1997-2020
Stock mean weights	Genetically assigned 6.aN fish from MSHAS
Survey variance	Calculated for the IBTS datasets from the modelled survey indices
Discards	Assumed to be negligible
Maturity ogive	Genetically assigned 6.aN fish from MSHAS
Natural mortality	From 2020 SMS key run

The configuration of the final SAM model developed is shown below in Table 3.13.

Table 3.13. Configuration settings used in the final SAM model presented.

```
$minAge
 1
$maxAge
 9
$maxAgePlusGroup
 1 1 1
$keyLogFsta
  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
2
$keyLogFpar
 -1 -1 -1 -1 -1 -1 -1 -1 -1
  0  1  2  3  4  5  6  7  7
  -1  8  9  10  11  12  13  14  14
$keyVarObs
  0  1  2  2  2  2  2  3  3
  4  4  5  5  5  5  6  6  6
  -1  7  7  7  7  8  8  8  8
$obsCorStruct
"ID" "AR" "AR"
$keyCorObs
 NA  NA  NA  NA  NA  NA  NA  NA
 0  0  1  1  1  1  1  1
 -1  2  2  2  2  2  2  2
$fbarRange
3 6
```

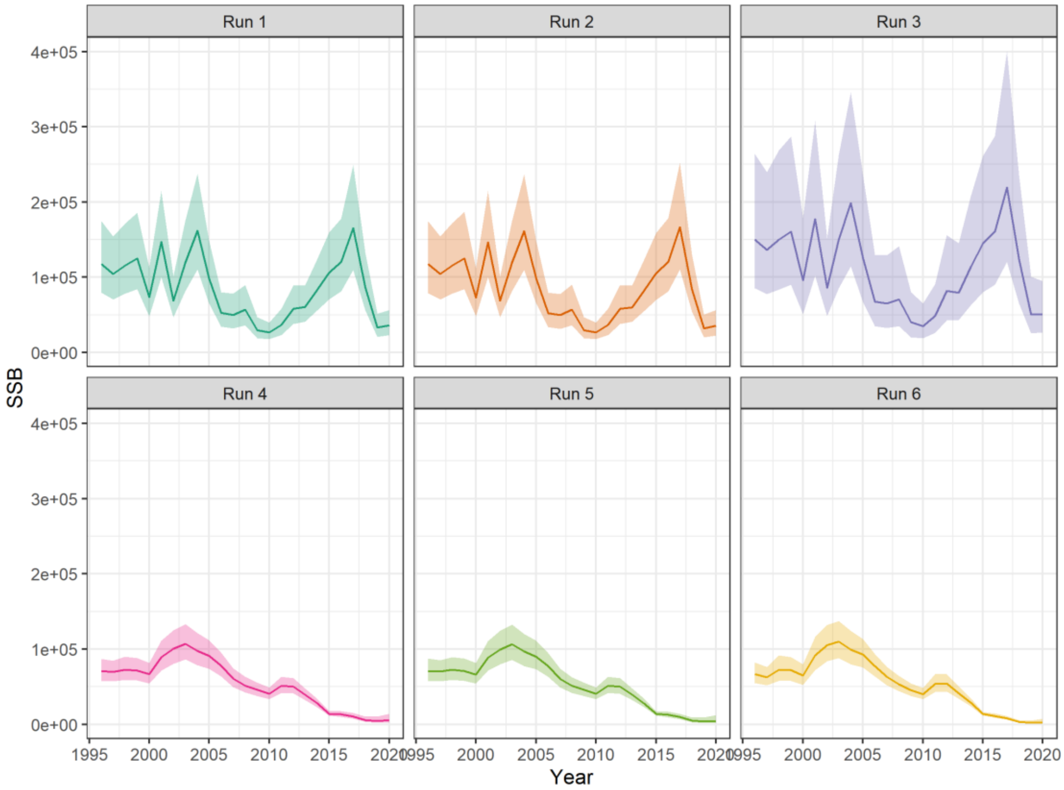

Figure 3.53. SSB estimates produced from different SAM model runs. Surveys included in the different runs are detailed in Table 3.11.3.

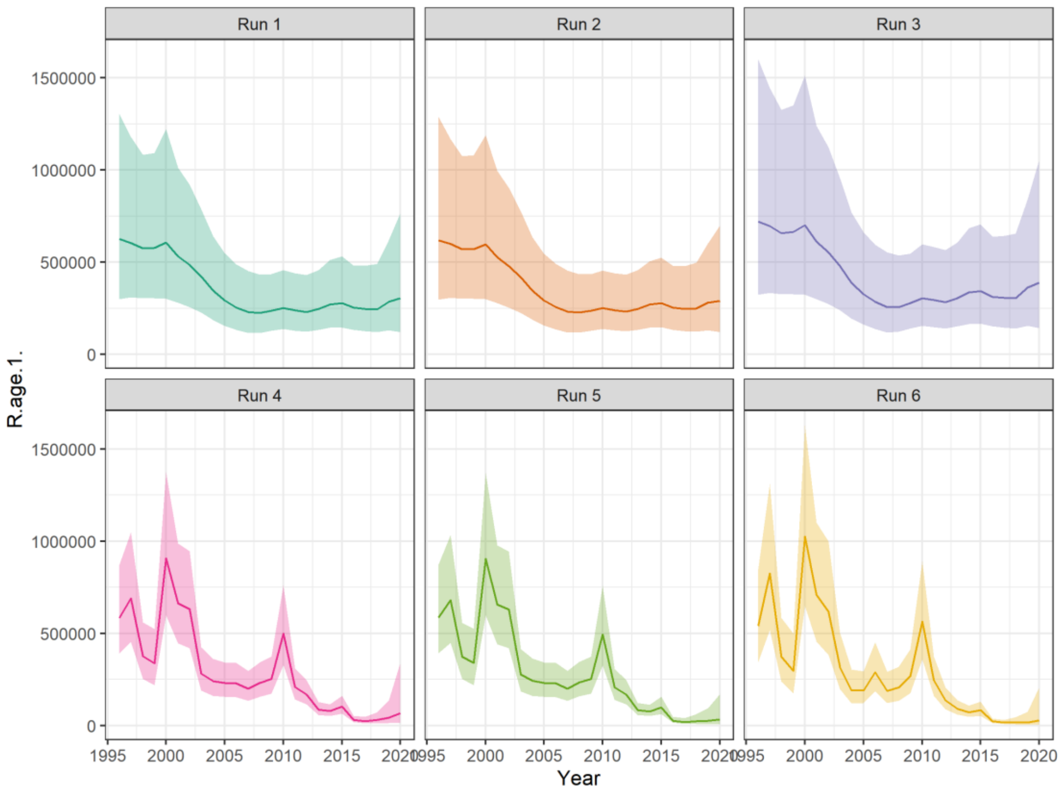

Figure 3.54. Recruitment estimates produced from different SAM model runs. Surveys included in the different runs are detailed in Table 3.11.3.

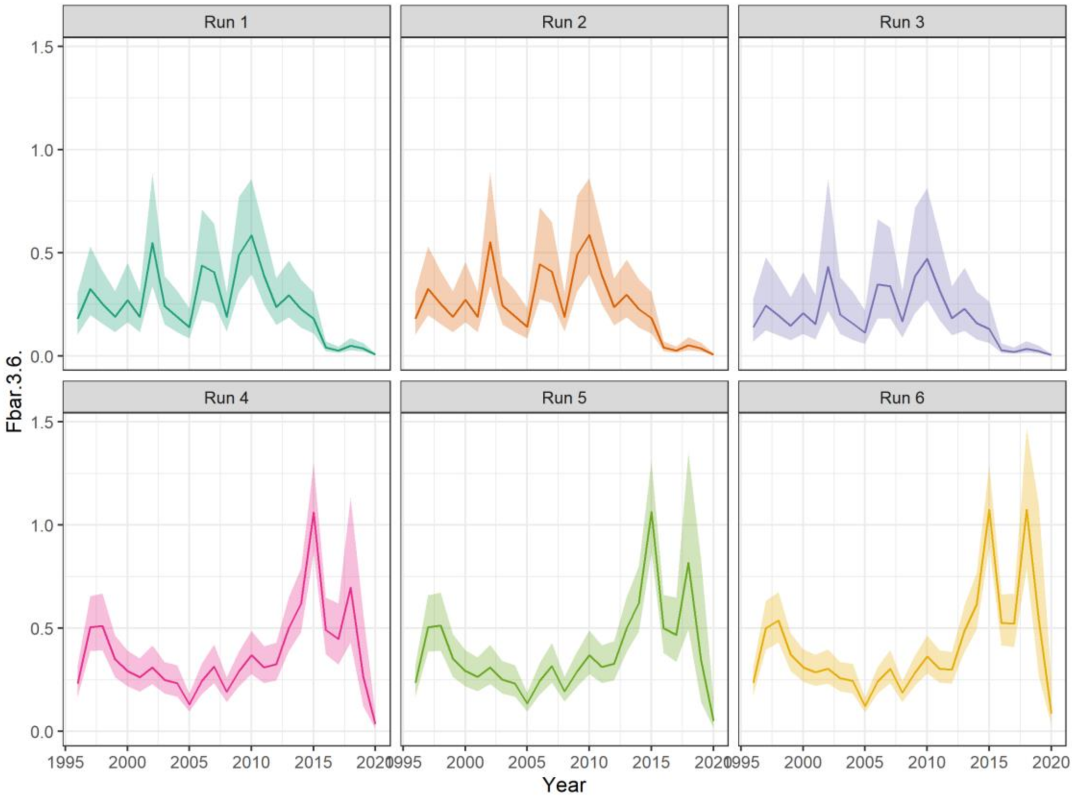

Figure 3.55. Fbar estimates produced from different SAM model runs. Surveys included in the different runs are detailed in Table 3.11.3.

Results from the final SAM model selected showed a decline in SSB from 2003 onwards, with SSB continuing to decline once the monitoring TAC was introduced in 2016 (Figure 3.56). Recruitment has been variable over time, but has remained at very low levels since 2015. Fishing mortality has increased over time, with very variable values observed since 2015 (Figure 3.56).

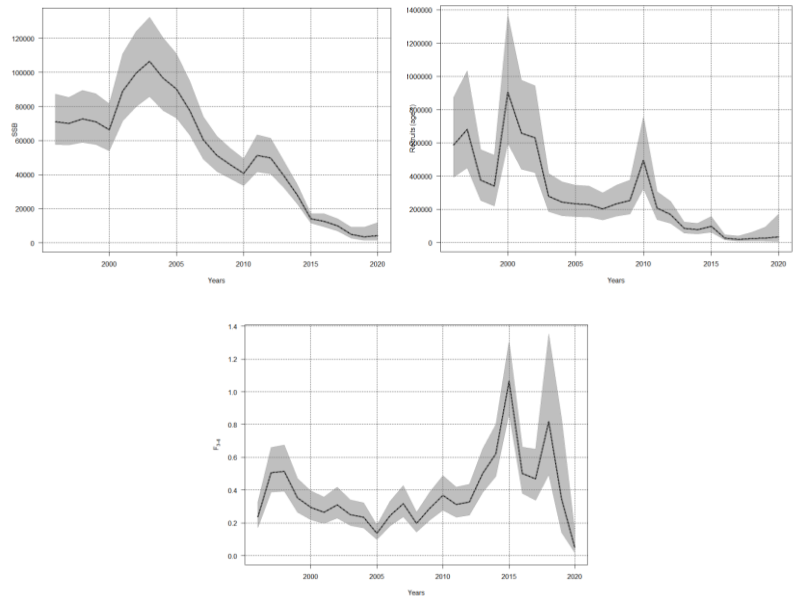

Figure 3.56. SSB, recruitment and Fbar plots from the final SAM model presented to the benchmark group.

Retrospective biases calculated from the model are shown in Figure 3.57. These values are within the acceptable Mohn's Rho limits for ICES assessments (Table 3.11), but did show a downward correction in F in recent years.

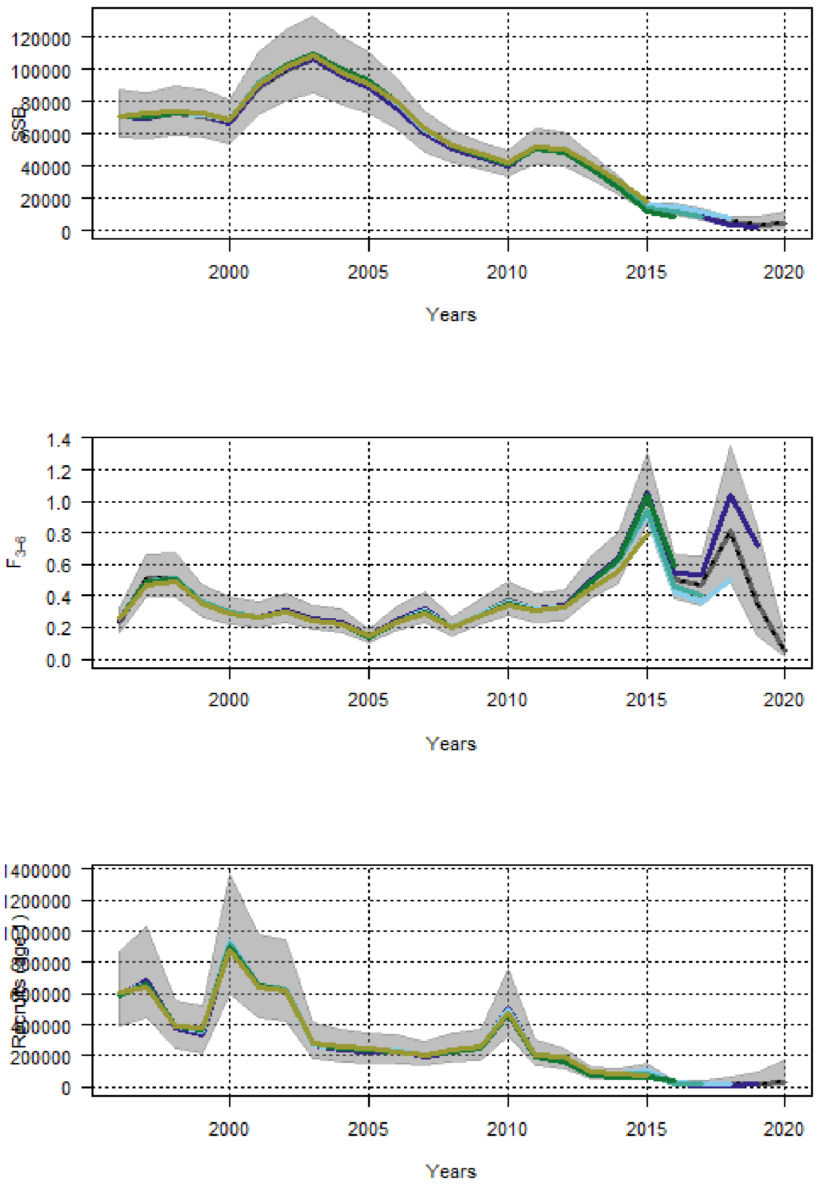

Figure 3.57. Retrospective plots from the final SAM model presented.

Residual patterns from the proposed SAM model are shown in Figure 3.58. No marked patterns in one direction are observed.

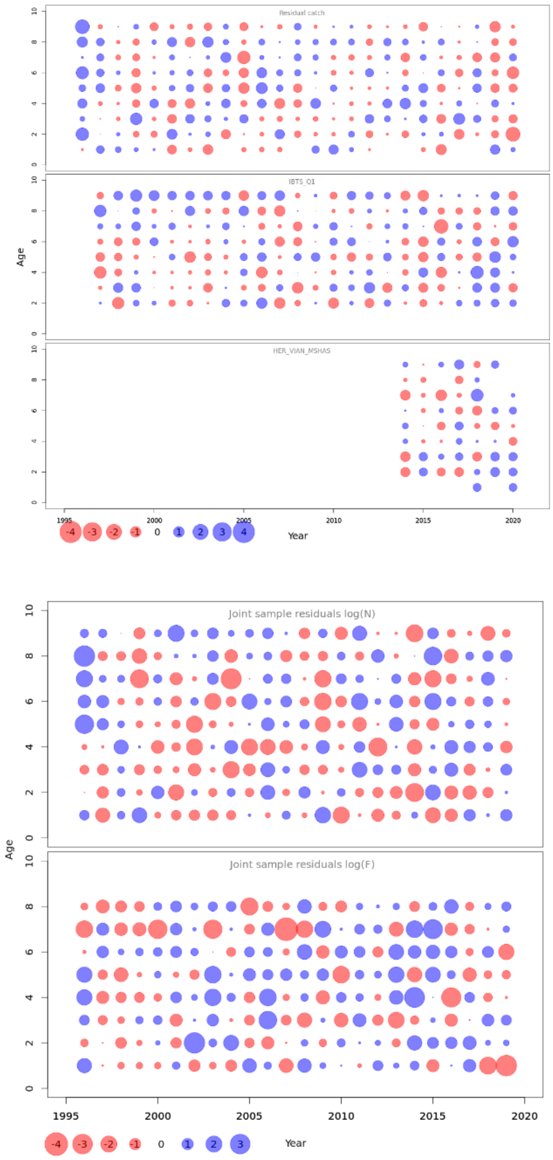

Figure 3.58. Standardised one-observation-ahead residuals (left) and standardised single-joint-sample residuals of process increments (right) from the SAM model presented to the benchmark group.

The SAM model was presented and discussed at the WKNSCS benchmark meeting. During the meeting misgivings over the model were examined.

The group raised concerns over the catch data and its influence on the assessment presented. Catch data are assumed to be from 6.aN autumn spawning herring, but with a lack of genetic sampling this is not certain. Additionally there are underlying stock identity questions for 6.aN herring relating to the relationship with populations in the North Sea that have not been resolved. Inconsistency plots from the assessment (Figure 3.59) show a lack of tracking between juvenile and older fish in the data and suggest that there are stock identity issues in the catch data that need to be resolved. Catches have plummeted since 2016 due to the monitoring TAC, and there has been poor uptake of the monitoring quota in recent years for various reasons. This has driven down the estimates of SSB produced from the SAM model (Figure 3.56) and therefore these estimates may not be reflective of herring abundance in the region.

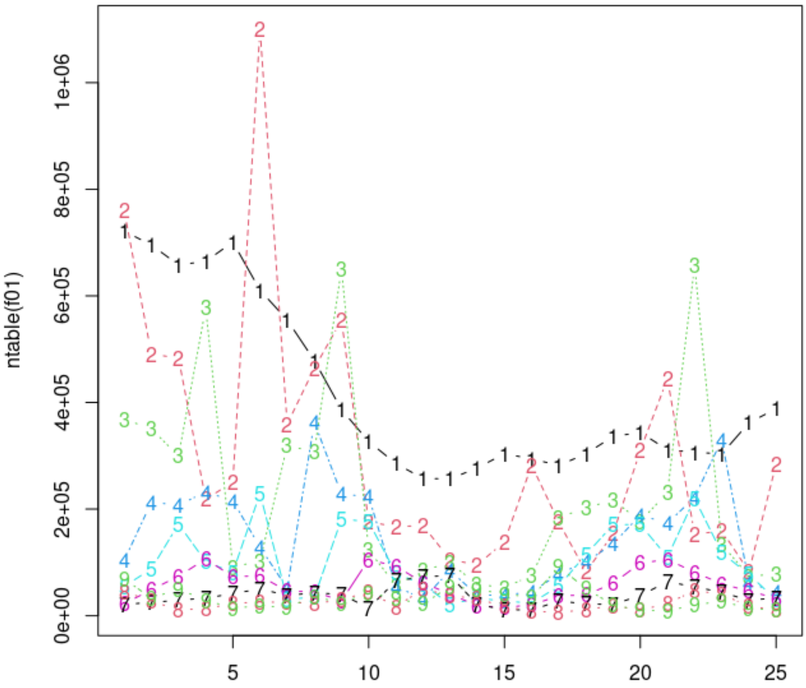

Figure 3.59. Numbers-at-age over time from catches in the assessment model.

The appropriateness of including the IBTS datasets in the SAM model was questioned. The two indices drove estimates of SSB and F in different directions, and have a large influence on the trends seen in the assessment. The geographic split used for calculating these indices assumed most herring would be part of the 6.aN autumn spawning component. Exploratory genetic sampling and the mixes of maturity stages observed in the biological data suggests that mixing of herring stocks north of the 56 degree line may occur to a larger extent than originally believed (Figure 3.48). The acoustic datasets available provide very variable estimates of abundance over a short period, retrospective estimates for runs excluding IBTS datasets were unacceptable (Table 3.11).

These issues reflect the knowledge gaps surrounding this stock and highlight the need for further research. As a result of these issues, the benchmark group determined that a SAM model did not provide a suitable perception of the stock in 6.aN. Therefore, a data-rich, full analytical assessment for this stock was deemed unsuitable and advice should be given using category 3 methods.

Category 3 Methods

Under category 3 methods advice is provided using biomass or abundance trends-based assessments.

The latest ICES guidance on applying these methods recommends that a SPiCT (Pedersen and Berg, 2014) assessment model should be attempted first. If an acceptable SPiCT model is not possible, other data-limited approaches should be attempted, based on the von Bertalanffy growth parameter *k* for the population being assessed (Figure 3.60).

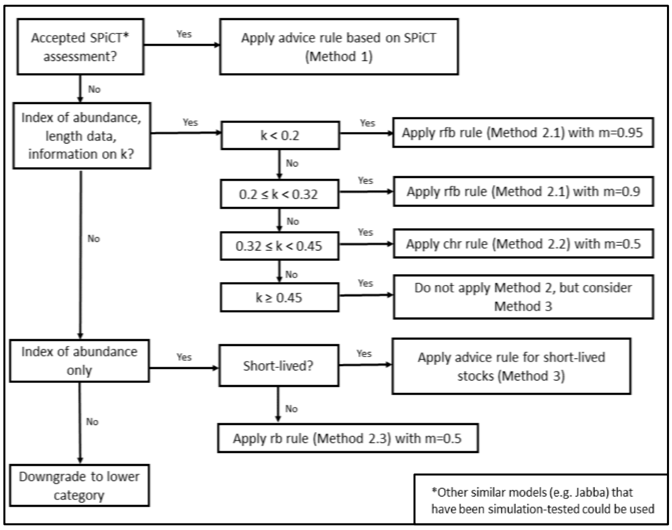

Figure 3.60. Flow chart from WKLIFE X (ICES, 2021e) indicating the methods that should be applied for category three stocks.

SPiCT model

Landings data (1957-2020), estimates of SSB of 6.aN autumn spawners (available since 2014), and SSB estimates from the 6.aN industry survey were used as data inputs for a SPiCT model (Figure 3.61). Due to concerns from the benchmark group over the use of west coast IBTS datasets in analytical assessments, these were not considered as data inputs for this method. Data were truncated to years with a suitable biomass index (2014 onwards), and the time of year was set to reflect the months that catch and surveys took place (Figure 3.61).

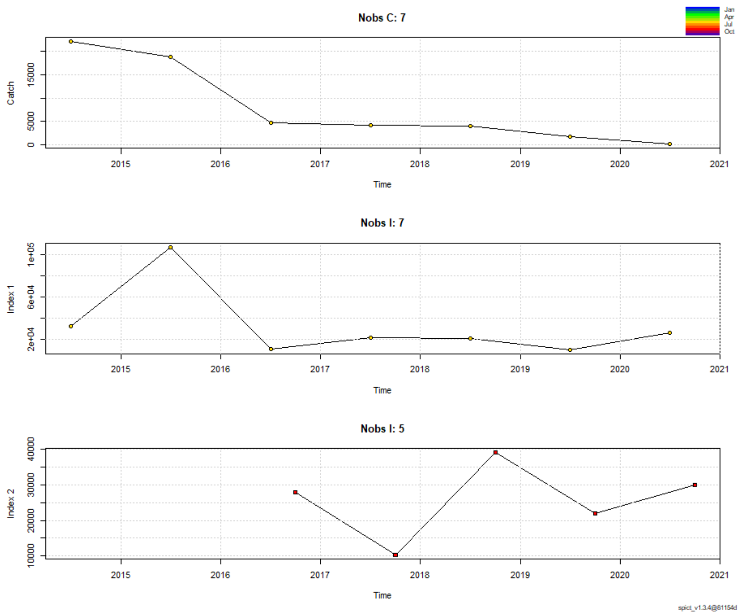

Figure 3.61. Catch and index datasets used in the SPiCT model for herring in 6.aN. Index 1 refers to the genetically split Malin Shelf survey, while index 2 refers to the 6.aN industry survey. All units are in tonnes.

Various model settings were used throughout the modelling process. The shape of the production curve was altered based on Thorson *et al*., 2012 to better fit the life history traits for clupeid fish. Logbeta and alpha priors were deactivated, and the standard deviation and catch error were reduced. An initial depletion level was set to better reflect the state of the stock.

Figure 3.62 shows the outputs from the final SPiCT configuration. The model is not able to account for the variable biomass estimates over time, and confidence intervals for estimates and reference points were large.

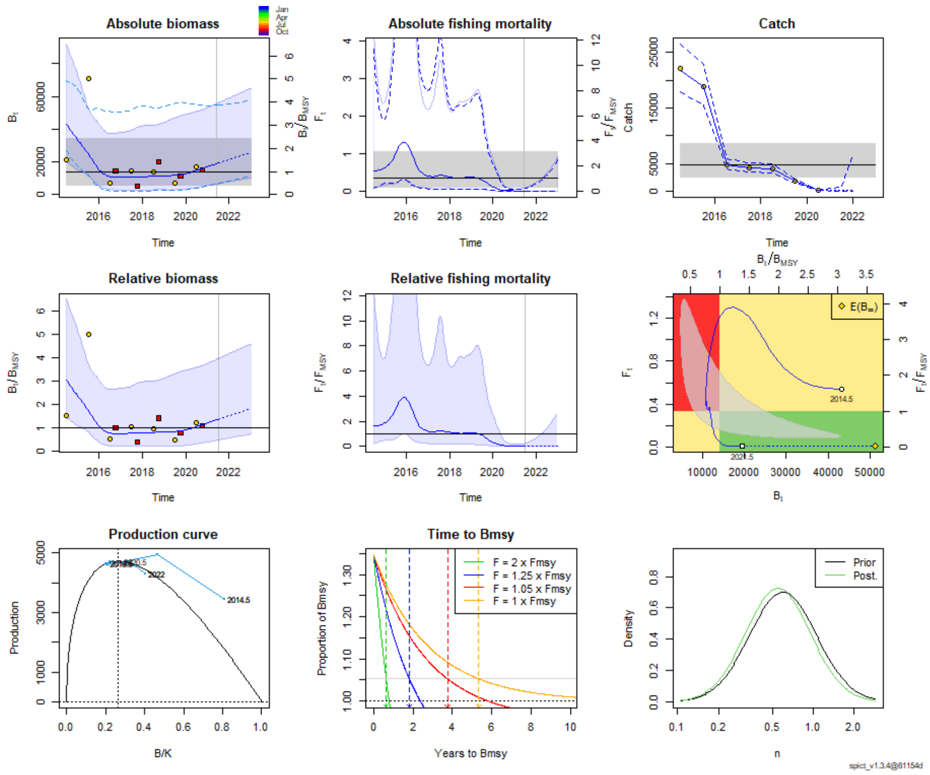

Figure 3.62. Outputs from the final SPiCT model developed for herring in 6.aN.

Retrospectives from the model would only run back two years, and these displayed high confidence intervals and concerning patterns in the estimates (Figure 3.63).

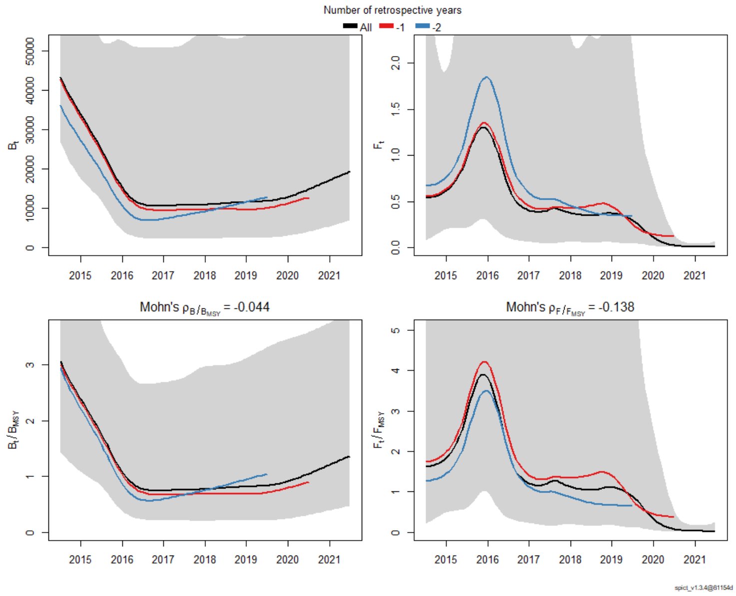

Figure 3.63. Retrospective patterns from the SPiCT model developed for herring in 6.aN.

With the short and variable nature of the biomass time-series available, this SPiCT model was not considered to be suitable as a category 3 option for herring in 6.aN.

Calculation of k value

The recommendations from WKLIFE (ICES, 2021e) suggest that the next approach should be based on the von Bertalanffy growth parameter k for the population being assessed (Figure 3.60).

During the benchmark meeting, biological data from the 6.aN genetically split acoustic survey were extracted from DATRAS and analysed to calculate k and asymptotic length (Figure 3.64). These fish are unquestionably 6.aN autumn spawning herring (compared to catch/IBTS data where we don't have genetic samples available).

During the early years of genetic sampling, fish smaller than 23 cm were not sampled (standard protocol) and so do not exist in the DATRAS database when split into genetic components. These years were excluded from k calculations. The R script for these calculations is available and estimates were bootstrapped. The SPM priors package (Winker, 2021) was used to tune these values. This method for estimating k was approved by the benchmark group. With a k value of 0.337, the WKLIFE guidelines (ICES, 2021e) recommend that calculating a Constant Harvest Rate to provide advice is appropriate for this stock (Figure 3.60).

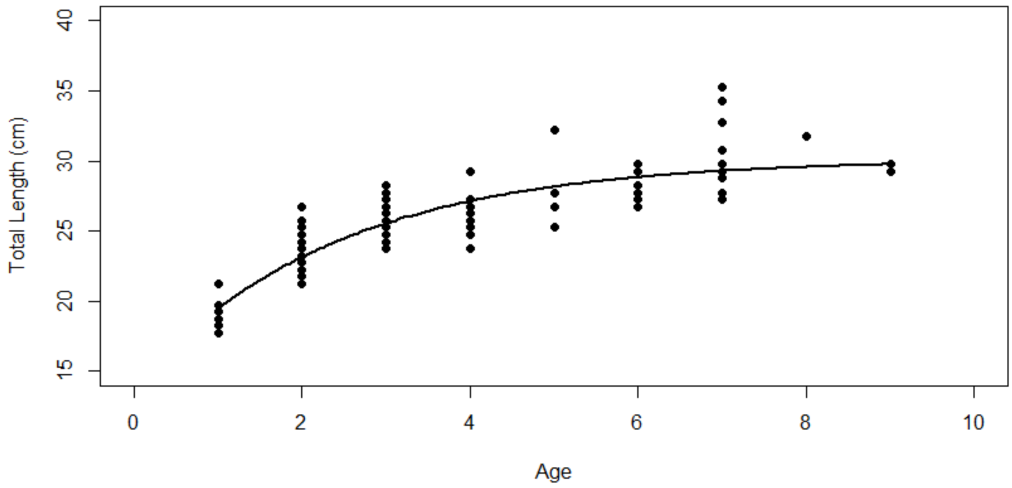

Figure 3.64. Growth curve calculated from the 6.aN acoustic survey data.

Constant Harvest Rate calculation

The constant harvest rate (CHR) applies a constant harvest rate ($F_{proxy\ MSY}$ calculated from catch length frequency data) that is considered a proxy for MSY harvest rate, and applies this to the biomass index. This rule is being applied using the genetically split acoustic index, so includes values from 2014 onwards. The $F_{proxyMSY}$ used in applying this rule is calculated from the length frequency data. As per ICES, 2021e, advised catch is calculated as follows, with the equation components described in Table 3.14:

$$C_{y+1} = I_{y-1} \times F_{proxy,MSY} \times b \times m$$

Table 3.14. Definitions of the components used to calculate chr (from ICES, 2021e).

Component	Definition	Description and use
I_{y-1}		The index in year y−1.
$F_{proxy,MSY}$	$\frac{1}{u}\sum_{y\in U} C_y/I_y$	Is the mean of the ratio C_y/I_y for the set of historical years U for which the quantity f > 1, and u is the number of years in the set U. The quantity f is the ratio of the mean length in the observed catch that is above the length of first capture relative to the target reference length (mean length/target reference length). The target reference length is $L_{F=M} = 0.75L_c + 0.25L_\infty$, where L_c is defined as length at 50% of modal abundance (ICES, 2018b).
b	$\min\left\{1, \frac{I_{y-1}}{I_{\text{trigger}}}\right\}$	Biomass safeguard. Adjustment to reduce catch when the most recent index data I_{y-1} is less than $I_{trigger} = 1.4I_{loss}$ such that b is set equal to $I_{y-1}/I_{\text{trigger}}$. When the most recent index data I_{y-1} is greater than I_{trigger}, b is set equal to 1. I_{loss} is generally defined as the lowest observed index value for that stock.
m	[0,1]	Multiplier applied to the harvest control rule to maintain the probability of the biomass declining below B_{lim} to less than 5%. May range from 0 to 1.0.
Stability clause	$min\{max(0.7C_y, C_{y+1}), 1.2C_y\}$	Limits the amount the advised catch can change upwards or downwards between years. The recommended values are +20% and −30%; i.e. the catch would be limited to a 20% increase or a 30% decrease relative to the previous year's advised catch. The stability clause does not apply when b < 1.

The target reference length ($L_{F=M}$) is calculated from the length frequency data (Figure 3.65) and is key to the $F_{proxyMSY}$ value calculation. Target reference length is calculated using the following equation:

$$L_{F=M} = (0.75*Lc_{(y)}) + (0.25*L_{inf})$$

This calculation assumes that the M/k ratio is equal to 1.5. When the actual M/k ratio is calculated for 6.aN herring the value comes to 0.65, which is considerably different to the assumed value. Using the assumed method with an M/k ratio of 1.5 would suggest a natural mortality estimate of 0.51 for herring in 6.aN. This value contrasts with the values taken from the 2020 SMS key run (Table 3.10). ICES technical guidelines (ICES, 2018) state that stock specific M/k values can be applied by using an alternative $L_{F=M}$ calculation from Jardim *et al*. 2015:

$$L_{F=\gamma M, K=\theta M} = \frac{\theta L_\infty + L_c(\gamma + 1)}{\theta + \gamma + 1}.$$

The CHR rule was run using both methods for calculating the target reference length (Table 3.15). Using the alternative approach increases the advised catch by only 68 tonnes, with the stability clause in place there is no difference between the two methods (Table 3.15). Therefore, it was decided that using the alternative calculation from Jardim *et al*. (2015) was appropriate for the stock moving forward.

Table 3.15. Difference in advised catch for 2021 calculated using the constant harvest rate calculation using different methods of defining target reference length.

Target Reference Length Method	Advised catch for next year (2021) before stability clause applied (tonnes)	Advised catch for next year (2021) with stability clause applied (tonnes)
Original assuming M/k ratio = 1.5	3591	2392
Alternative using Jardim *et al.* 2015	3659	2392

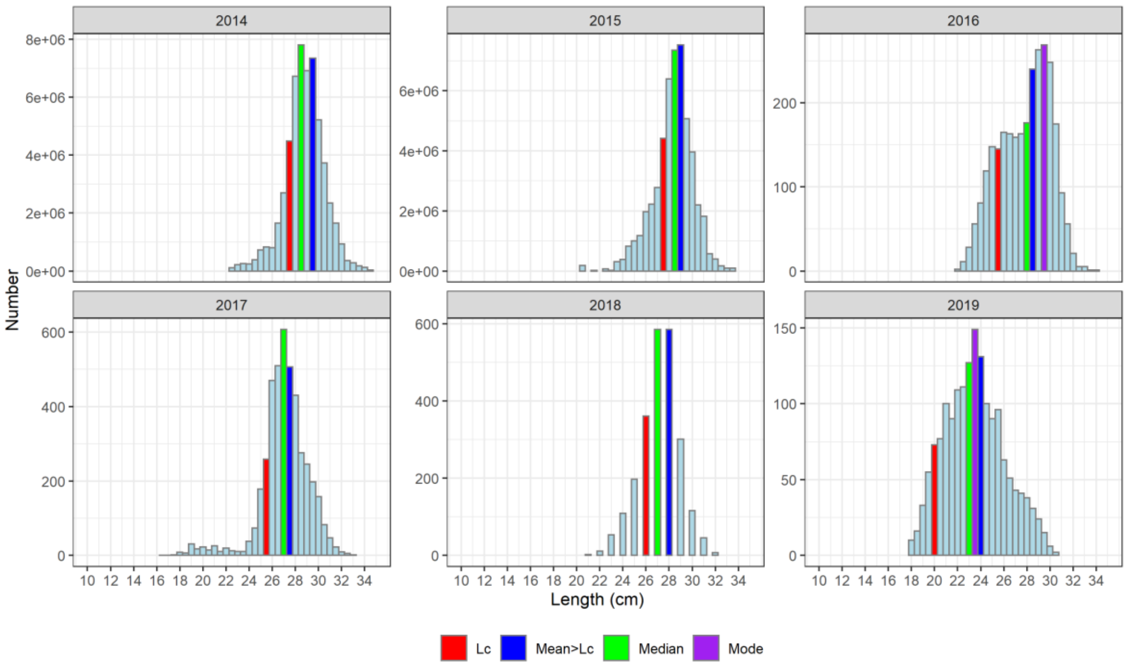

Figure 3.65. Length frequency data for herring in 6.aN, with length at first capture (Lc), mean length above length of first capture (Mean>Lc), median and modal catch in each year marked. Note that since 2016 a monitoring TAC has been in place. Some data in 2018 were only reported to a 1 cm resolution, and therefore all data have been binned to this level. No length data from commercial hauls are available for 2020.

For both herring stocks it was agreed that the starting value (usually the advised catch in the last year), would be set to the average of the past three years. Both stocks are under zero catch advice and a monitoring TAC, neither of these values were deemed appropriate as a starting point for these stocks. This decision may be revisited by the working group in 2022.

The method of applying the CHR rule for 6.aN herring was approved by the working group, with final review and approval by external reviewers using the updated length-frequency data.

Resulting Advice

Advice for the next year (2021) was much higher than the average of the last three year's catches (4373 tonnes), but the stability clause that constrains the advice change to -30% or +20% brings this down to an advised 2392 tonnes.

3.8 Short-term projections

Not applicable for this stock

3.9 Appropriate Reference Points

The $F_{proxyMSY}$ for herring in 6.aN is estimated at 0.34 and the target reference length for the latest year is 22.97cm. Table 3.16 values calculated from the length-frequency data used in the calculation of the $F_{proxyMSY}$ value. Herring caught in 2019 were smaller than for other years, consequently the calculation of F for this year is below one and is not used in calculations of $F_{proxyMSY}$.

Table 3.16. Values calculated from length-frequency data that are used to calculate the $F_{proxyMSY}$ value in the CHR rule and constants used in the final calculation.

Value	2014	2015	2016	2017	2018	2019	2020
Lc (cm)	27.5	27.5	27	25.5	26	20	NA
Mean>L_c (cm)	29.45	29.21	29.54	27.7	28.07	23.98	NA
Median (cm)	28.5	28.5	28.5	27	27	23	NA
Modal catch (cm)	28.5	29	29.5	27	27	23.5	NA
Target Ref (cm)	28.74	28.74	28.46	27.61	27.9	24.5	NA
F	1.02	1.02	1.04	1	1.01	0.98	NA
Cy_ly	0.68	0.18	0.43	0.19	0.2	NA	NA
Cy-2 (mean of last 3 years catch, t)	1993						
Iy-1 (latest survey SSB, t)	26070						
Fproxy,MSY	0.335						
b (biomass safeguard)	1						
m (multiplier)	0.5						
chr	4373						
% Change (from previous 3yr catch)	119						
Stability clause applied (-30% or +20%)	2391.6						
Advised Catch	2391.6						

3.10 Future Research and data requirements

The benchmark has focussed on using genetic data to split into two separate components a combined assessment that covered all stocks of herring in 6.aN and 6.aS.7.b-c.

In doing so, the new assessment for 6.aN covers only the autumn spawning herring population in 6.aN. However, according to the genetic analyses presented to the benchmark there exists a stock of late winter/spring spawners whose origin is uncertain and whose abundance is estimated to be considerably larger than the present 6.aN autumn spawning stock. In assessment terms, these late winter/ spring spawners of uncertain origin are no longer accounted for in the herring present in 6.aN, despite the fact that there is some (albeit very limited) evidence that they may be caught by the fishery in 6.aN in quarter 3.

At present there are no surveys dedicated to assessing the state of this unaccounted 6.aN spring spawning stock. Future work on locating and collecting genetic baseline samples from this stock should be conducted so that it is possible to estimate the origin and size of this stock with reliability through the results from the from the Malin Shelf Herring Acoustic Survey. In addition work should be conducted to establish the proportion of these herring caught in the fishery.

A meaningful evaluation of the utility of the abundance index of 6.aN herring derived from the 6aSPAWN industry acoustic survey was not possible because it the time-series was considered too short at present to reliably track age composition. The index shows a good consistency with the West of Scotland component of the Malin shelf acoustic survey index, and if extended could provide an important secondary index for use in future analytic assessments. The survey itself also serves as the vehicle to undertake sampling of genetic baselines and monitoring changes in the distribution of spawning over a wider area in 6.aN known to have been spawning areas in the past. For these reasons it is advisable to continue for the foreseeable future.

The uptake of the monitoring tac in recent years has been low, reducing the catch sampling data available for herring in 6.an. If this trend continues this will severely impact whether a data-rich assessment is possible in the future for this stock. To this end, efforts should be made to utilise available monitoring tac and ensure samples from commercial catch include both biological and genetic sampling necessary to determine stock components in the catch.

Genetic work also shows with a very high degree of certainty that autumn spawning herring in 6.aN are from the same population as herring in the North Sea. The significance of this is important both for the biological basis for stock assessment and also the management of herring fisheries, and should be reviewed in the future.

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4 Herring (*Clupea harengus*) in Division 6.a South (South of 56°00’N and West of 07°00’W) and 7.b-c (northwest and west of Ireland) – her.27.6aS7bc

Atlantic herring to the northwest of Ireland and west of Scotland are currently recognized by ICES and are subject to assessment and management. The 6.a.S,7.b-c herring spawn off Donegal in northwest Ireland in winter (November to March) and the 6.a.N herring spawn off Cape Wrath in northwest Scotland in Autumn (September/October). The stocks are believed to form mixed feeding aggregations west of the Hebrides in summer, where they are surveyed by the Malin Shelf Herring Acoustic Survey (MSHAS), conducted annually by the Marine Institute and Marine Scotland Science. The MSHAS survey index is a primary input into the stock assessments of the two stocks. Up to now it has not been possible to separate the data from the MSHAS into stock of origin, therefore only a combined index was available and hence a combined assessment (ICES, 2015). Based on the combined assessment, ICES provides combined advice for the two stocks and has recommended a zero TAC since 2016. The last benchmark for these stocks (WKWEST, 2015) concluded that there was ‘*a clear need to rapidly develop robust methods of being able to identify individuals to their spawning population, both in the catches and surveys. The development of the methods is a matter of priority and this recommendation should be addressed to the EU, national governments, ICES, National laboratories and the prosecutors of the fisheries (fishers and processors etc)*’.

4.1 Stock ID and sub-structure

4.1.1.1 Genetically Split Malin Shelf Herring Acoustic Survey (MSHAS)

In response to the WKWEST (2015) report a programme of stock identification research was developed (see summary in ICES HAWG, 2021). The programme initially relied on industry and national institute funding (2016-2018) before the European Commission’s Executive Agency for Small and Medium-sized Enterprises (EASME) funded a 36-month project (2018-2020) entitled ‘Herring in Divisions 6.a, 7.b and 7.c: Scientific Assessment of the Identity of the Southern and Northern Stocks through Genetic and Morphometric Analysis’. This project comprised an extensive review of the history of the existing stock delineations, comprehensive sampling for both genetics and morphometrics, genetic marker development, genetic screening of samples, the establishment of a genetic protocol for large scale sample screening, morphometric analyses and comparative analyses of both methods (see Farrell *et al.*, 2021). The results of this project together with the previous industry and institute funded programme component were compiled into a final project report (Farrell *et al.*, 2021), which was reviewed by the Stock Identification Methods Working Group (SIMWG). The SIMWG concluded that ‘*the study should serve as an example of good practice for optimal use of existing resources and result reproducibility*’, ‘*the methodology is rigorous throughout*’ and ‘*there is no doubt in SIMWG that the* (genetic) *approaches presented can be used to*’:

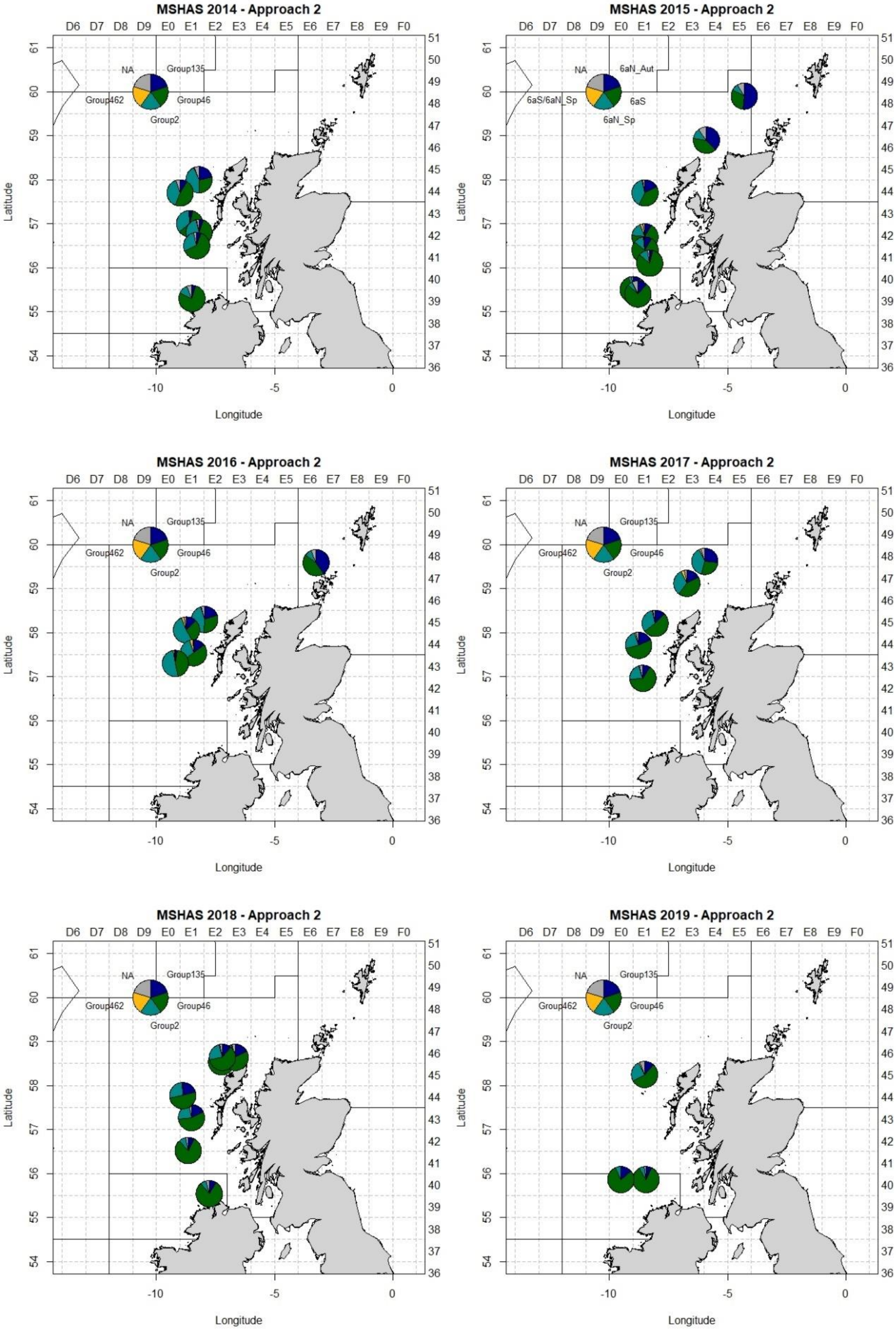
1. *Distinguish the 6aS late winter spawners from the 6aN autumn spawners;*
2. *Distinguish, more subtly, the spring-spawning contingent in 6aN from 6aS (even though the relatedness between these two is high);*
3. *Confirm essentially the ‘North Sea nature’ of the 6aN autumn spawners;*
4. *Assess the mixed MSHAS catches (which appear primarily composed of 6aS fish, with the proportion of autumn-spawning fish increasing as one moves north-east towards Cape Wrath and the Orkneys).*

Subsequent to the completion of the EASME funded component of the 6.a stock identification programme and prior to the WKNSCS benchmark it was possible to undertake additional genetic analyses in order to fill any potential data gaps identified during the EASME project. As detailed in the 2021 HAWG report (ICES, 2021) a short-term project extension was developed with the existing project partners. During this extension additional spawning baseline samples were added to the baselines and using the same approaches as specified in Farrell *et al*. (2021) the 2020 and 2021 MSHAS samples were genetically assigned to their stock of origin. A detailed summary of the genetic approaches underpinning the splitting of the MSHAS data is provided in O'Malley *et al*. (2021), the full stock identification project report in Farrell *et al.* (2021) and a draft manuscript of the genetic baseline based on the updated baseline in Farrell et al. (in preparation), which is on the WKNSCS SharePoint. A brief summary is provided below.

Genetic baseline: Baseline spawning samples (2014-2021; n = 64 samples, 4826 individuals), putatively mixed MSHAS samples (2014-2021; n = 66, 5812 individuals) and non-baseline putatively mixed samples from Divisions 6a,7b-c (n = 28, 1765 individuals) were collected and analysed with a panel of 45 informative genetic markers (SNPs) derived from whole genome sequencing analyses undertaken as part of a Norwegian/Swedish/Danish funded project entitled '*GENetic adaptations underlying population Structure IN herring*' (GENSINC) (Han *et al.*, 2020).

The baseline genetic analyses indicated that herring in ICES Division 6.a comprise at least three distinct populations; 6.a.S herring, 6.a.N autumn spawning herring and 6.a.N spring spawning herring. The 6.a.S herring are primarily a winter spawning population though there is a later spawning component present in the area also. These components are currently inseparable and for the purposes of stock assessment should be combined as 6.a.S herring. No baseline spawning samples could be collected in Divisions 7.b or 7c therefore the relationship between the herring that spawn in this area and those that spawn in 6.a.S is unknown. The 6.a.N spring spawning herring are distinct from the 6.a.N autumn herring and spawn in the Minch in February and March. This population is not currently subject to stock assessment or specific management measures. There is no historical or contemporary evidence to support the differentiation of 6.a.N autumn spawning herring and North Sea autumn spawning herring. The Downs herring were confirmed to be distinct from the North Sea autumn spawning herring though it could not be reliably discriminated from the Celtic Sea and Irish Sea samples with the current panel of markers. The Celtic Sea herring and Irish Sea herring are distinct from each other and from the populations in ICES Divisions 6.a however the current genetic marker panel is not optimised for their inclusion in the baseline assignment dataset. For the purposes of developing an assignment model only the populations confirmed as being present in Division 6.a were included in the baseline assignment dataset; 6.a.S, 6.a.N autumn and 6.a.N spring.

A Support Vector Machine learning (SVM) algorithm was used to develop the classification model (O'Malley Farrell *et al.*, 2021; O'Malley *et al.*, 2021). Two assignment approaches were developed with Approach 1 based on prior knowledge of baseline sample origin and Approach 2 based on genetic clustering of baseline samples (Fig 4.1). Both approaches resulted in self-assignment rates of >90% indicating a high level of assignment accuracy and both were endorsed in an independent review by the ICES Stock Identification Methods Working Group (ICES 2021). Both approaches enabled accurate splitting of the 6.a.N autumn spawning herring from the other populations in Division 6.a. However, Approach 2 provided a more robust separation of the 6.a.S herring from the 6.a.N spring herring and was chosen as the preferred approach from splitting the MSHAS samples (O'Malley *et al.*, 2021).


MSHAS 2014 - Approach 2
MSHAS 2015 - Approach 2
MSHAS 2016 - Approach 2
MSHAS 2017 - Approach 2
MSHAS 2018 - Approach 2
MSHAS 2019 - Approach 2
D6 D7 D8 D9 E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 F0
NA
Group135
Group462
Group46
Group2
6aN_Aut
6aS/6aN_Sp
6aS
6aN_Sp
Latitude
Longitude

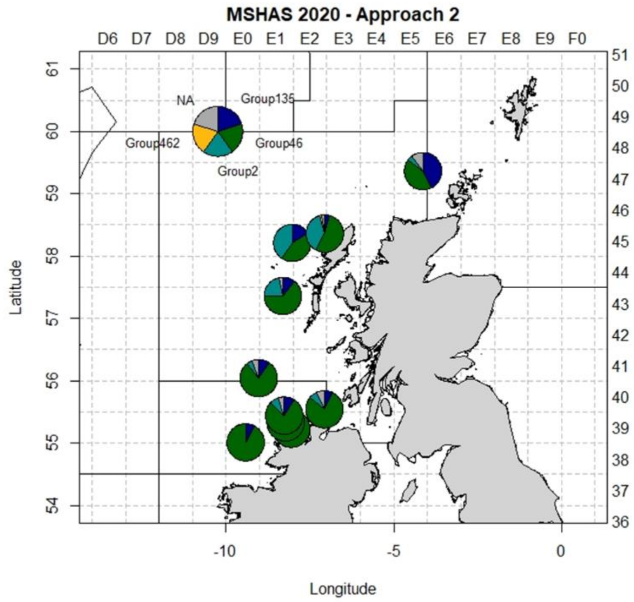


Figure 4.1. MSHAS 2014 – 2020. Hauls split according to the approach 2 (clustered) genetic assignment. Group135 = 6.a.N autumn, Group46 = 6.a.S, Group2 = 6.a.S/6.a.N spring.

Across the eight years of MSHAS samples that were genetically assigned (2014-2021), there was a consistent pattern of a higher proportion of 6.a.S herring in the samples than 6.a.N autumn spawning herring. The 6.a.S assigned fish were distributed across the survey area both south and north of the current stock delineation line of 56°N latitude, confirming that this geographic delineator for the collation of survey data is not appropriate. The highest proportions of 6.a.S fish were observed in the hauls closest to the Irish coast. The highest proportions of 6.a.N autumn spawning fish were observed in the most northerly hauls adjacent to the 4°W stock delineator. Potential 6.a.N spring spawning herring comprised a significant proportion of the MSHAS hauls west of the Hebrides.

The assignment of non-baseline putatively mixed samples from Divisions 6a,7b-c collected outside of the MSHAS period also provided useful information. Analysis of a subset of the hauls on the Q1 2019 Scottish West Coast International Bottom Trawl Survey (SWC-IBTS) indicated a high degree of mixing of the 6.a populations within the hauls. Analysis of Q3 samples from the 6.a.N. industry acoustic survey indicated that juveniles in the northern Minch area most likely belonged to the 6.a.S or 6.a.N spring populations and samples from the Cape Wrath area were composed of a mix of the 6.a populations.

Analysis of the Q4 samples from the 6.a.S monitoring fishery indicated the samples comprised primarily 6.a.S herring. Samples of herring from Lough Foyle were shown to be genetically and biologically 6.a.S herring, though they are currently defined as 6.a.N autumn spawning herring according to the ICES stock delineation. Non-spawning herring caught in Division 7b assigned genetically to the 6.a.S population.

4.1.2 Issue List

The issue list in the table below outlines the issues that are relevant to herring in 6aS, 7b,c.

Issue	Problem/ Aim	Work needed/ possible direction of solution
1. Fisheries data	1.3 6aS Historical data - Review methods for allocation of transboundary catches between 6aS and 6aN.	Revisit and document catch data and WG allocations revised at WKWEST
2. Tuning series	2.1 Surveys contain an unknown mix of stock components.	The 6a summer acoustic survey (HERAS/WESPAS) to be split by component as far back as possible using stock splitting methodologies developed in WESTHER and EASME. Develop methods in the survey estimation software StoX to handle 2 survey inputs and split index outputs
	2.3 IGFS Q4 index	Calculate herring index from the Irish groundfish survey Q4 and investigate its utility as a tuning index
	2.5 6aS industry acoustic survey	Develop index of abundance at age and biomass from industry survey in 6aS (2016-2020) Investigate whether index can be used in assessment
3. Biological parameters	3.1 Maturity-at-ages 2 and 3 is highly variable among years	Examine maturity at age data over time and compare with maturity ogive used in the assessment
	3.2 Review updated M values from WGSAM	Examine new M values provided by WGSAM and compare with previously used values
4. Assessment method	4.1 Investigate assessment methods that are sensitive to issues of stock mixing (6aS, 6aN, autumn spawners and spring spawner + other potential components.) Explore separate assessments for 6aS and 6aN	Consider results from genetic stock structure work (EASME) that will be completed towards the end of 2020. (See 2.1) Consider assessment model types and parameterisations, including SAM, ASAP, SPiCT (building on inter-benchmark work). Explore a range of model settings and different input data combinations
5. Biological Reference Points	5.1 Investigate reference points using EqSIM and other available packages	Revise reference points with updated assessment Examine sensitivity of reference points to potential changes in productivity over time and assumptions due to model configuration.
	5.2 Simulation test the impact of uncertainty in connectivity rates on exploitation potential through the use of an MSE	Examine how uncertainty on historic connectivity rates impact our perception of the stock(s) and simulation test a range of exploitation scenarios to illustrate the impact of uncertainty
6. Environmental data	6.1 Declines of Western herring have occurred in spite of reductions in fishing pressure. The same is true for Celtic Sea herring and other fish stocks on the Western shelf.	Information on changes in the environment should be considered in the assessment. Learn from work in WKIRISH? Review literature. Benchmark guidelines state 'Task 1. Review all available data for use in the assessment with the aim to improve integration of environmental information into the assess-

Issue	Problem/ Aim	Work needed/ possible direction of solution
		ment’

4.1.3 Scorecard on data quality

No major biases are considered to occur in the data for the 6aS, 7b,c herring stock (see text Table below):

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				
Final indicator				
B. LANDINGS WEIGHT				
1. Missing part				
2. Area misreporting				Misreporting suspected with adjacent areas
3. Quantity misreporting				
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				Unknown level of mixing, varies over the historical record
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				

1. Sampling allocation scheme			
2. Raising variable			
3. Size of the catch effect			
4. Damaged fish discarded			
5. Non response rate			
6. Temporal coverage			
7. Spatial coverage			
8. High grading			
9. Slipping behaviour			
10. Management measures leading to discarding behaviour			
11. Working conditions	NA		
12. Species replacement	NA		
Final indicator			
D. EFFORT			
1. Unit definition	NA		
2. Area misreporting	NA		
3. Effort misreporting	NA		
4. Source of information	NA		
Final indicator			
E. LENGTH STRUCTURE			
1. Sampling protocol			
2. Temporal coverage			
3. Spatial coverage			
4. Random sampling of boxes/trips			
5. Availability of all the landings/discards			
6. Non sampled stra-			

ta				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				Last workshop was held in 2005, last exchange 2015
5. International reference set				
6. Species/stock reading easiness				
7. Staff trained for age readings				
8. Age reading method				
9. Statistical processing				
10. Temporal coverage				
11. Spatial coverage				
12. Plus group				
13. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				

5. Calibration equipment		
6. Working conditions		
7. Conversion factor		
Final indicator		
H. SEX RATIO		
1. Sampling protocol		
2. Temporal coverage		
3. Spatial coverage		
4. Staff trained		
5.Size/maturity effect NA		
6. Catchability effect NA		
Final indicator		
I. MATURITY STAGE		
1. Sampling protocol		
2. Appropriate time period all along the year		
3. Spatial coverage		
4. Staff trained		
5. International reference set		
6. Size/maturity		
7. Histological reference		
8. Skipped spawning		
Final indicator		**Green as for assessment of maturity only data collected during appropriate period and using appropriate scale**

4.2 Multispecies and mixed fisheries issues

The targeted fishery for herring in the 6aS, 7b,c, is considered to be clean in terms of by-catch, disturbance of the seabed and discarding (ICES HAWG, 2010). The Irish observer programme which has been in place since 2007 carries out sampler-at-sea trips on this targeted herring fishery. The monitoring TAC, introduced in 2016, has led to a change in the pattern of the fishery. In previous years, larger vessels dominated in the fishery and took their quotas often in one haul, in a somewhat opportunistic basis (ICES, 2015). The monitoring TAC is now allocated to vessels in six different categories from over 24 m down to under 12 m. The fishery in now concentrated in two statistical rectangles close inshore and take place from mid-November to mid-December annually.

4.3 Ecosystem Drivers

The Atlantic herring, *Clupea haregus*, is numerically one of the most important pelagic species in North Atlantic ecosystems. As well as being a commercially important species, herring represent an important prey species in the ecosystem west of the British Isles (ICES, 2021). Herring link zooplankton production with higher trophic levels (fish, sea mammals and birds) but also can act as predators on other fish species by their predation on fish eggs (ICES, 2015).

In this area the main oceanographic features are the Islay and Irish Shelf fronts. The waters to the west of Ireland are separated by the Irish shelf front. These fronts create turbulence and this may bring nutrients from deep waters to the surface, promoting the growth of phytoplankton and dinoflagellates in areas of increased stratification. Aggregations of fish are associated with these areas of increased productivity. The Islay front persists throughout the winter due to the stratification of water masses at different salinities (ICES, 2006). The ability to quantify any variability in frontal location and strength is an important element in understanding fisheries recruitment (Nolan and Lyons, 2006). These fronts play an important role in the transport of larvae and juveniles.

Grainger (1978, 1980) found significant negative correlations between sea surface temperature and catches from the west of Ireland component of this stock at a time-lag of 3–4 years later. This indicates that recruitment responds favourably to cooler temperatures. The influence of the environment on herring productivity means that the biomass will always fluctuate (Dickey-Collas *et al.*, 2010).

Changes in environmental conditions can have significant impacts for a variety of marine fish species. Oceanographic variation associated with temperature and salinity fluctuations appears to impact herring in the first year of life, possibly during the winter larval drift (Grainger, 1980). In addition, temperature increases and a positive AMO (Atlantic multi-decadal oscillation) index are thought to be related to drops in weight-at-age in Celtic Sea herring (Lyashevska, 2020). This study by Lyashevska, 2020 also found more stable size at age for herring in 6aS, 7b,c and this may reflect the stocks more northerly distribution, where there is less exposure to sub optimal temperatures. Reductions in size of after 1990 are noted which indicates a vulnerability to future temperature rises.

4.4 Stock Assessment

4.4.1 Catch – quality, misreporting, discards

In the 1960s and 1970s the main fisheries took place around Donegal Bay and Galway Bay and consisted mainly of spent herring caught during Autumn and early winter. In the 1980s the location and timing of the fisheries gradually changed. The most important fisheries were off the North and West coast of Donegal from December to February with winter and spring spawners dominating (Molloy, 2016). At this time there was a market for roe and many catches were slipped if they did not contain the appropriate maturity stage. This slippage is not reflected in the historic catch data. Discarding is known to take place on the part of freezer trawlers targeting other species in this area (ICES, 2012). Overall discarding is considered to be negligible (ICES, 2015).

There is some uncertainty about the catch data which covers the period when the fishery in 6a was closed. Fishing continued with large catches reported from 7b. During the period when the fishery in 6a was closed many fleets diverted their fishing effort to the west coast of Ireland. Also during the late 70s Eastern European fleets operated to the west of Ireland and it was difficult to obtain information about their catches (Molloy, 2006). The quality of the catch data has improved markedly, owing to improvements in control and enforcement, especially since 2004. In recent years the landings have all been taken by Ireland. Ireland has 91% of the quota in 6aS with the remaining 9% for the Netherlands. The Dutch proportion is often swopped with Ireland.

The northern boundary of the management area (56°N) is not considered meaningful in a biological context. Research has shown that fish cross the boundary in the feeding season and one of the spawning grounds straddles it. Irish catches that are reported north of the boundary but are associated with the 6aS, 7b,c stock are reallocated from 6aN to 6aS, 7b,c each year (ICES, 2015). Since 2011, VMS data is used to inform the reallocation of catch data. In the 1980s significant proportions of the catch were classified as unallocated. Unallocated catch refers to catch that was taken when quotas had been exhausted and cannot be attributed to a particular nation (Molloy, 2006).

A revision to the total catch used in the assessment was made for 2001 and 2004 where data from 7b,c were not included in the total figure. The catch from 7b,c in 2001 was 1,542 t and in 2004 was 1,340 t. This was added to the total catch and the catch numbers at aged raised accordingly.

4.4.2 Surveys

Since the last benchmark two new survey indices have been developed and the MSHAS has been genetically split. Detailed methodology for each of these new indices is reported in separate working documents for WKCSNS 2022. Brief overviews are included below.

Genetic Split of Malin shelf Herring Acoustic Survey (MSHAS)

The genetic assignments described above were used to derive separate indices for the herring stocks surveyed on the MSHAS i.e. genetically split the abundance and SSB. A detailed working document outlining the splitting procedure was presented to the WKCSNS benchmark data meeting (O'Malley *et al.* 2021, WD to WKCSNS). A brief outline is presented here.

The whole MSHAS index includes all herring in the stock complex located in ICES areas 6a and 7bc. The survey area is bounded in the west and north by the 200m depth contour, in the south by the 53.5°N latitude, and in the east by the 4°W longitude (Figure 4.2). The survey targets herring of 6.a.N and 6.a.S spawning origin in mixed feeding aggregations on the Malin Shelf in the summer. Until recently the differentiation between 6aS7bc and 6aN was purely geographical. Genetic sampling began in 2014.

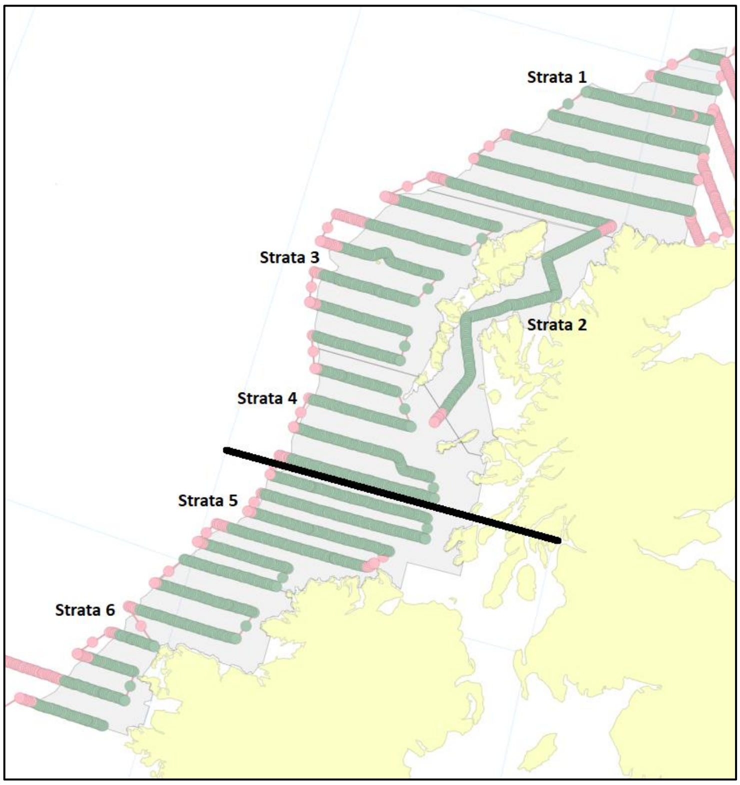


Figure 4.2. Typical design for the Malin Shelf Herring Acoustic Survey. Transect lines are shown in green.

Genetic sampling on MSHAS (2014–2020)

The number of genetic samples obtained in the years 2014–2020 averaged about 6 samples per year, but varied between 3 samples in 2019 and 10 samples in 2020. The target for an individual sample was 120 fish per haul, with most sampling events reaching that target. In the early years of the project, sampling effort was targeted only at fish >23 cm, this was to align with a corresponding effort that was underway looking into stock splitting using morphometric methods; a continuation of the SGHERWAY project methods (ICES SGHERWAY, 2010). Prior to 2018, hauls comprising mostly <23 cm fish were not sampled. The stock had also been at a low level during these years, some of the lowest in the time-series, meaning that obtaining samples on the MSHAS survey was generally very difficult during this time.

Application of the Genetic Assignments

Genetic Analyses: Baseline spawning samples and putatively mixed MSHAS samples were analysed with a panel of 45 informative genetic markers (45 SNPs) derived from whole genome sequencing analyses undertaken as part of a Norwegian/Swedish/Danish funded project entitled '*GENetic adaptations underlying population Structure IN herring*' (GENSINC) (Han *et al.*, 2020). The baseline genetic analyses indicated that herring in ICES Division 6.a comprise at least three distinct populations; 6.a.S herring, 6.a.N autumn spawning herring and 6.a.N spring spawning herring. The 6.a.S herring are a primarily a winter spawning population though there is a later spawning component present in the area also. These components are currently inseparable and for the purposes of stock assessment should be combined as 6.a.S herring. The Celtic Sea herring and Irish Sea herring are distinct from each other and from the populations in ICES Divisions 6.a however the current genetic marker panel is not optimised for their inclusion in the baseline assignment dataset. This is not considered to be a significant issue as there is no robust evidence that Irish Sea herring are found in large abundance west of the Hebrides during summer. Subsequent to the completion of the EASME project further analyses were undertaken and additional baseline samples added to the 6.a.S herring and 6.a.N autumn spawning herring baselines. The revised baseline was used for the final assignment of the MSHAS 2014-2020 samples.

Genetic Assignment method: A Support Vector Machine learning (SVM) algorithm was used for classification of fish from mixed MSHAS samples to baselines, based on (Approach 1) prior knowledge of baseline sample origin and (Approach 2) genetic clustering of baseline samples. Approach 2 is more precautionary but neither approach would artificially inflate either stock in the resulting split as each approach allows for 'mixed' and 'unknown' categories that would not be included in either 6aN or 6aS indices. Both approaches resulted in self-assignment rates of >90% indicating a high level of assignment accuracy and both were endorsed in an independent review by the ICES Stock Identification Methods Working Group (ICES SIMWG 2021). The more objective classification method of approach 2, genetic clustering, was therefore chosen by the sub-group. All further reference to genetic assignment refers to approach 2.

Successful Assignment Threshold (0.67): A probability of classification of 0.67 was used as the threshold for successful stock assignment of an individual herring. This threshold indicated that an individual was twice as likely to be from one baseline group than the alternate group. The effects of different assignment thresholds were investigated by the sub-group. The results of this work are presented in the working document. Most resulting probabilities for approach 2 were in the region of 0.95 and the sub-group decided that a threshold probability of 0.67 struck an appropriate balance between certainty of stock assignment and retaining as many fish as possible in the analysis.

Genotyping fails vs. threshold fails: It was decided by the sub-group that genotyping fails were to be disregarded from the analysis (e.g. samples that could not be genetically analysed due to DNA degradation or did not pass genotyping quality control etc. See section 4.8 page 81 of the EASME report for details). Such samples were NOT included as 'unknown' her-27.6a7bc when proportioning biomass. Threshold failures however WERE included in the analysis and were therefore counted towards 'unknown' her-27.6a7bc.

StoX survey analysis software: The group decided that using StoX (Johnsen *et al.* 2019) would be the preferred method to split the MSHAS index. StoX is the accepted survey analysis software tool used by MSHAS and the wider WGIPS group dealing with acoustic surveys for herring in the Northeast Atlantic. StoX programmers (IMR, Norway) designed the StoX project and functions to suit the MSHAS split work. This helps ensure that the project is easily implemented in the Transparent Assessment Framework (ICES TAF) and that the survey projects can be re-run by any StoX user by downloading files from the ICES DB. The StoX project is designed to include bootstrapping of results to generate associated CVs.

MSHAS Splitting Results

Overall the sum of the combined split SSB are very close to the original SSB for the Malin Shelf area for the years 2014-2020 considered here (Figure 4.3). The slight differences are due to the change in length frequencies applied to transects according to the differences in the length frequencies of the stocks as the split is applied.

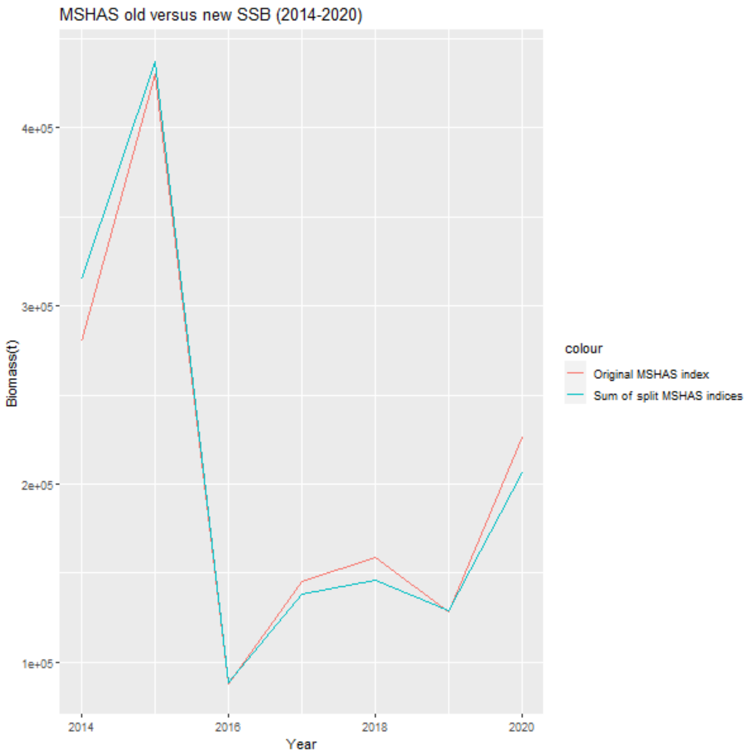


Figure 4.3. SSB (t) comparison between the original MSHAS index and the sum of the combined split indices.

In all years apart from 2014, the difference between the original MSHAS index SSB and the sum of the combined split SSB is <10% (see WD for further details).

The TSN numbers in the new combined split projects match well with the originals also similar trends in numbers persist in all years. There are two years where there appears to be a slight discrepancy in the 1-wr fish. This happened in years when the <23 cm fish were not targeted for sampling.

CVs on the split survey estimates are within expected values for acoustic surveys for herring in this area.

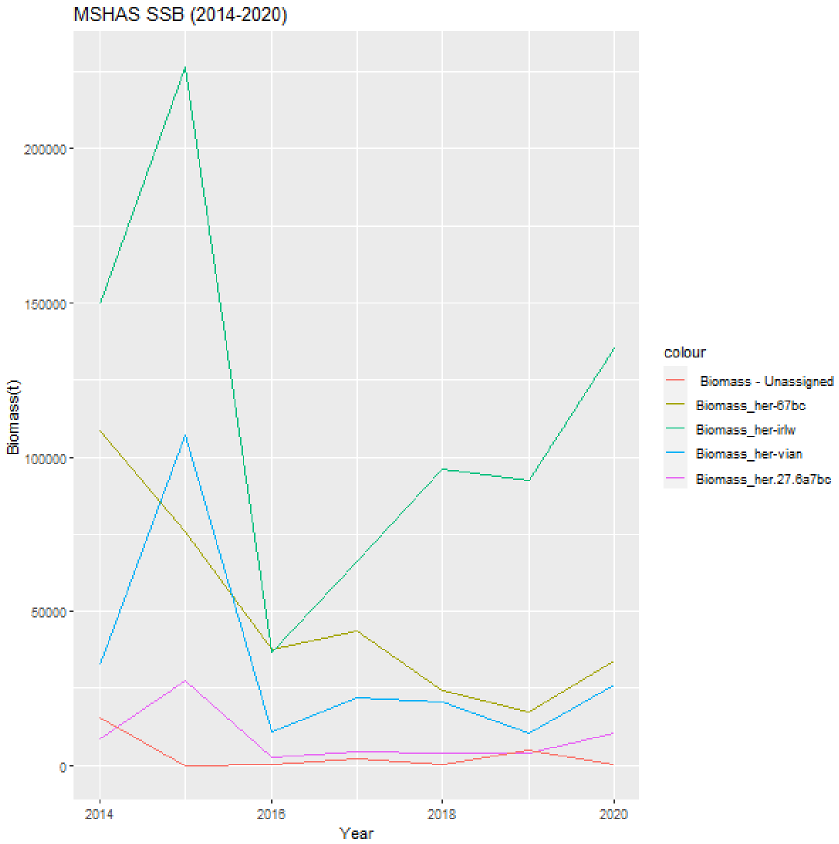


Figure 4.4. SSB (t) time-series for the individual MSHAS split indices (2014 – 2020). her-irlw refers to her.27.6aS,7bc

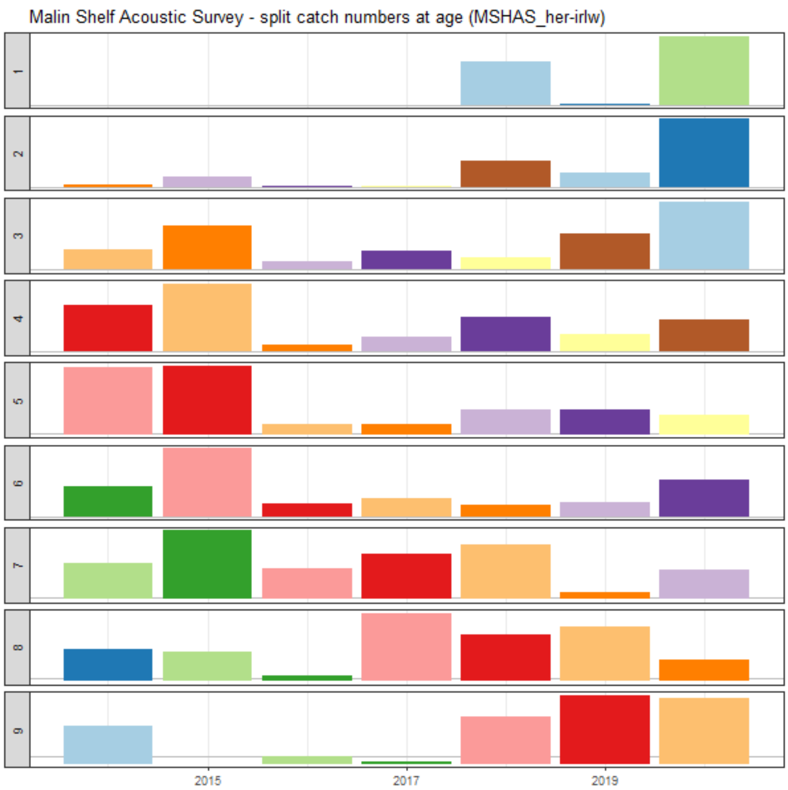


Figure 4.5. Malin Shelf Acoustic Survey - split catch numbers-at-age her.27.6aS7bc.

A comparison of the proportions at age in the catch versus the split MSHAS 6aS7bc index is shown in Figure 4.4. Smaller and younger fish, particularly 1-wr fish are caught sporadically on this survey, and in some years don't appear in the samples on the survey. Younger immature fish may be outside of the survey area during the survey, and can be difficult to sample in some years. Cohort tracking of the catch numbers at age of the split MSHAS for 6aS7bc is shown in Figure 4.5. Propotion at age from the catch and acoustic index since 2014 are shown in Figure 4.6.

Table 4.1. Time-series of TSN, SSB and survey CV for MSHAS 6aS7bc split, 2014 – 2020.

	Abundance at age (TSN x 10^6)												
Year	**Age(-wr)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9+**		**CV**	**SSB (t)**
2014	**her-irlw**	0.0000	30.0215	118.6330	271.0141	252.2080	99.3417	31.3819	10.3914	4.8973		0.263919	**149270**
2015	**her-irlw**	0.0000	122.5152	255.6748	395.2611	254.8183	225.2797	58.9608	9.3817	0.0000		0.237824	**226293**
2016	**her-irlw**	0.0000	8.0892	45.2178	42.1824	38.0626	42.3432	26.0502	1.7079	0.9087		0.225782	**36707**
2017	**her-irlw**	0.0000	6.5547	112.5661	87.6862	39.2217	58.6593	39.2075	21.6470	0.3307		0.328388	**66342**
2018	**her-irlw**	572.9450	303.5882	68.3010	199.1444	92.3418	36.8026	47.0780	14.6288	6.1442		0.573993	**96138**
2019	**her-irlw**	3.8002	170.6983	213.9642	103.4593	91.9746	47.1626	5.9276	17.2714	8.9242		0.264386	**92364**
2020	**her-irlw**	895.1145	776.2013	401.7521	188.2019	71.4467	120.2135	24.7746	6.6401	8.5084		0.242645	**135335**

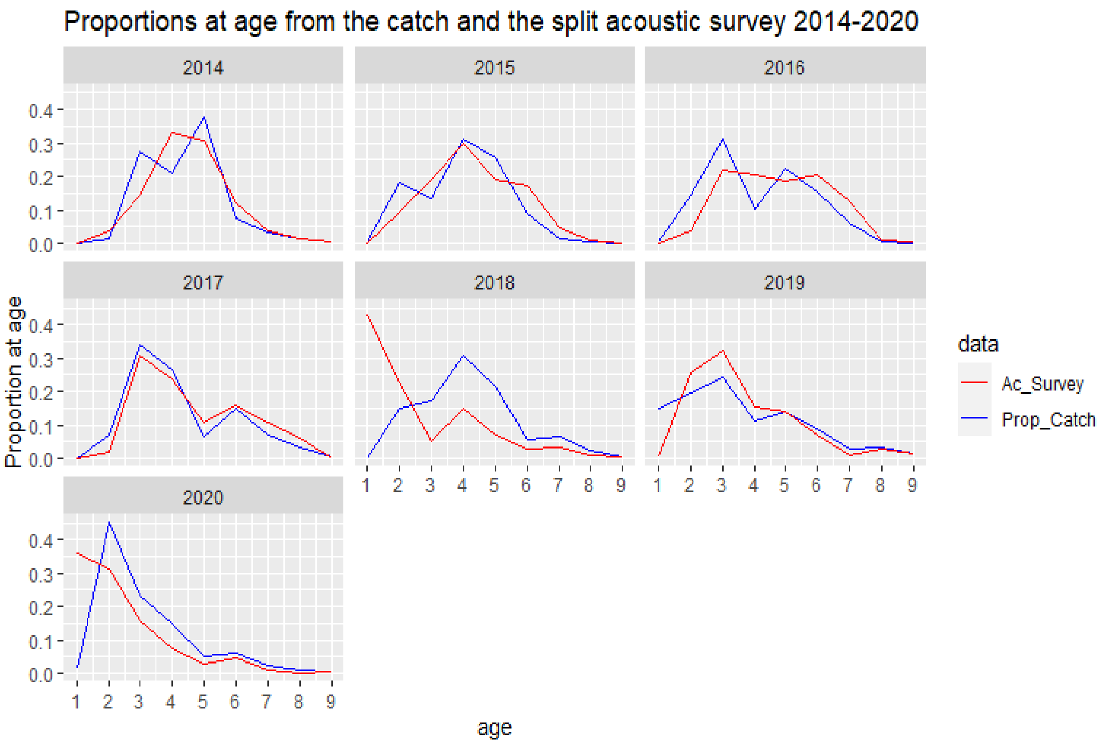


Figure 4.6. Proportions at age in the catch and split 6aS7bc MSHAS 2014 – 2020

MSHAS 6aS7bc 2008-2013 Estimation

The MSHAS began in 2008 and genetic sampling to differentiate the populations began in 2014. The proportion of herring genetically assigned to each population in the survey is relatively stable over the time-series (Figure 4.7) so, in order to maximise the available data and provide the best opportunity for a stock assessment model to converge, the split 6aS7bc abundance by age and SSB from 2008 to 2020 were estimated by applying the average proportion of the genetic split (by age and strata). (Morphometric methods were also investigated but the resulting split proved too variable over time.)

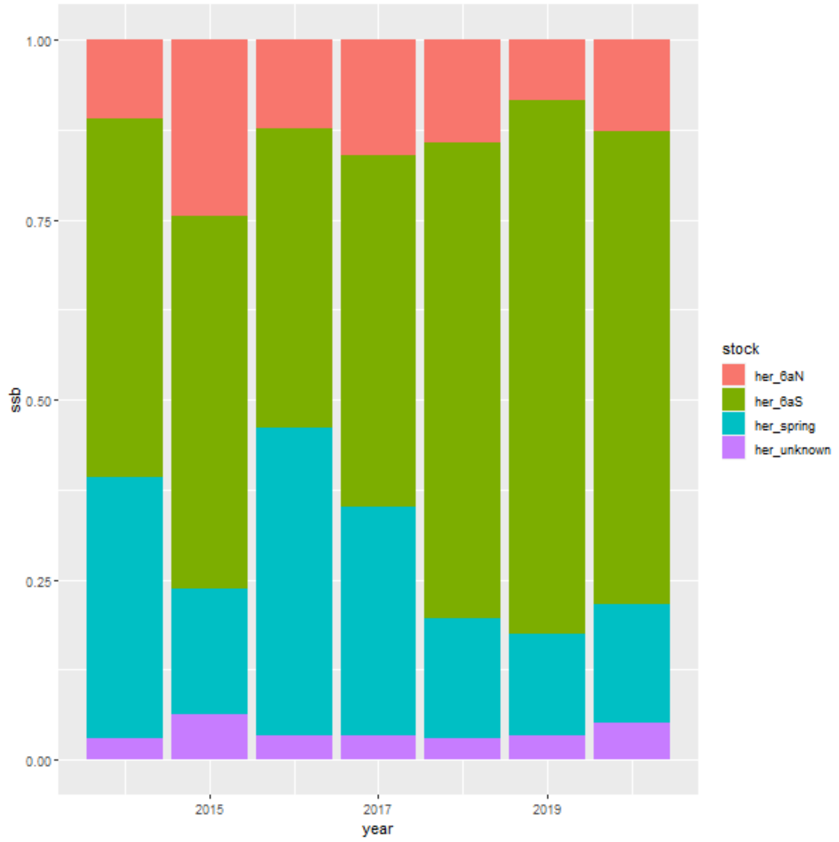


Figure 4.7. Stacked bar chart showing the proportion of the total MSHAS SSB genetically assigned to each split stock for the years 2014–2020.

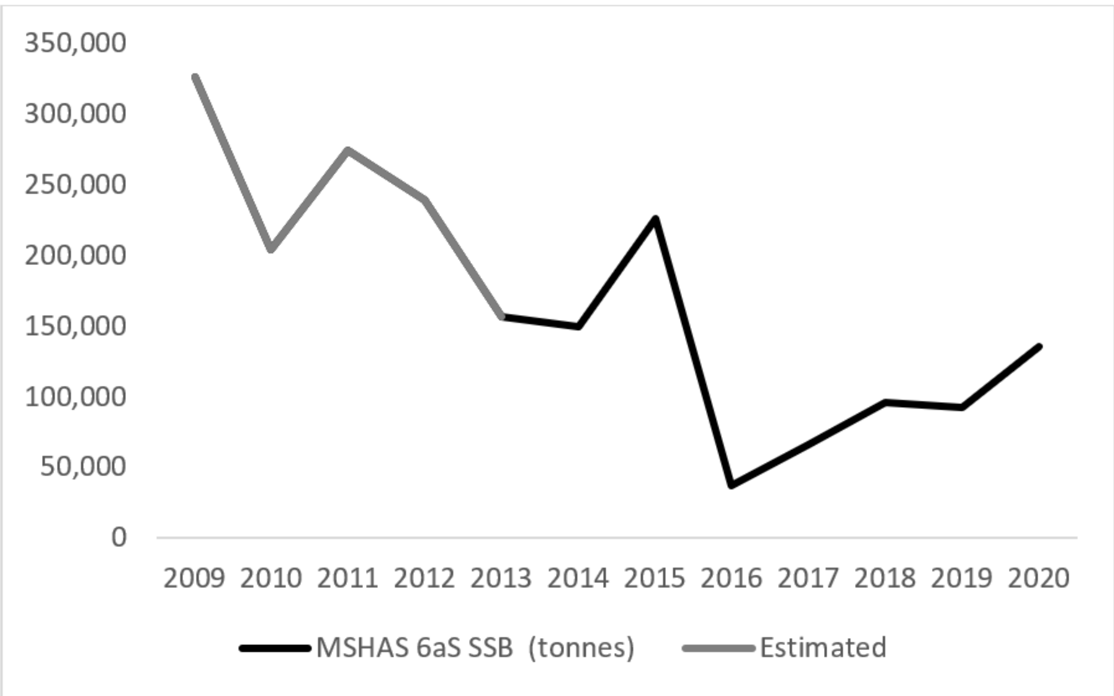


Figure 4.8. MSHAS 6aS Split Spawning Stock Biomass (tonnes) by year. Back estimated values 2008-2013 in grey.

MSHAS 6aS7c Split Index: Conclusions

The genetically split MSHAS 6aS7bc abundance and biomass estimates for 2014-2020 (incl.) are robustly calculated and provide the most reliable index for this stock. The stock ID methods have been independently review by ICES Stock Identification Methods Working Group (ICES SIMWG 2021). SIMWG stated that '*the methodology is rigorous throughout*' and that '*There is no doubt in SIMWG that the approaches presented can be used to distinguish the 6aS late winter spawners from the 6aN autumn spawners….*'.

Back-estimates from 2008-2013 were required for some exploratory assessment runs to converge but ultimately were not included in any further explorations or the category 3 calculations described below.

The split MSHAS 1-wr herring estimates are unreliable in some years due to under sampling. This happened particularly before 2018 when <23 cm fish were not targeted for sampling. However, estimation of 1-wr herring is also poor for the unsplit MSHAS so 1-wr fish were therefore removed from further exploratory assessments.

Groundfish Survey Index 6aS7bc

Using the same methodology as that used for the index developed for the combined 6a, 7bc herring stock, a groundfish survey index for 6aS, 7bc from 2003-2020 for ages 2-7 winter ring was developed using three trawl surveys: IE-IGFS, SWC-IBTS, and SCOWCGFS (see WKCSNS WD Campbell). The model combines GAMs and continuation ratio logits (CRL) to model the probability of age given fish length and location. A geographic split was used, i.e. hauls were only included in the index calculation if they occurred within ICES divisions 6aS or 7bc (Figure 4.9). The age range to include is based on the internal consistency of the index which is poor outside of the range 2-7. The youngest ages are only sporadically caught in the survey. The 6aS, 7bc groundfish index was used in the exploratory assessment runs described below.

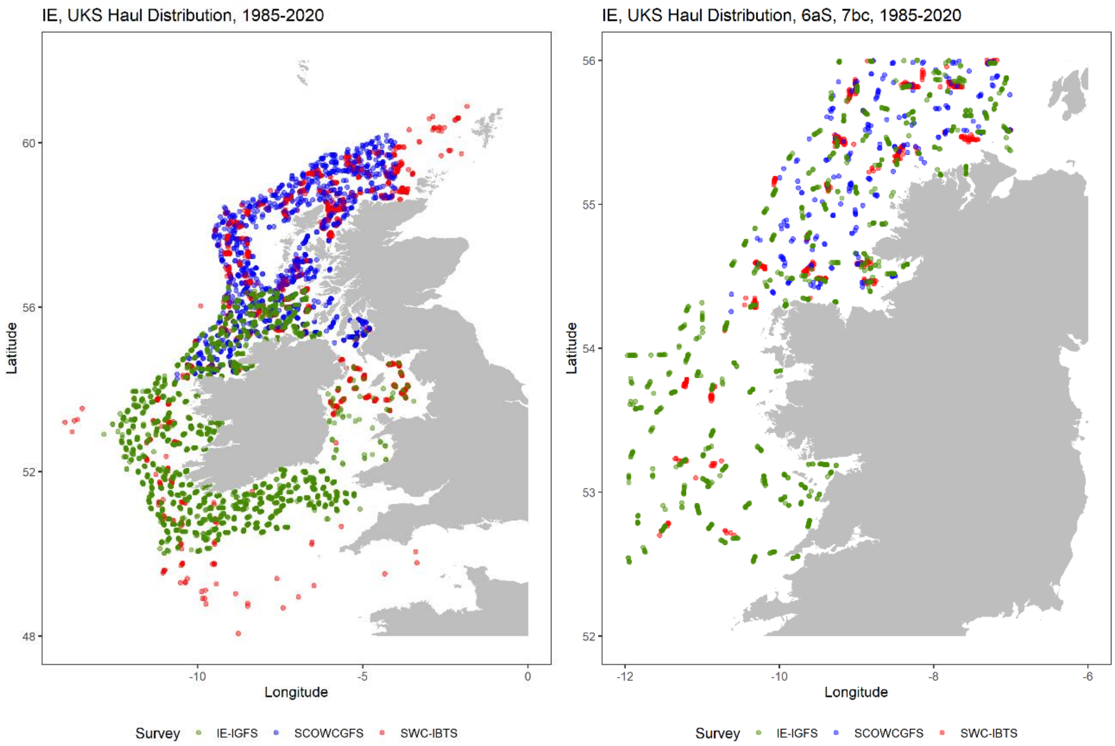


Figure 4.9. IBTS hauls positions from IE-IGFS (green), SWC-IBTS (red) and SCOWCGFS (blue) surveys, left – all hauls, right hauls in div 6a, south of 56˚N and divisions 7b and 7c.

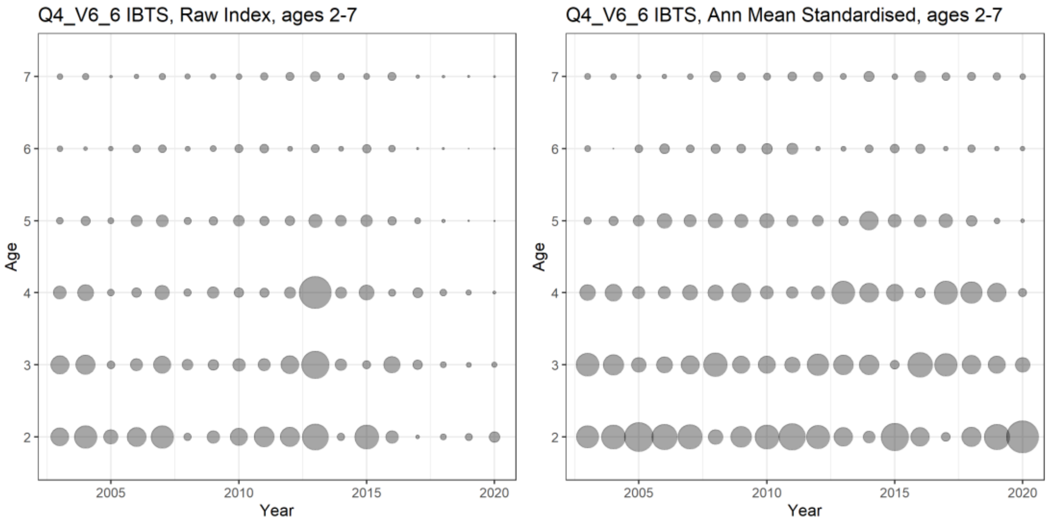


Figure 4.10. Results of GAM-based delta-lognormal model for Groundfish survey index 6aS7bx. Abundance at age, raw (left) and standardised by the yearly mean (right), ages 2-7.

Industry Acoustic Survey (Q1 and Q4)

A winter acoustic survey of pre-spawning herring in 6aS7bc has been conducted since 2016. The survey design and coverage have been evolving year-on-year based on experience gained and latest ICES recommendations (Figure 4.11). The current design uses small chartered fishing vessels to survey known spawning areas multiple times over the spawning season. One area, Lough Swilly, has a consistent, unbroken time-series since 2016 and is a possible index for inclusion in a separate 6aS7bc stock assessment (Table 4.2, Figure 4.11 and Figure 4.12).

The Industry Acoustic Survey (Q1 and Q4) index was used in some exploratory assessment runs but ultimately was not included in the assessment.

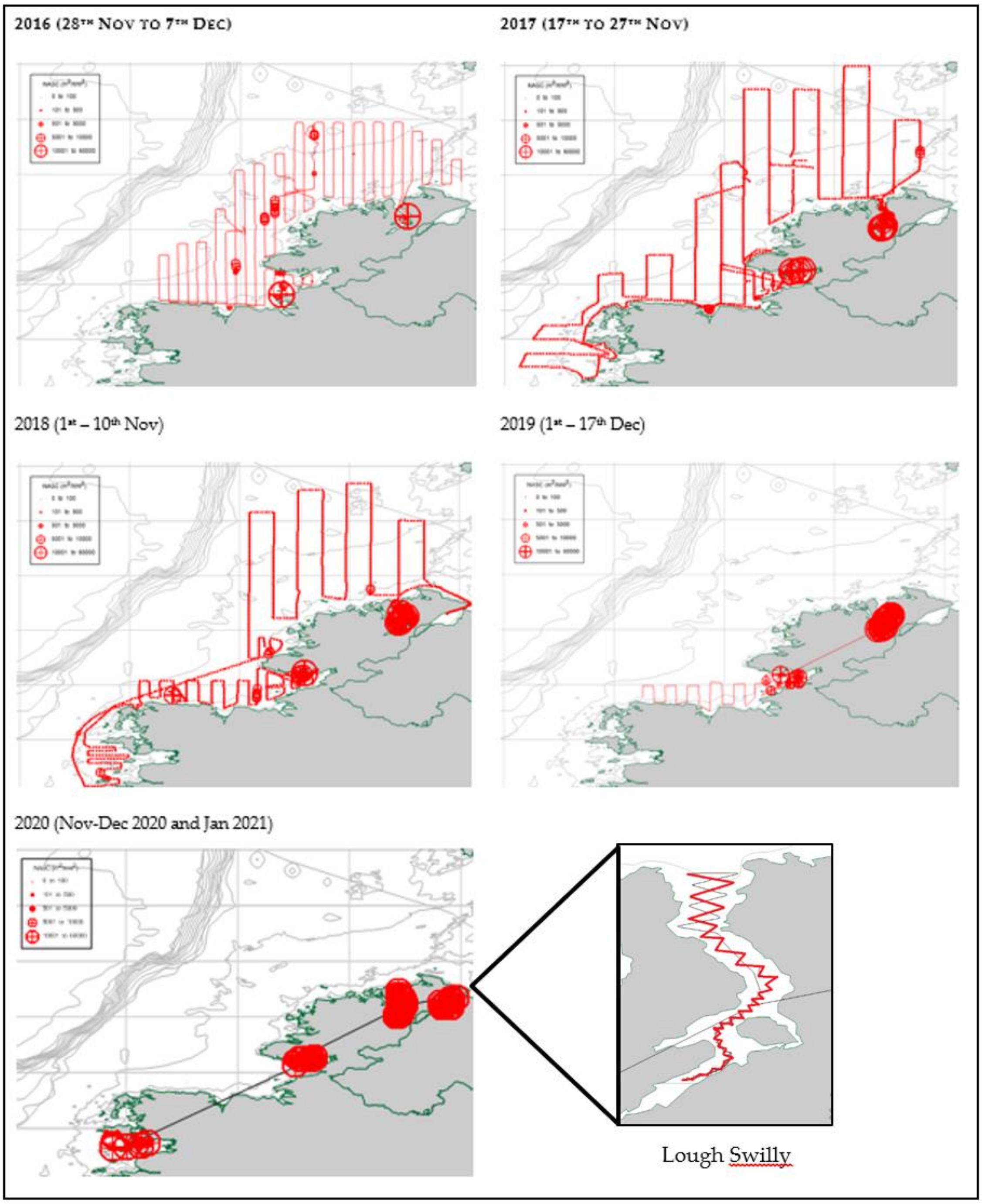


Figure 4.11. 6aS7bc industry acoustic survey: NASC distribution in the surveys 2016-2020. The survey design has been evolving since its inception in 2016. In 2019 and 2020, the area covered was much reduced compared to previous years, instead focus on core bays. Inset shows typical Lough Swilly survey track.

Table 4.2. 6aS/7bc industry herring acoustic survey: Lough Swilly strata area index - age-disaggregated (-wr) TSN ('000) and SSB ('000) of herring from the industry acoustic survey 2016 – 2020.

Year	1	2	3	4	5	6	7	8	9	10	SSB	CV
2016		11418	15075	6463	16060	6134	2742	621			9411	0.79
2017	278	12032	28758	19786	6136	11888	6990	2092	307		11948	0.55
2018	426	38287	41122	63660	44581	14532	15290	2758	825	581	31972	0.71
2019	43826	41660	16468	15770	21419	11797	9630	1902	2792	347	17626	0.15
2020		23902	29624	21461	16546	24768	12661	1702	1700		18068	0.29

Figure 4.12. 6aS/7bc industry acoustic survey: cohort tracking of Lough Swilly strata only herring ages (-wr) in surveys from 2016 to 2020.

4.4.3 Weights, Maturities, Growth and Natural Mortality

Mean Weights in the Catch

Catch weights are calculated from Irish sampling data from all quarters of the fishery (Figure 4.13). Mean weights were stable from the late 1980s up to the late 2000s. There were increases across most ages up to 2012. Declines can be seen since then with the 2020 estimates the lowest in the time-series. Declines in mean weight can also be seen for other herring stocks around Ireland such as Celtic Sea and Irish Sea herring.

A study by Lyashevska *et al*. 2020, analysed data up to 2012 and found that the declines in size at age seen in Celtic Sea herring since the 1980s are most strongly associated with increasing sea temperature as with a positive AMO index. In the Northwest of Ireland stock (6aS, 7b,c) the more stable size at age trend may reflect the stock's more northerly distribution and lower exposure to metabolically sub-optimal temperatures. The northwest population also displays temperature related declines in size that indicate a vulnerability to future temperature rises. Temperatures have increased in this area in the last decade.

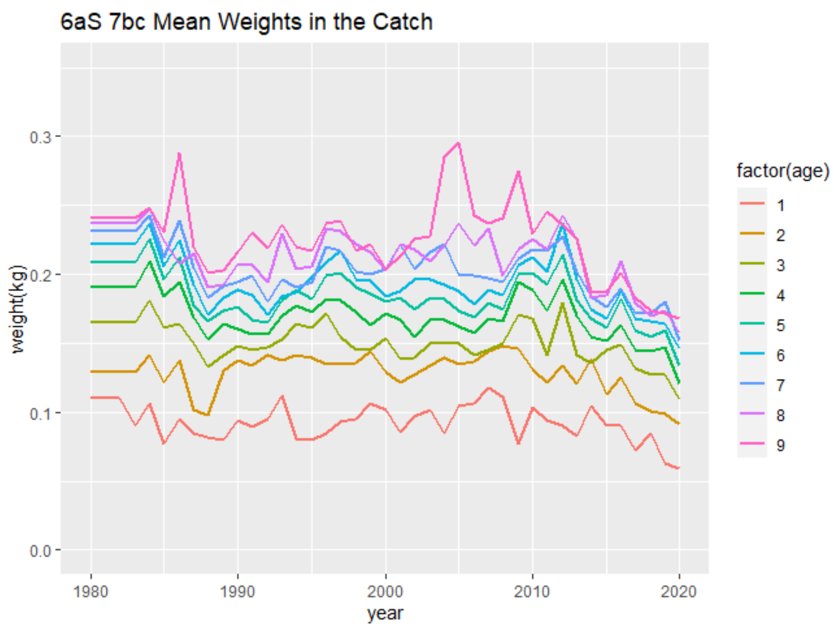


Figure 4.13. Herring in 6aS, 7b,c Mean weights in the catch

Mean Weights in the stock

The mean weights in the stock are shown in Figure 4.14. Variable mean weights are available from 1985. In the previous separate assessment, the stock weights were calculated from Irish samples collected during the main spawning period that extends from October to February. These weights are used from 1985-2007. Mean weights from the Malin shelf acoustic survey are used from 2008-2013 and from the split acoustic survey from 2014. There is a downward trend in the stock weights over time but it is not as pronounced as for the catch weights. Greater variability is seen at the older ages. In some years there were no 1 wr fish found on the survey. In these years a three-year running average is used.

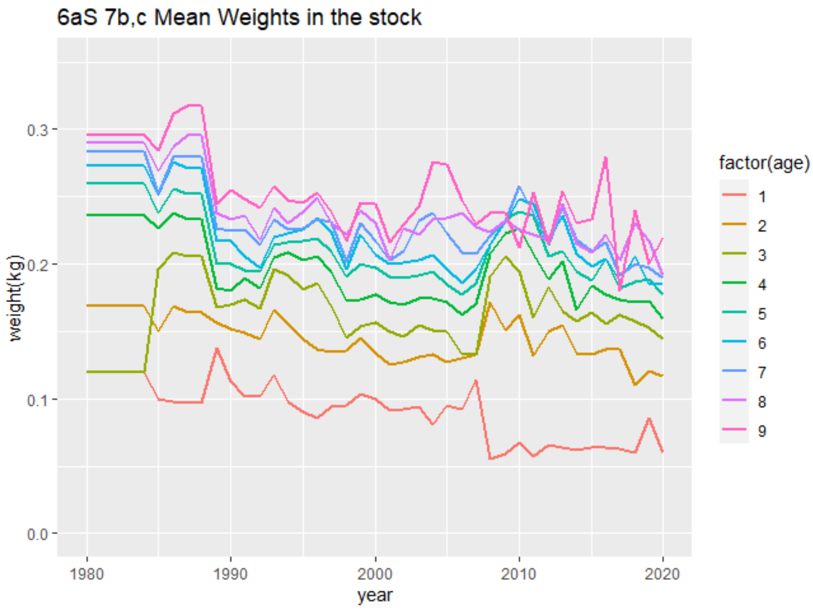


Figure 4.14. Herring in 6aS, 7b,c Mean weights in the stock

Maturity-at-age

The proportions at age of herring in 6aS, 7b,c that are considered mature are presented in Figure 4.15. A constant maturity ogive is used from 1957–2007 which assumes 0%, 57% and 96% maturity at 1, 2 and 3 wr respectively and from 2008 to the present the ogive is derived from the summer acoustic survey in quarter 3. The full survey is used from 2008-2013 and the split survey used from 2014–2020. The majority of herring in this area are mature at 4 wr with the greatest annual variability can be seen for 2 and 3 wr herring. The proportion mature at 2 wr is highly variable without any apparent trend and varies between 25% and 100%. For 3 wr herring the proportion mature varies between 64% and 100%. A high proportion of immature fish were encountered in the 2020 survey. Overall, it is not clear what drives this annual variability and it is also seen for other herring stocks such as North Sea and Irish Sea herring. It is likely a combination of limited sampling of that age group, varying proportions of herring from each population within the survey area and natural variability (ICES, 2015).

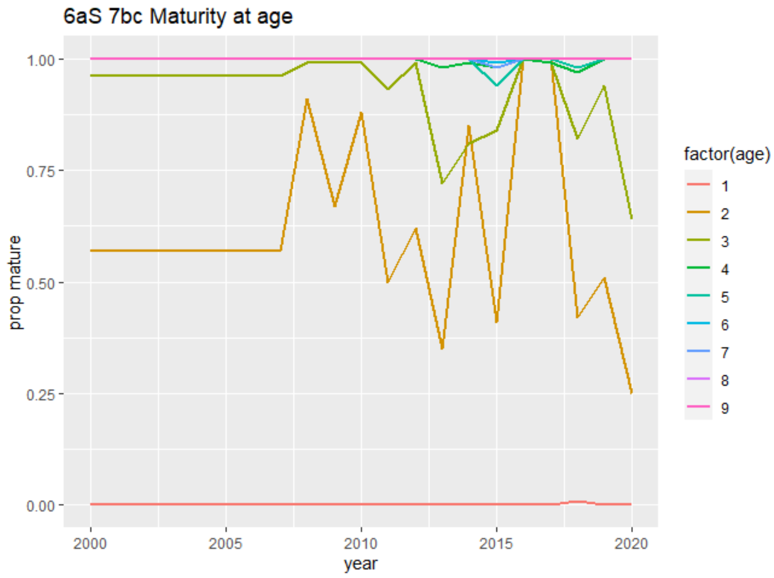


Figure 4.15. Herring in 6aS, 7b,c Maturity-at-age.

Growth

See Category 3 methods

Natural Mortality

Natural mortality of herring in this area was examined in detail by WKWEST (ICES, 2015). When the two stocks were assessed separately prior to 2015, natural mortality was fixed in time but varied by age. The highest M was found for 1-ringers (1.0), this decreased to 0.3 for 2-ringers, 0.2 for 3-ringers and 0.1 from 4-ringers up. At WKWEST it was decided to change the natural mortality values used in the assessment based on updated information from the North Sea.

The natural mortality values used in the current combined assessment are derived from the North Sea multispecies SMS key run. The average M at age values over the time-series 1974-2013 were used. This time-series reflected the most recent period of stability for M from the NS-SMS (excludes the gadoid outburst of the 1960s). This natural mortality time-series varies with age but is time invariant (ICES, 2015).

Since the benchmark in 2015 there have been a number of updates to the SMS key run in the North Sea by the working group on multispecies assessment methods (WGSAM). Natural mortality predictions from SMS are dependent upon several things:

- (i) changes in the relative abundance of predators in the model
- (ii) changes in the diets and consumption rates of predators
- (iii) changes in the species that are included in the model that predate on herring
- (iv) changes to non-predation mortality (Mackinson and Hintzen, 2018)

In the SMS key runs predation mortality of herring follows the same trend in the 2017 and 2020 key runs but there are changes between the runs. The biggest difference is a lower M2 in the most recent years for age 2+ which is mainly due to a lower stock of the predators, cod and saithe estimated in the 2020 run (ICES, 2021b). M1 is the residual mortality and is assumed to be 0.1 for herring. M2 is the predation mortality and is estimated by the model (M=M1+M2).

Following the procedure agreed at WKWEST 2015 and applied to other herring stock around Ireland, the natural mortality values for the assessment were updated. The average M at age over the time-series 1974-2019 from the 2020 SMS key run was calculated and is presented in

Figure 4.16 with the previous values used in the combined assessment for comparison. The updated values show a lower natural mortality across all ages.

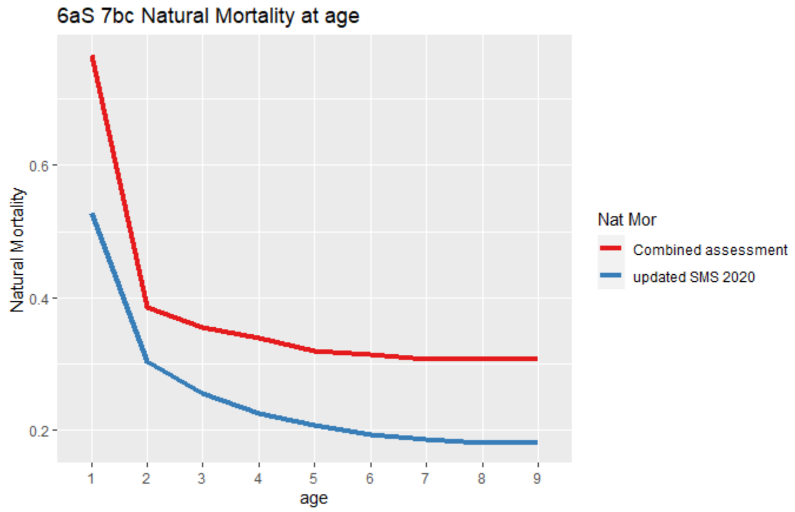


Figure 4.16. Herring in 6aS, 7b,c Plot of the updated natural mortality values and the values used in the combined assessment.

There is empirical evidence that M is closely related to body size in pelagic fish populations (Petersen and Wroblewski, 1984; Lorenzen, 2000; Powers, 2014). At WKWEST, M values were derived from relationships described by Peterson and Wroblewski (1984), Lorenzen (1996), and McCoy and Gillooly (2008) using *west* and *weca* data from 2013. This was updated using data from 2020 and compared with the M values used in the 6aS,7b,c assessments. The values of M-at-age for the various functions used are shown in Figure 4.17. All M values are highest at 1-winter ring followed by a fairly rapid decrease to a stable low rate from 3-wr onwards. The lowest M values are from the previous assessment prior to 2015 followed by the updated average M values based on the SMS key run 2020.

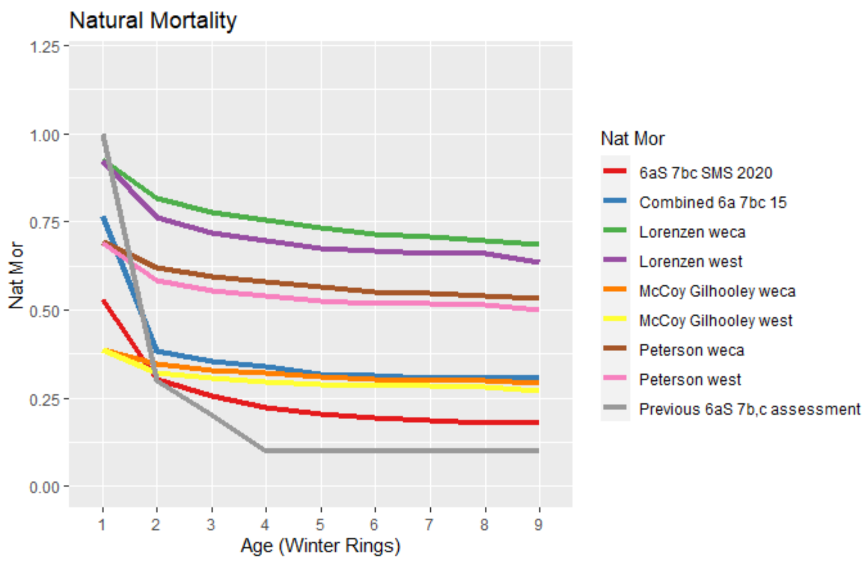


Figure 4.17. Herring in 6aS, 7b,c Natural mortality (M) estimates versus age (winter rings) for various functions using 2020 data.

4.4.4 Assessment Models

SAM Assessment Explorations

A number of exploratory SAM assessments were configured and run from www.stockassessment.org (run prefix Her_6aS7bc_WKNSCS22). An initial run (Her_6aS7bc_WKNSCS22_Init), with the default SAM settings was configured with the following input data:

- Catch data from 1980-2020 with plus group of 9+. The early part of the available catch data (1957-1979) was disregarded for the initial assessment run as it is considered to be the most uncertain. Investigations with shorter catch data series (*i.e.* start dates of 1990 and later) did not yield an assessment that converged and were not considered further.
- Acoustic survey (MALIN_08_20) from 2008-2020 for ages 2-7 winter ring. Estimates for the 6aS7bc stock for survey years 2014-2020 are derived from genetic analyses of the survey haul samples (see WD of O'Malley *et al.*). For the earlier period (2008-2013), the estimated split between 6aN and 6aS7bc is derived using the average strata-level proportions from 2014-2020. Data for ages 1, 8 and 9 were disregarded due to a large number of missing or very low values.
- Groundfish survey index (IBTSQ4_03_20) from 2003-2020 for ages 2-7 winter ring (see WD Campbell). The age range to include is based on the internal consistency of the index which is poor outside of the range 2-7. The youngest ages are only sporadically caught in the survey.

Weights, maturities and natural mortality inputs for the assessment are as described in Section 6.3. of this report chapter.

The SAM parameter settings for run Her_6aS7bc_WKNSCS22_Init are given in Table 4.3.

Table 4.3. SAM parameter settings for exploratory assessment Her_6aS7bc_WKNSCS22_Init.

Param	Setting								
$minAge, $maxAge	1,9								
$maxAgePlusGroup	1,0,0								
$keyLogFsta	0	1	2	3	4	5	5	5	5
Coupling of fishing mortality states	-1	-1	-1	-1	-1	-1	-1	-1	-1
	-1	-1	-1	-1	-1	-1	-1	-1	-1
$corFlag	2								
$keyLogFpar	-1	-1	-1	-1	-1	-1	-1	-1	-1
Coupling of catchability parameters. No catchability for catches	-1	0	1	2	3	4	4	-1	-1
	-1	5	6	7	8	9	9	-1	-1
$keyQpow	-1	-1	-1	-1	-1	-1	-1	-1	-1
No power law model for any survey	-1	-1	-1	-1	-1	-1	-1	-1	-1
	-1	-1	-1	-1	-1	-1	-1	-1	-1
$keyVarF	0	0	0	0	0	0	0	0	0
Coupling of fishing mortality RW variances	-1	-1	-1	-1	-1	-1	-1	-1	-1
	-1	-1	-1	-1	-1	-1	-1	-1	-1
$keyVarLogN	0	1	1	1	1	1	1	1	1
Coupling of log abundance random walk variances									
$keyVarLogObs	0	0	0	0	0	0	0	0	0
Coupling of the observation variances	-1	1	1	1	1	1	1	-1	-1
	-1	2	2	2	2	2	2	-1	-1
$obsCorStruct	ID,ID,ID								
Fleet covariance structure									
$keyCorObs	NA	NA	NA	NA	NA	NA	NA	NA	
Coupling variance parameters	-1	NA	NA	NA	NA	NA	-1	-1	
	-1	NA	NA	NA	NA	NA	-1	-1	
#params	16								
Log(L),AIC	-650.49, 1332.98								

The process variance parameter (logSdLogN_1) for the survival was estimated to be almost zero during initial investigations. To aid model stability it was fixed at zero for the initial and subsequent assessment runs.

The initial assessment was further developed by examining of output and associated diagnostics (Likelihood, AIC, residuals, individual index fits at age). The following incremental updates were made to the initial assessment:

- Her_6aS7bc_WKNSCS22_0.1fvars - binding of the F random walk variances, allowing F at the youngest age to have a different variance to the older ages which remain bound.
- Her_6aS7bc_WKNSCS22_0.2obsvars - selection of appropriate bindings for the age-based observation variances (catch, acoustic and groundfish surveys). Separate variances are estimated of ages that tend to be less well represented in the data e.g. youngest and oldest ages while grouping the remaining ages.
- Her_6aS7bc_WKNSCS22_0.3obscor_1 - investigating the assumption of an error structure within the acoustic survey index (MALIN_08_20).
- Her_6aS7bc_WKNSCS22_0.3obscor_2 - investigating the assumption of an error structure within the groundfish survey index (MALIN_08_20).
- Her_6aS7bc_WKNSCS22_0.4fsta - binding of the F states, investigating if improvement could be achieved by decoupling the F random walk processes at older ages.

The configuration changes associated with each of these updates along with the associated number of parameters and AIC is detailed in Table 4.4.

Table 4.4. Configuration changes associated with each of the assessment updates along with the associated number of parameters and AIC.

Run Name	Parameter Updated	Value	#par	AIC
Init	-	-	16	1333
0.1fvars	$keyVarF	0,1,1,1,1,1,1,1	17	1283
0.2obsvars	$keyVarObs	0,1,2,2,2,2,3,3,4 -1,5,6,7,7,7,7,-1,-1 -1,8,9,10,10,10,10,-1,-1	25	1169
0.3obscor_1	$obsCorStruct (MALIN)	AR -1,0,1,2,3,4,-1,-1	30	1102
0.3obscor_2	$obsCorStruct (IBTSQ4)	AR -1,5,6,7,8,9,-1,-1	35	1042
0.4fsta	$keyLogFsta	0,1,2,3,4,5,6,7,7	35	1034
Baseline			35	1034

Each of the changes described above resulted in an improved assessment in terms of AIC and other model diagnostics with the most significant improvements due to revision of the observation variances and the assumption of correlation in survey indices. The resulting assessment (Her_6aS7bc_WKNSCS22_Baseline) incorporates all the updates described above.

The one-step ahead residuals for the baseline assessment are shown in Figure 4.18.

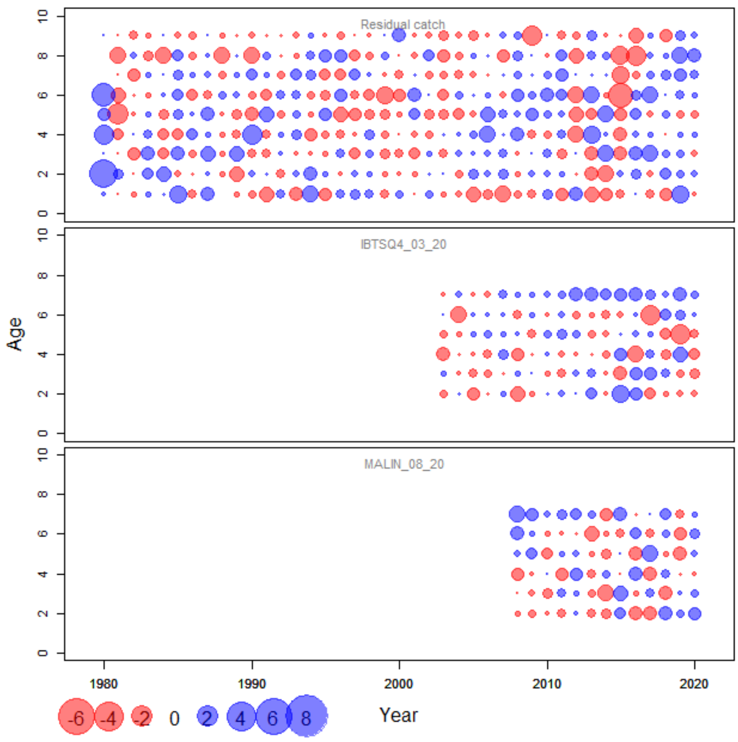


Figure 4.18. Her_6aS7bc_WKNSCS22_Baseline assessment one-step ahead residuals

The following can be discerned from visual examination of the structure of the residual patterns:

- The oldest age in the groundfish survey (age 7) has a positive residual for much of the time-series.
- There is a clear year effect in the catch data series associated with the introduction of the monitoring TAC in 2015 (which total annual catch by approximately two thirds).
- Mostly positive residuals for older fish (6-9 winter ring) in the most recent period of the catch data.
- A cohort effect can be seen in the catch data, associated with the strong 1987 year-class.
- Positive residuals for the oldest age (7) in the acoustic survey from 2008-2013, coinciding with the period for which the survey stock split has is based on results from 2009-2014.

These issues were investigated by running additional incremental assessments with subsets of the baseline data series. The first run removed the age 7 winter ring from the groundfish index. Then, a reduced plus group of 8+ for the catch data series was introduced. For the final change, the early part of the acoustic time-series (2008-2013) was disregarded and the assessment model refit. These changes and resultant model AIC values are summarised in the table below.

Assessment	Data	Previous	Updated	#par	AIC
Her_6aS7bc_WKNSCS22_Baseline	-	-	-	35	1034
Her_6aS7bc_WKNSCS22_IBTS2_6	IBTSQ4	Ages 2-7 winter ring	Ages 2-6 winter ring	33	981
Her_6aS7bc_WKNSCS22_8PG	Catch	9+ winter ring	8+ winter ring	33	853
Her_6aS7bc_WKNSCS22_2014Aco	MALIN	2008-2020	2014-2020	33	801

The one-step-ahead residuals from assessment Her_6aS7bc_WKNSCS22_2014Aco, which incorporates all three data updates are shown in Figure 4.19.

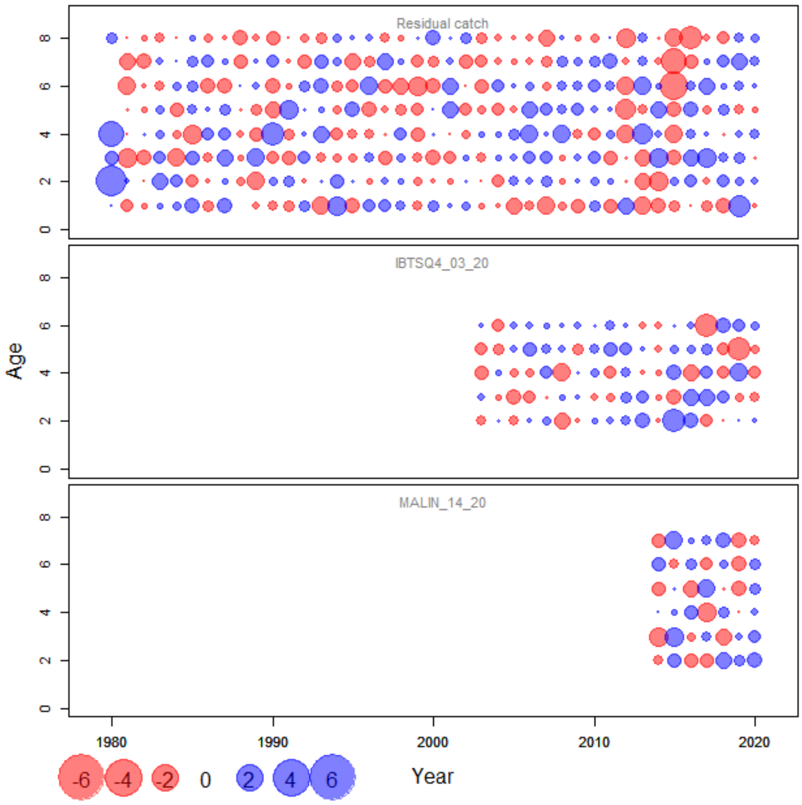


Figure 4.19. Her_6aS7bc_WKNSCS22_2014Aco assessment one-step ahead residuals

Improved balance in the residuals for the catch plus group (now 8+) and the older groundfish survey age can be seen. Patterns associated with the 1987 year class and the introduction of the monitoring TAC remain. The absolute size of the largest positive residuals is also reduced with these updates. However, the removal of half the acoustic time-series disregards a significant proportion of the fishery independent information. A comparison of the observations variances with this update are shown in Figure 4.20.

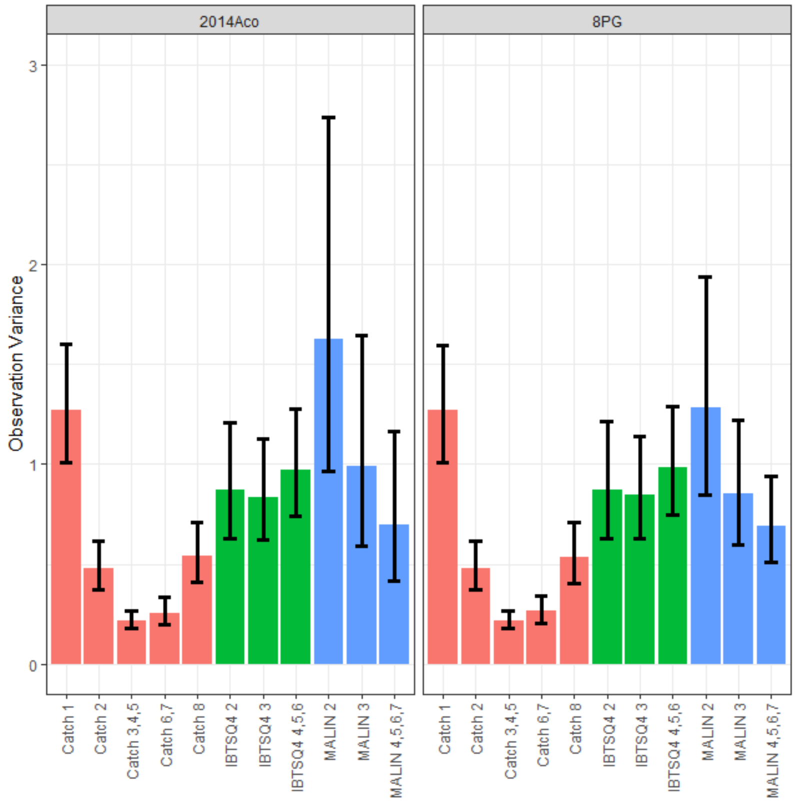


Figure 4.20. Observation variances from runs with the full acoustic survey time-series from 2008-2020 (Her_6aS7bc_WKNSCS22_8PG) and the truncated acoustic survey time-series from 2014-2020 (Her_6aS7bc_WKNSCS22_2014Aco).

The model estimates separate observation variances for groups of ages for each data source (1,2,3-5 and 6-7 for the catch data, 2,3 and 4-6 for the IBTS and 2,3 and 4-7 for the acoustic survey). The lowest observation variances are estimated for the catch data for 3-5 and 6-7 indicating a close fit to the catch data for these ages. A higher observation variance is estimated for the catches of age 2 and 8 winter ring. The assessment fits less well to these data although still with a higher weight than any of the fishery independent series. The fit to the youngest age in the catch (1) is poor, reflecting the sporadic nature of catches at this age. A similar pattern is seen in the acoustic survey index with the highest variances estimated for the youngest fish. The three separate variances estimated for the groundfish survey are broadly similar suggesting a future assessment could reduce the number of model parameters by binding some, or all of these ages.

The estimate and uncertainty of the observation variance for the acoustic survey in increased, notably for the youngest age groups (winter ring 2 and 3) with the truncated acoustic time-series.

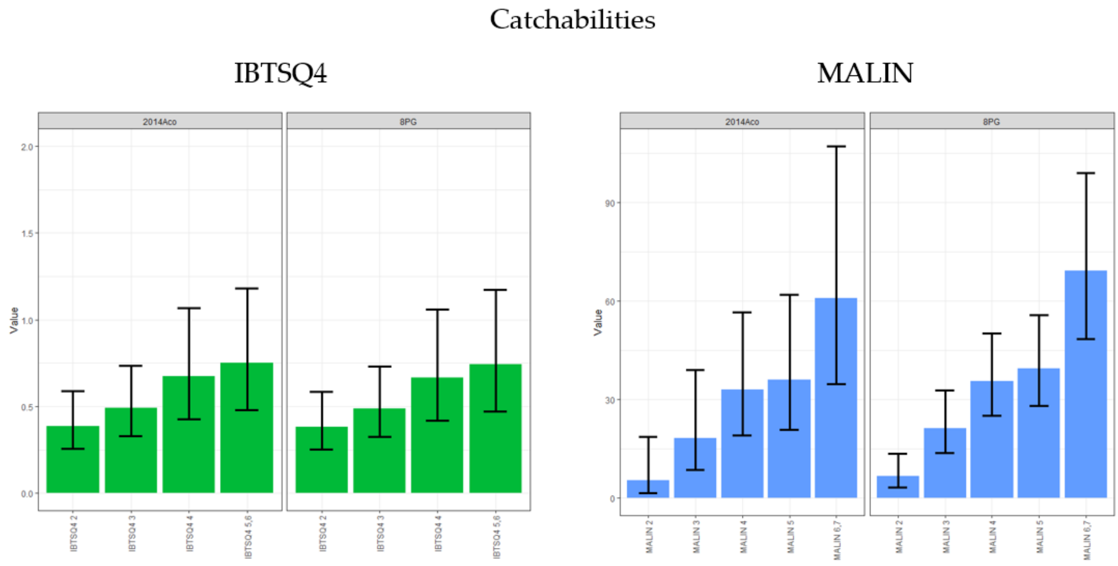


Figure 4.21. Scaling parameter estimates from runs with the full acoustic survey time-series from 2008-2020 (Her_6aS7bc_WKNSCS22_8PG) and the truncated acoustic survey time-series from 2014-2020 (Her_6aS7bc_WKNSCS22_2014Aco).

Both assessments estimate similar catchabilities for the groundfish survey. For the truncated acoustic time-series, lower catchabilities are estimated for the acoustic survey, most noticeably for the oldest ages (6 and 7).

A comparison of the estimated SSB, TSB, Fbar and Recruitment for the Her_6aS7bc_WKNSCS22_Init, Her_6aS7bc_WKNSCS22_Baseline and Her_6aS7bc_WKNSCS22_2014Aco assessments is shown in Figure 4.22.

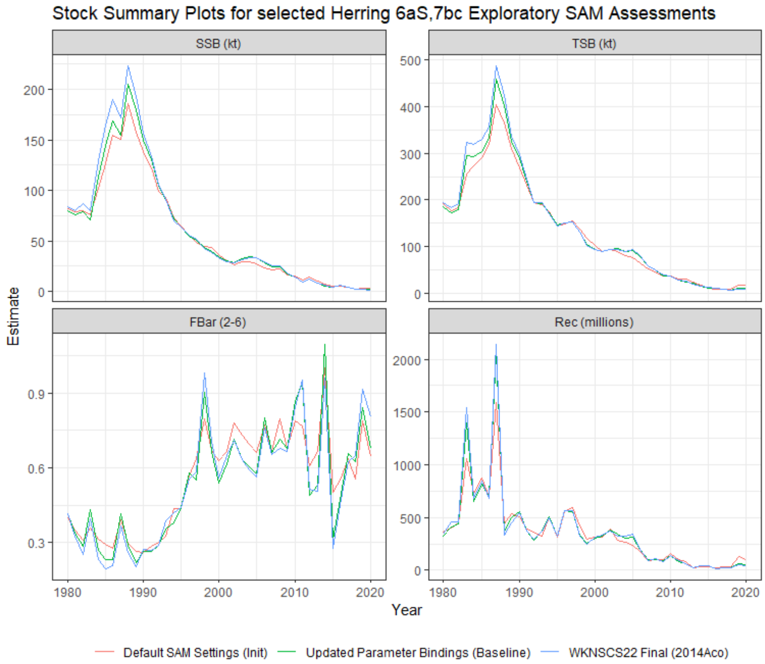


Figure 4.22. Stock summary comparison.

All exploratory assessments considered indicate that the SSB is at or close to a historic minimum and below 5kt in the terminal assessment year (2020). With default SAM settings, TSB is estimated to have increased slightly in the most recent period, due to a moderate recruitment estimate for 2019. This year class does not yet contribute to SSB as it is immature. While the other exploratory assessments also consider the 2019 recruitment to be greater than the recent average, the estimate is lower than that of the initial run and hence the modest recovery in stock size is less evident. The assumption of a correlation in the survey indices, introduced to reduce year effects that were evident in the residual pattern, is the most influential configuration change in this regard.

All assessments estimate fishing mortality to have been greater than 0.4 in the last 20 years, with the exception of 2015 when catches were initially reduced following the introduction of the monitoring TAC. Despite catches remaining very low since 2015, F is estimated to have increased again and has been above 0.6 since 2016.

Separate correlation parameters are estimated for the adjacent pairs of ages in each of the surveys. The introduction of these correlations leads to an improved assessment fit with stronger correlations estimated for the acoustic survey.

The selectivity of the fishery for the final assessment (2014Aco) is shown in Figure 4.23.

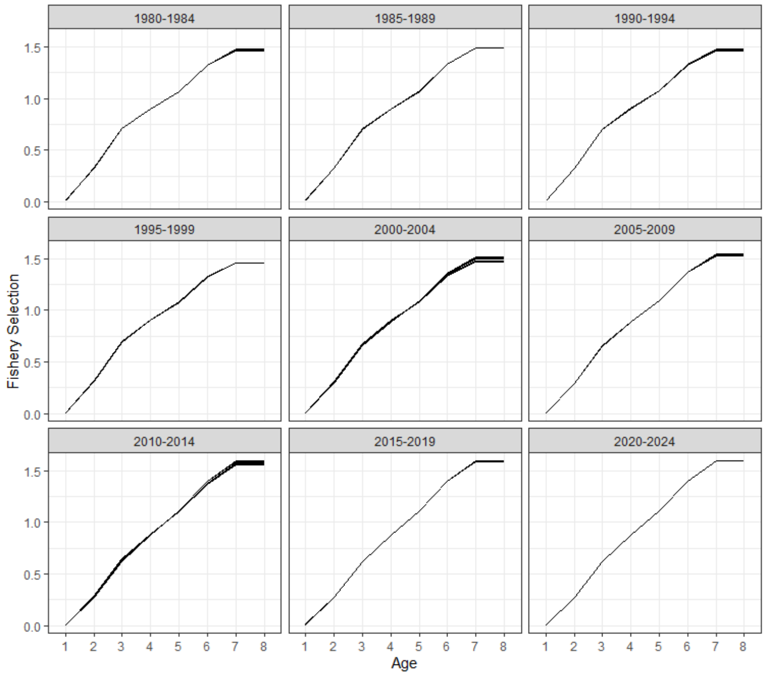


Figure 4.23. Estimated selectivity for the period 1980-2020 (annual fishing mortality-at-age divided by F3-6)

There is little evidence of changes in selectivity over the period of the assessment, which is considered rather unlikely given the changes in the stock status and fishery, particularly in the most recent period. Since the introduction of the monitoring TAC, the fishery has been carried out almost exclusively by smaller (mainly inshore) vessels than had previously been involved when the stock was estimated to be larger. The assessment estimates do not correspond with indications from the fishery and acoustic survey that indicate a stock that has been increasing in the most recent years (minimum acoustic estimate in 2016). Feedback from fishery participants indicate that the monitoring TAC of approximately 2 kt is easily obtained by the fleet. The estimated SSB of less than 5 kt is not considered credible. The corresponding fishing mortality is very high and more variable than expected given the monitoring TAC has remained at a low level since its introduction. Combined with the very low estimate of SSB is an unrealistically high catchability estimate for the acoustic survey such that the assessment considers the survey to overestimate the stock size by a factor of over 50. A more realistic estimate of 0.4-0.75 is obtained for the groundfish survey.

Retrospective analyses (5 peels) were conducted for each exploratory assessment. Peels for the assessment with the truncated acoustic time-series (Her_6aS7bc_WKNSCS22_8PG) did not converge, perhaps due to the short survey time-series (7 years). Significant retrospective patterns are evident for the assessment with the full acoustic time-series (Her_6aS7bc_WKNSCS22_8PG) with Mohn's rho values well outside of acceptable limits, a consistent upward revision in SSB (Mohn's rho = -0.45) and recruitment (-0.54) and downward revision of fishing mortality (0.77).

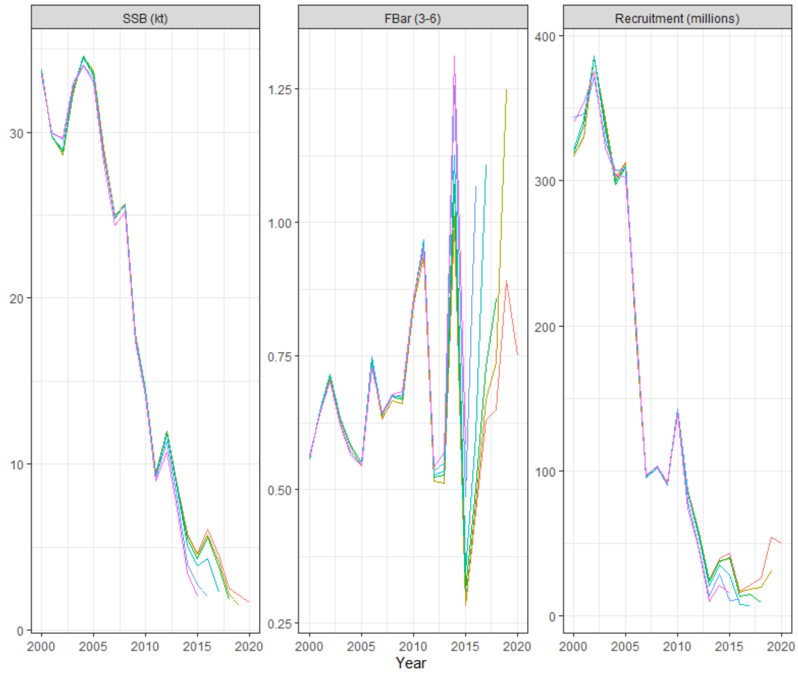


Figure 4.24. Retrospective analysis for exploratory assessment Her_6aS7bc_WKNSCS22_8PG (from 2000)

Conclusions

Using the stockassessment.org platform, a SAM assessment was configured with catch-at-age data from 1980 and two fishery independent surveys - a groundfish survey (from 2003) and an acoustic survey (from 2008), both providing estimates of abundance at age. A number of updates to the default SAM configuration were investigated (parameter bindings, survey error structure) which resulted in improved assessment diagnostics. Updates to the input data were also considered (reducing the catch at age plus group to 8+, exclusion of the age 7 winter ring in the groundfish survey index and truncation of the acoustic survey time-series to the most recent period where genetic analysis is available) were also investigated. Although incremental improvements in the assessment diagnostics were achieved via these explorations, there are a number of issues outstanding and none of the assessment configurations are considered to be of sufficient quality to provide a basis for future catch advice. The following issues require further investigation

- Model estimates of SSB in the recent period are unrealistically low (<5kt) given information available from acoustic surveys and the fishery
- The acoustic survey indicates the stock size has been increasing since 2016. All exploratory assessments, with the exception of the initial run (default SAM configuration) indicate a continually decreasing stock size with the lowest value in the terminal year (2020)
- Changes in the fishery since 2015 (much reduced catch, reduced proportion of older fish) are not reflected in the model fit
- The estimated catchability for the acoustic survey is very high
- The retrospective performance of the assessments is poor with associated Mohn's rho values outside of acceptable limits
- Convergence could not be achieved for some assessment configurations

ASAP Assessment Explorations

ASAP Version 3.0.1 7 NOAA Fisheries toolbox (http://nft.nefsc.noaa.gov)

The Age Structured Assessment Program (ASAP) is an age-structured stock assessment model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population abundances given observed catches, catch-at-age, and indices of abundance. The separability assumption is relaxed by allowing for fleet-specific selectivity at age that can change smoothly over time or in blocks of years. ASAP can handle years with missing data and uncertainty on catch and on recruitment can be specified.

Input Data

A number of exploratory assessments were carried out using ASAP for herring in 6aS, 7bc using combinations of the catch and survey data shown in Table 4.5. The remaining assessment input data is described in working document 6 (Egan and Nolan 2021).

Table 4.5. Data options tested in ASAP exploratory assessments.

Data	Year Ranges	Age Ranges
Catch-at-age data	1957-2020, 1970-2020, 1980-2020, 1990-2020, 2000-2020	1-9+, 1-8+, 1-7+
Malin shelf Acoustic Survey	2008-2020, 2009-2020, 2014-2020	1-9, 2-8, 2-7
IBTS Q4	2003-2020	2-4, 2-7, 2-6

ASAP Exploratory Runs

Catch Data

The catch data time-series extends back to 1957. Exploratory assessments were run starting in 1980 due to uncertainty about the quality of the catch data prior to this. Shorter time-series starting in 1990 and 2000 were also investigated but did not show improvements. The plus group was also examined with 7+, 8+ and 9+ tested. Reducing the plus group from 9 did not improve diagnostics in ASAP.

Survey Indices

The split Malin shelf acoustic survey from 2014-2020 is the primary index that is available for herring in 6aS, 7bc and is the only index that has been split by stock based on genetic analysis. The survey started in 2008 but prior to 2014 genetic sampling was not carried out. A split was calculated for 2008-2013 based on an average strata level split from 2014-2020 and this extended survey series was used in the assessment initial runs along with catch at age 1-9 winter ring. The fit to the survey index age 1, where limited data were available, and 8 and 9 was poor, particularly in the averaged part of the time-series and further runs used ages 2-7 ringers. The numbers at age were very high in 2008 with particularly high numbers of 7 winter ring fish. The fit to this year was not good and additional runs were carried out starting in 2009. In many runs the fit to this averaged data was not good and further runs used data from 2014 -2020.

The IBTS Q4 survey started in 2003 and includes data for ages 1-9 ring. The internal consistency is best for ages 2-7 winter ring and the fit to this data in the assessment is reasonably good in most years. The full time-series and ages 2-7 are used in the runs.

ASAP Settings Tested

Index CV and Effective Sample Size (ESS)

A CV for the acoustic survey abundance (sum of the numbers-at-age) data is calculated by the STOX software when the biomass estimate was calculated. Values are calculated annually using a consistent approach and vary from 0.23 to 0.57 over the time-series. The effective sample size is set at 50 as this survey is given a higher weight in the assessment.

The IBTS survey CV is arbitrarily set at 0.3 for all years and the sample size is set at 25. Other options were tested including using the number of samples collected in the survey but there is considerable variation in the amount of herring sampled and a more consistent approach was chosen which had little impact on the diagnostics.

Fleet CV and Effective Sample Size (ESS)

The quality of the catch data has improved over time, owing to improvements in control and enforcement, especially since 2004. In the late 1980s and early 1990s, there was a market for roe and many catches were slipped if they did not contain the appropriate maturity stage. This slippage is not reflected in the historic catch data (ICES, 2015). The catch CV set to 0.2 from 1980-2003 and at 0.1 from 2004-2020. The effective sample size is derived from the number of catch samples obtained by the Irish national sampling program.

Recruitment Deviations and CV on recruitment

The effect of including recruitment deviations in the ASAP likelihood function was examined by setting the lambda parameter to 1. Recruitment deviations are constrained based on the specified annual CVs and a number of CVs were tested. Smaller CVs will constrain recruitments more while minimal constraint is achieved with a higher CV. Excluding the recruitment deviations leads to a poor fit to age 1 and high uncertainty in recruitment estimates. Constraining the recruitment leads to a deterioration in the model fit. Further runs included the deviation with a minimal constraint.

Selectivity

The catch numbers at age data for herring in 6aS, 7bc show a decreased proportion of older fish since 2000 and this has continued until 2020. A monitoring TAC was introduced for this stock in 2015. This is a low TAC which was established to ensure the continuation of sampling given a zero-catch advice. Since the introduction of the monitoring TAC, the fishery has taken place over a few weeks in November and December mainly inshore. It is more restricted in space and time than it was in the past and is a different type of fishery than earlier in the time-series. Consequently, it is expected that changes in the selection of the fishery would have taken place over the course of the time-series. To account for the changes that have taken place in the fishery a number of runs with varying selection blocks were tested in ASAP.

Results

Diagnostics from two selected runs are presented in Figure 4.25 to Figure 4.36. In the run with 1 selection block, selection is fixed at 8 and 9 winter ring and free at all other ages. In the run with 2 selection blocks, selection is fixed at 6 and 7 from 1980-2003 and 5 and 6 from 2004-2020 (Figure 4.25).

The standardised catch residuals are presented in Figure 4.26 and show a clear pattern of negative residuals at the oldest ages when one selection block is specified for the full time-series. The residuals change to all negative from around 2004 with the residuals being larger for the period after the introduction of the monitoring TAC. Figure 4.27 shows an improved residual pattern when an additional selection block is included. In all of the model runs, if selection is left free at ages 8 and 9, the model predicts a drop-in selection at these ages. This drop-in selection is more pronounced for 9 winter ring fish.

The observed and predicted catch proportions at age from the fishery are shown in Figure 4.28. The run with 1 selection block shows a mismatch at 7,8 and 9 winter ring in the most resent years with predictions greater than observations. When 2 selection blocks are used the fit to this data improves.

The standardised survey residuals are presented in Figure 4.29 (1 selection block) and Figure 4.30 (2 selection blocks). For the IBTS survey, when 1 selection block is used the residuals are mainly positive for 7 winter ring fish with this becoming more balanced when 2 selection blocks are applied. The main difference for the Malin shelf acoustic survey can be seen at 5 winter ring with an age effect (with only negative residuals) when 2 selection block are used.

The observed and predicted index proportions at age for each index are shown in Figure 4.31 for 1 selection block and in Figure 4.32 for 2 selection blocks. The fit to the IBTS survey is similar for most ages with an improvement seen for 7 winter ring fish in the early part of the time-series when 2 selection blocks are used. For the Malin shelf acoustic survey predictions are higher than observations for all years as is seen in the index residuals.

The catchability from each survey using the different selectivity assumption is shown in Figure 4.33. The catchability on the IBTS survey is 0.53 with 1 selection block and this decreases to 0.069 with 2 selection blocks. A more significant difference can be see for the Malin shelf acoustic survey where the catchability is high, at 15.4 with 1 selection block, reducing to 1.7 with two blocks.

Retrospective Analysis

All of the assessment runs carried out in ASAP showed a poor retrospective performance over a 5-year peel. Mohn's Rho values were well in excess of the recommended 20%. An analytical retrospective for each run is shown in Figure 4.34 (1 block) and Figure 4.35 (2 blocks). The Mohn's rho for SSB is lower when two selection blocks are used but there is less convergence in the earlier part of the times-series.

Comparison of Runs

The exploratory assessments indicate that ASAP is very sensitive to the assumptions about fishery selectivity. Figure 4.36 shows the SSB, Mean F (3-6) and recruitment trajectories from the runs. When 1 selection block is used the recent SSB trajectory remains stable at a low level. This is similar to the SAM runs which do not show evidence of a change in selection. However, the SSB follows a very different trajectory if there are 2 selection blocks. F is also fluctuating at a higher level with 1 block than if two selection blocks are used. When 2 selection blocks are used the recruitment of 1 ringers diverges from 1996 where higher recruitment is estimated, with peaks in 2010 and 2019 which are not seen with 1 selection block.

Conclusions

A poor model fit is seen with one selection block and the selection fixed for ages 8 and 9 winter rings. The diagnostics presented show improvements when two selection blocks are included. Several different combinations of selectivity were tested but no clear best run could be identified. It is unlikely that fishery selection has been constant over the time-series given the changes that are known to have taken place. The assessment is very sensitive to the assumptions regarding the selectivity of the fishery in particular the age at which selection is fixed. When older ages are left free selection drops dramatically. This results in very low fishing mortality at these ages and an increase in population numbers at age estimated by the model. Further work is required to inform how selection should be specified in ASAP.

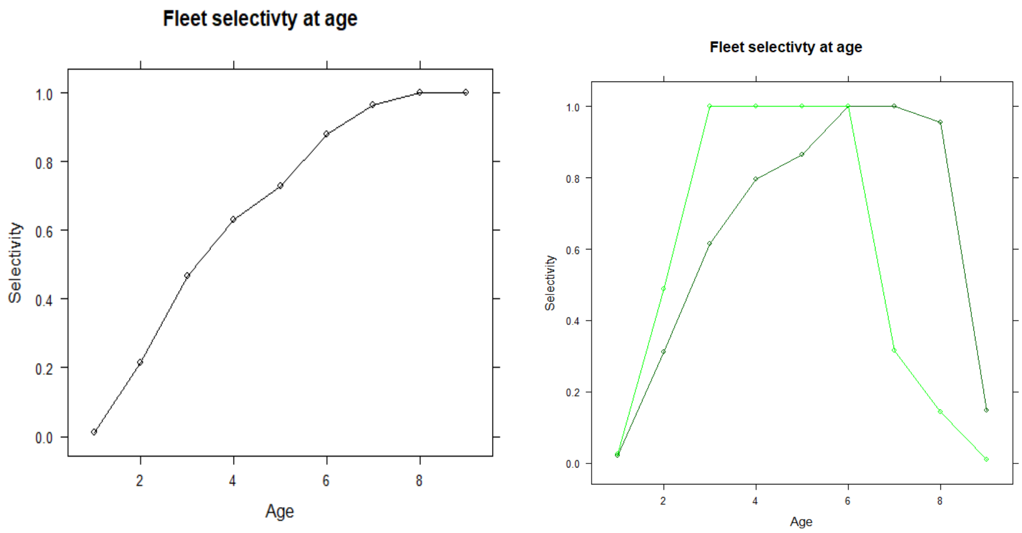


Figure 4.25. Fleet selectivity when selection is fixed at age 8 and 9 (left) and when 2 blocks are specified – block 1: fixed at 6 and 7 and block 2 fixed at 5 and 6 (right)

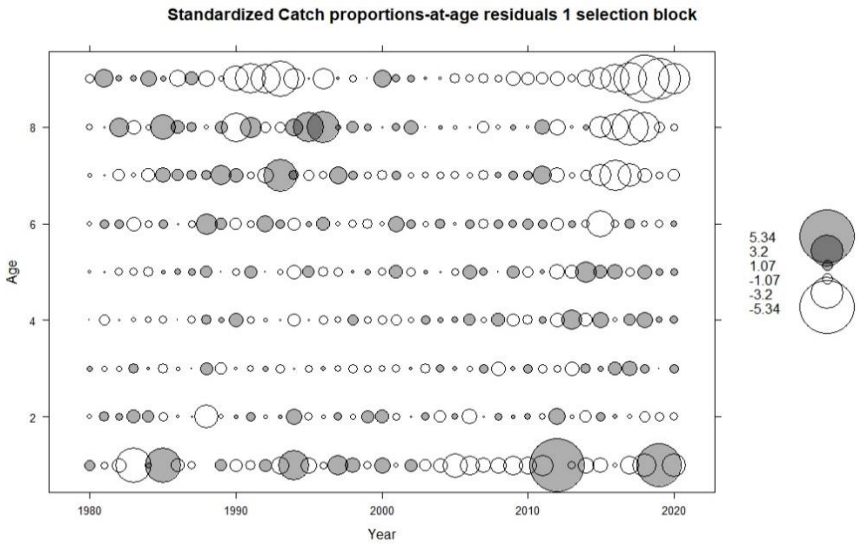


Figure 4.26. Standardised catch proportions at age residuals with 1 selection block

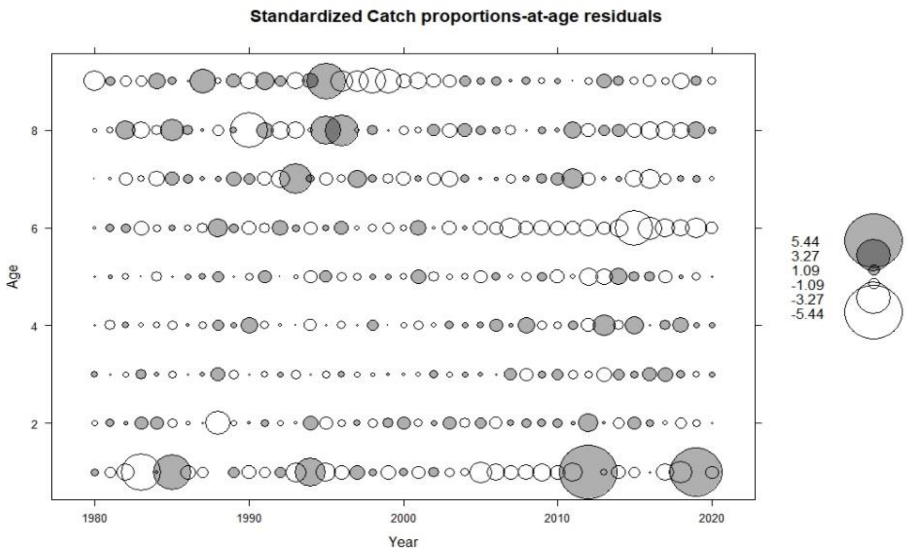


Figure 4.27. Standardised catch proportions at age residuals with 2 selection blocks

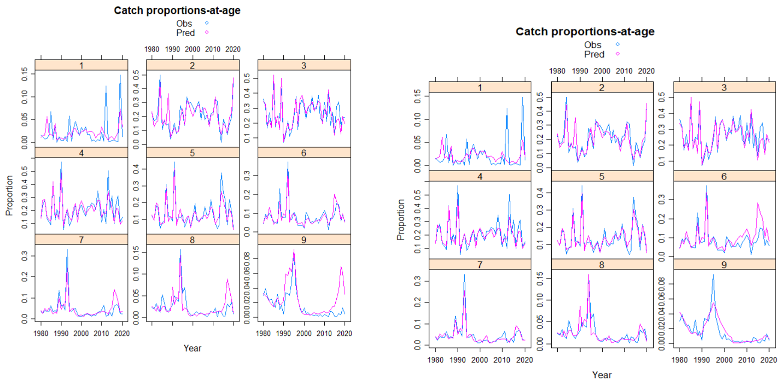


Figure 4.28. Observed and Predicted catch proportions at age with 1 selection block (left) and 2 selection blocks (right)

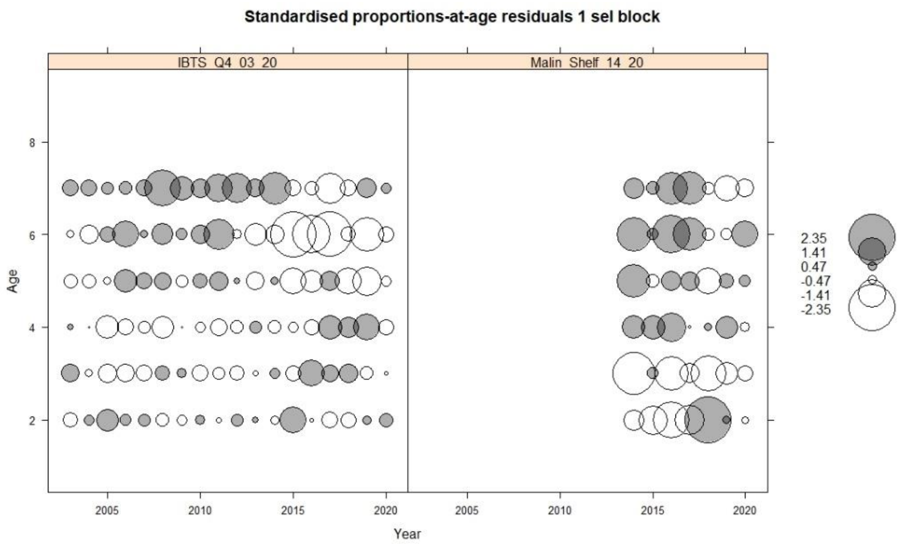


Figure 4.29. Standardised proportions at age residuals from each index with 1 selection block

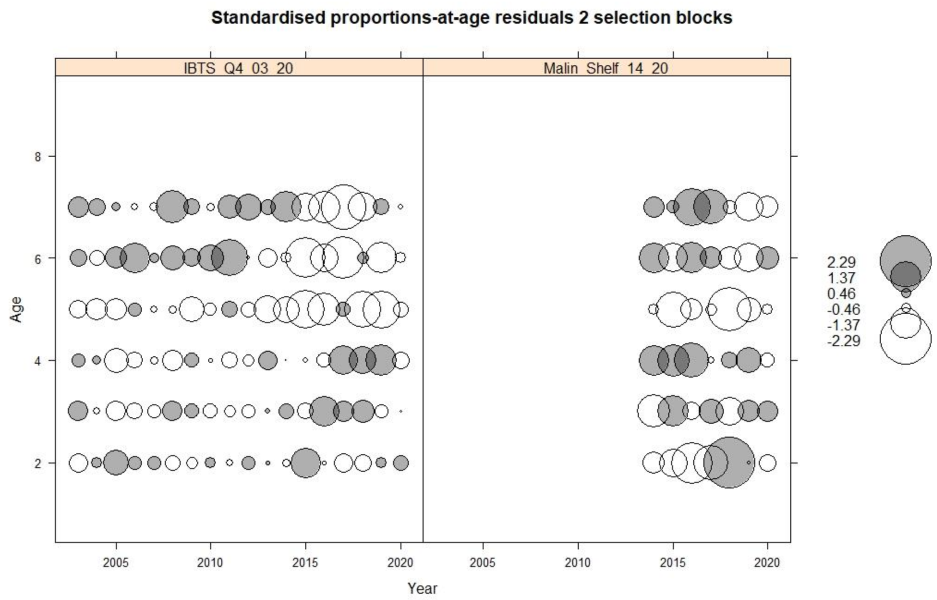


Figure 4.30. Standardised proportions at age residuals from each index with 2 selection blocks

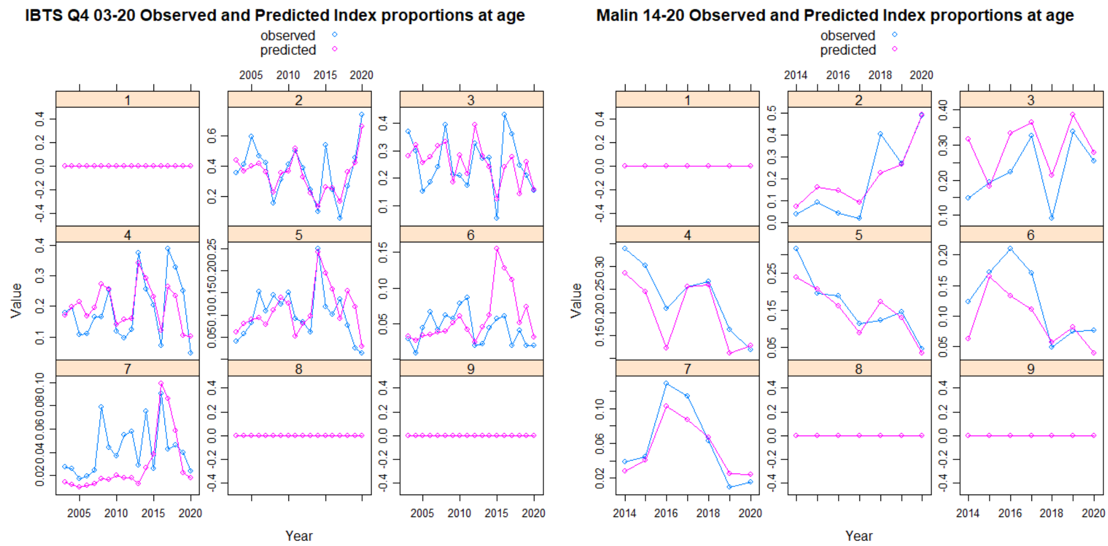


Figure 4.31. Observed and predicted proportions at age from the IBTS (left) and Malin Shelf Acoustic Survey (right) when 1 selection block is specified

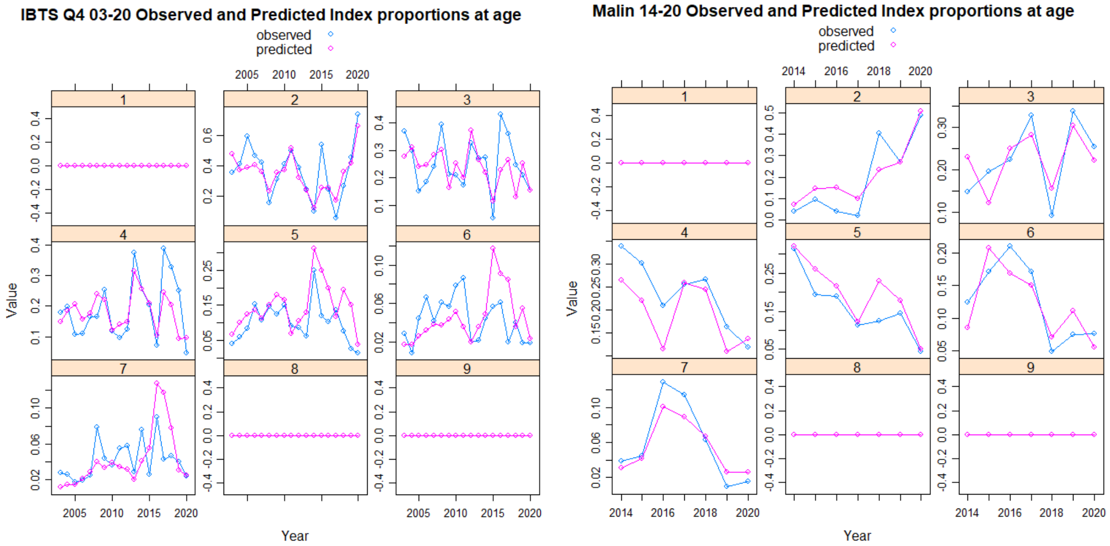
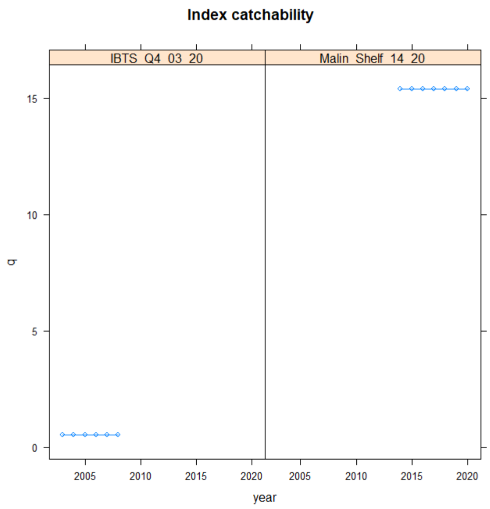


Figure 4.32. Observed and predicted proportions at age from the IBTS (left) and Malin Shelf Acoustic Survey (right) when 2 selection blocks are specified



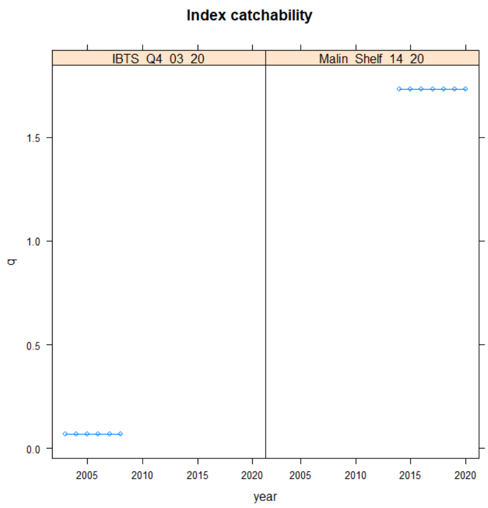


Figure 4.33. Index catchability with 1 selection block (left) and 2 selection blocks (right)

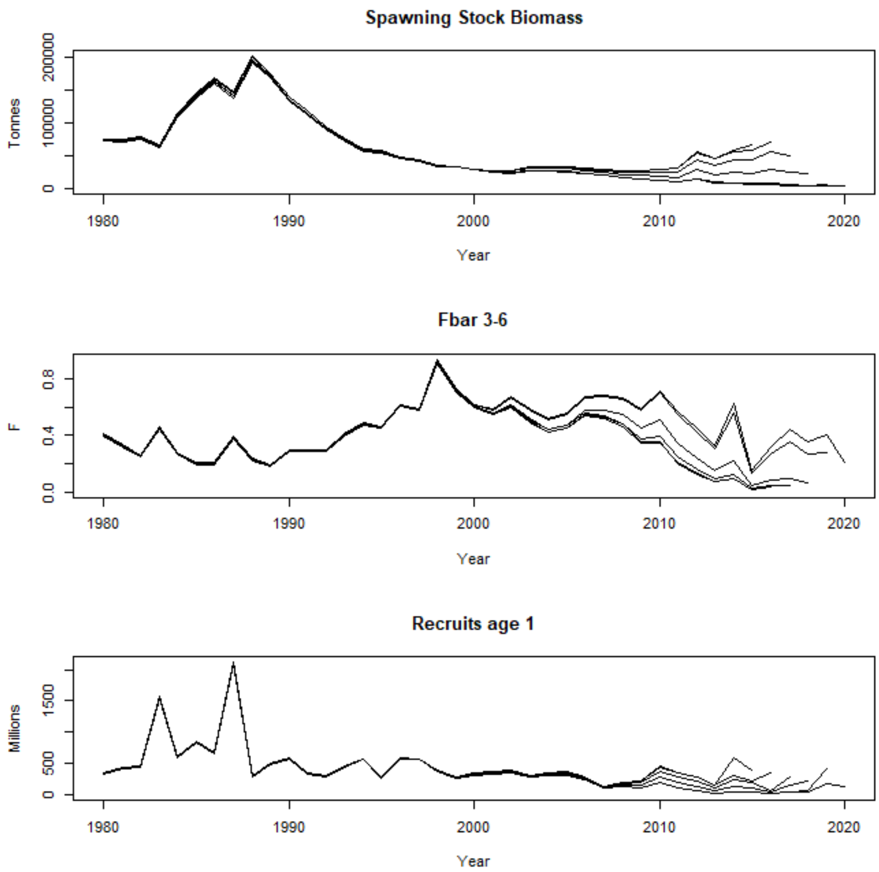


Figure 4.34. Analytical Retrospective with 1 selection block

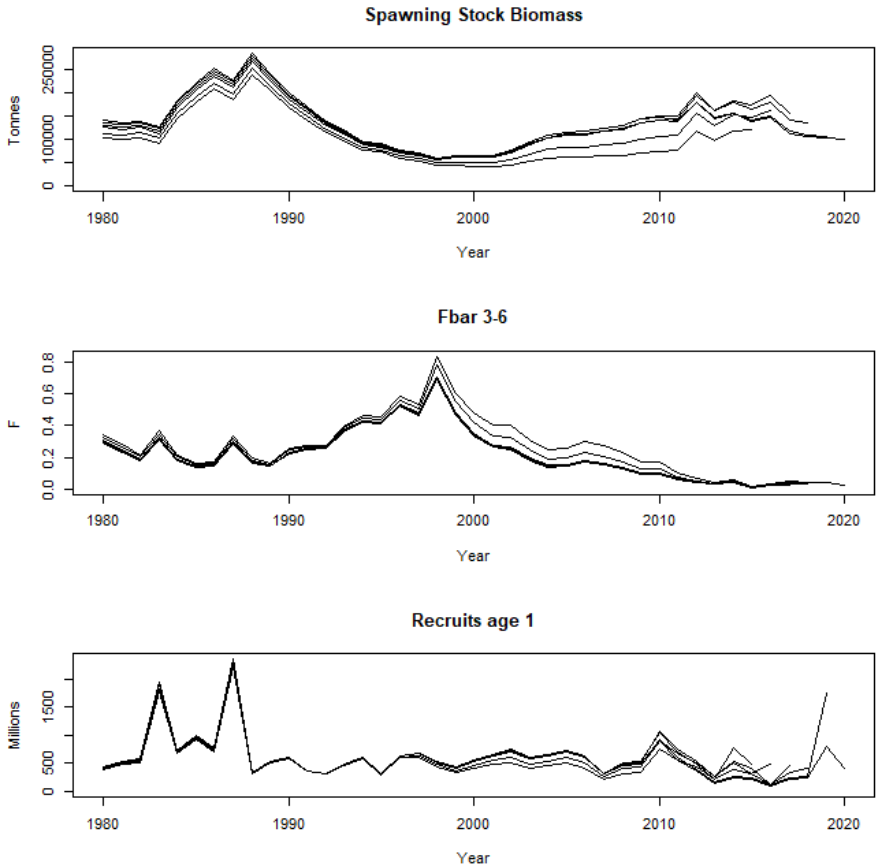


Figure 4.35. Analytical Retrospective with 2 selection blocks

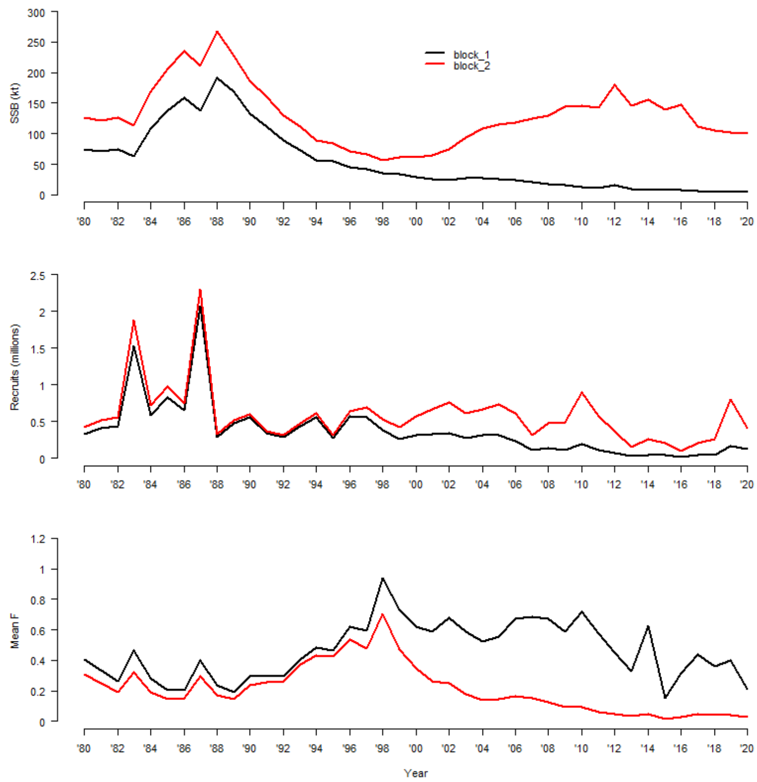


Figure 4.36. SSB, Recruitment and Mean F trajectories using 1 (black line) or 2 selection blocks (red line)

SPiCT

As neither the SAM nor ASAP exploratory assessments reached sufficient quality to be used as the basis for category 1 catch advice, a category 3 SPiCT assessment was trialed. The input data consisted of the split MSHAS index 2008-2020 for 6aS7bc (2008-2013 estimated) and the 6aS7bc catch data 1957-2020. In total, five trial runs were performed and in each run, an assumption was tested (a high initial depletion level, a shape parameter for the order *Clupeiformes*, an uncertainty factor around 2015 catch, a robust estimation around the 2008 index and the removal of the alpha and beta priors).

In Run1 where only a high depletion level was tested, the model could not maximize the log likelihood and therefore the model did not reach convergence. In Run2 the shape parameter was included and model convergence was reached; however, it encountered negative elements during fitting and as a result did not meet the normality assumption for the catch data (Figure 4.37). Focusing on the catch data, the 2015 data point was considered an outlier. To test this assumption, an uncertainty factor around the 2015 catch value was tested in Run3. The model converged and the normality assumption was upheld (Figure 4.38) but there were no significant retrospective patterns observed for fishing mortality or biomass (Figure 4.39).

In an effort to improve the retrospective patterns and the Mohn's rho, the next two runs included a robust estimation around the 2016 index data point and removing the alpha and beta priors separately but both runs produced similar results to Run3. In conclusion, the SPiCT assessment was deemed inappropriate for use as the basis of category 3 advice and was not presented in plenary during the benchmark meeting.

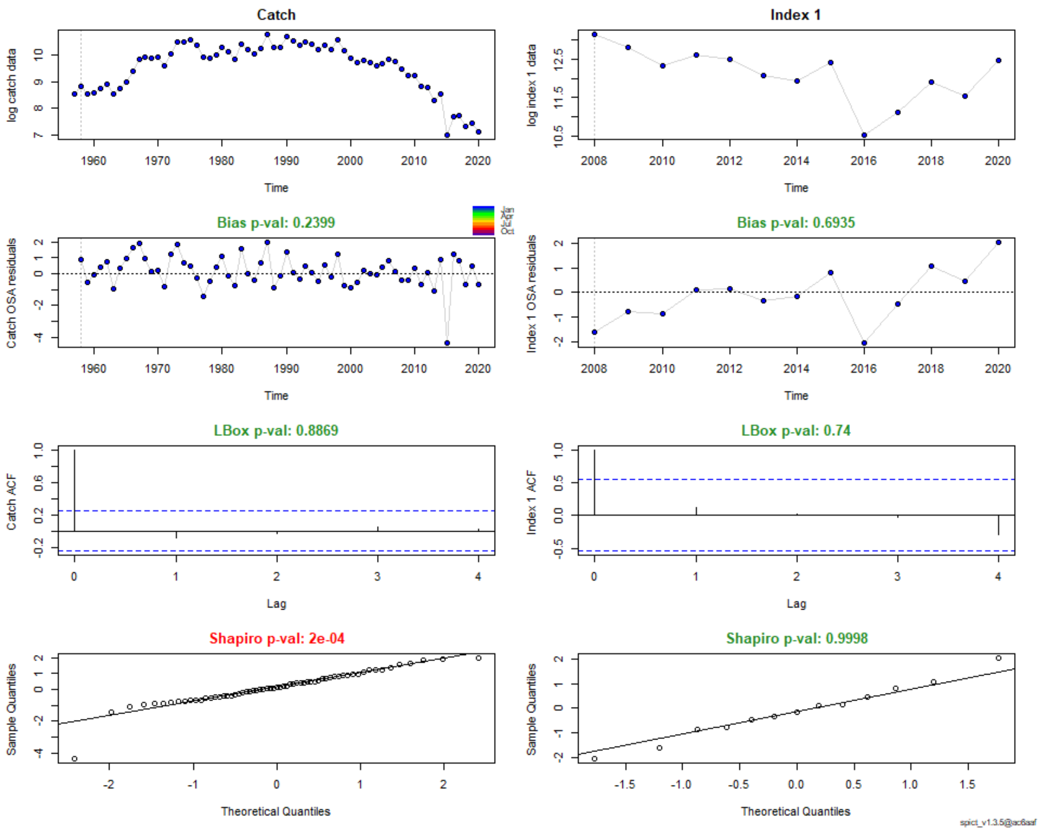


Figure 4.37. Model diagnostics for SPiCT Run2 her.27.6aS7bc.

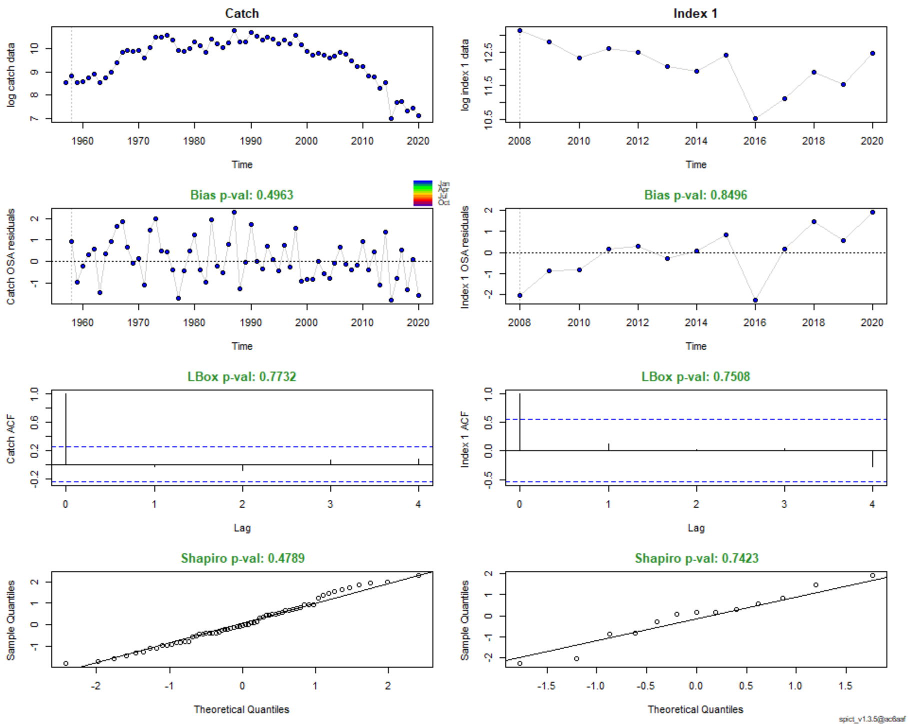


Figure 4.38. Model diagnostics for SPiCT Run3 her.27.6aS7bc.

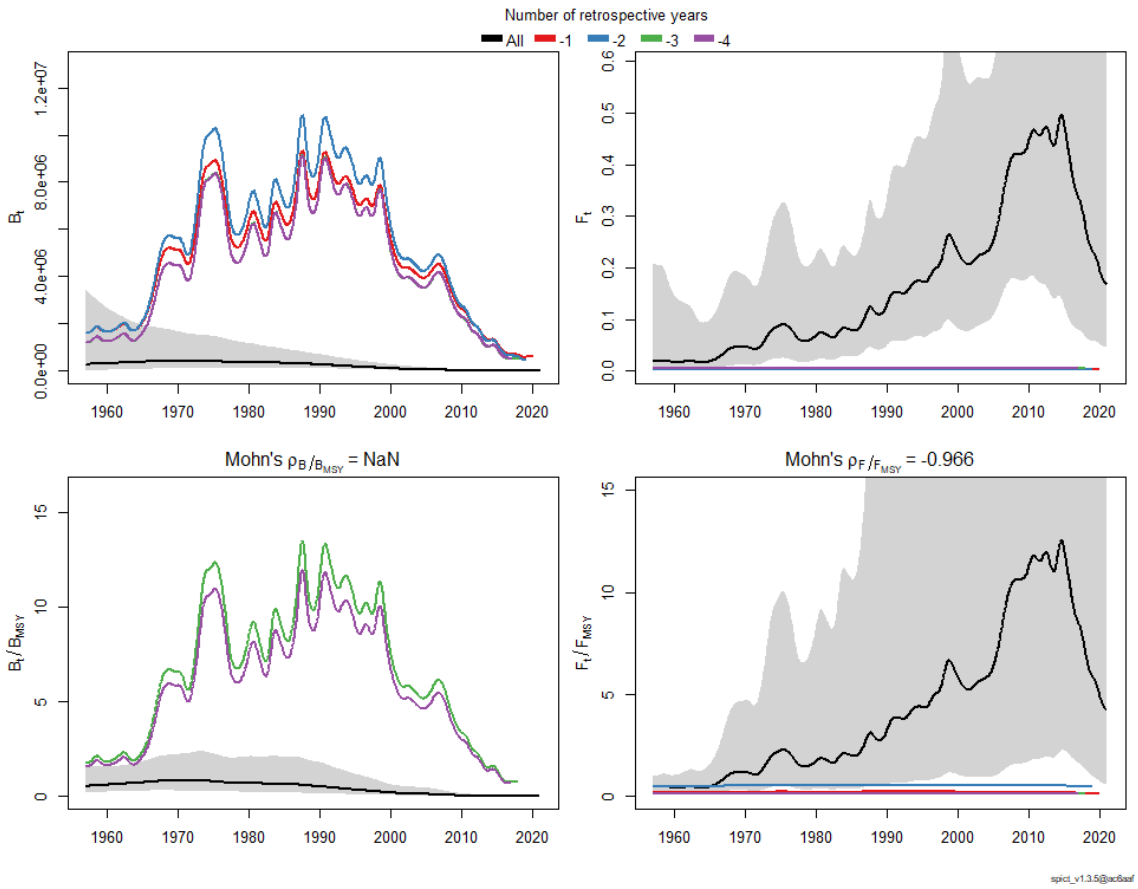


Figure 4.39. Retrospective peels for SPiCT Run 3 her.27.6aS7bc.

Category 3 Methods

Category 1 assessments were tried using SAM and ASAP as described above. SAM had issues with survey catchability and model convergence as well as with the SSB and F trajectories. ASAP was very sensitive to the assumptions about fishery selectivity. Both models had poor retrospective performance with Mohns Rho values outside acceptable limits. Neither model was deemed to be at a standard acceptable for either category 1 or 2 advice. Therefore, the new category 3 guidelines from ICES WKLIFEX (2021) were applied.

The choice of which data limited method to apply was based on the WKLIFEX flow diagram (Figure 4.40). A SPiCT model was tried but there were issues with model convergence and poor diagnostics (detailed above). An index of abundance, length data and information on k are available for this stock. The von Bertalanffy growth parameter, k, for this stock was calculated as 0.339, therefore method 2.2 'Constant Harvest Rate' Rule was chosen.

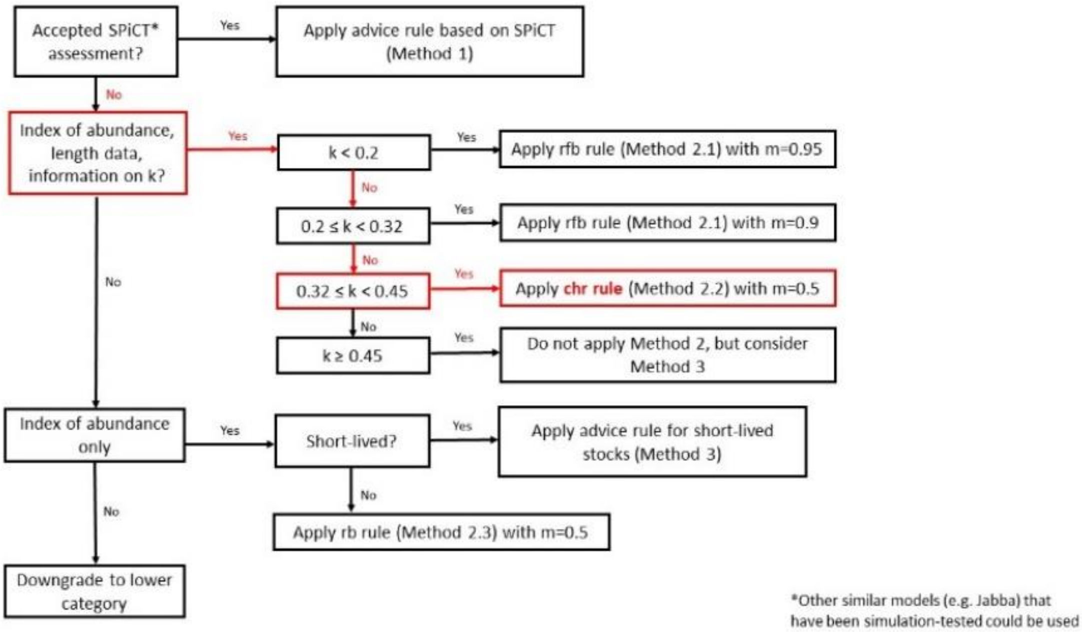


Figure 4.40. WKLIFEX Category 3 flow diagram for data limited methods. Red outlines depict the decisions taken for herring in 6aS7bc.

Calculation of k

The growth parameter k was calculated using length data from commercial catch sampling. Only samples from 6aS and 7b from 2000-2021 were included in the analysis. This totaled over 594 thousand individual herring caught in a variety of gear types. The R packages 'FSA' and 'nlstools' were used to estimate the growth parameters and to plot the fit of the growth curve (Figure 4.41). The resulting growth parameters were:

- $k = 0.339$
- $L_{inf} = 30.50$cm
- $t0 = -2.61$

Catches of 6aS7bc herring have been taken close to the north-west coast of Ireland since the introduction of the monitoring TAC in 2015. To ensure the growth fit was not influenced by mixed catches before 2015, an estimate using length data from 2015-2021 was also run. The resulting k was almost identical. This value is further supported by the literature, with a k of 0.37 for herring north-west of Ireland reported by Brunel and Dickey-Collas (2010); albeit calculated on the weight rather than the length.

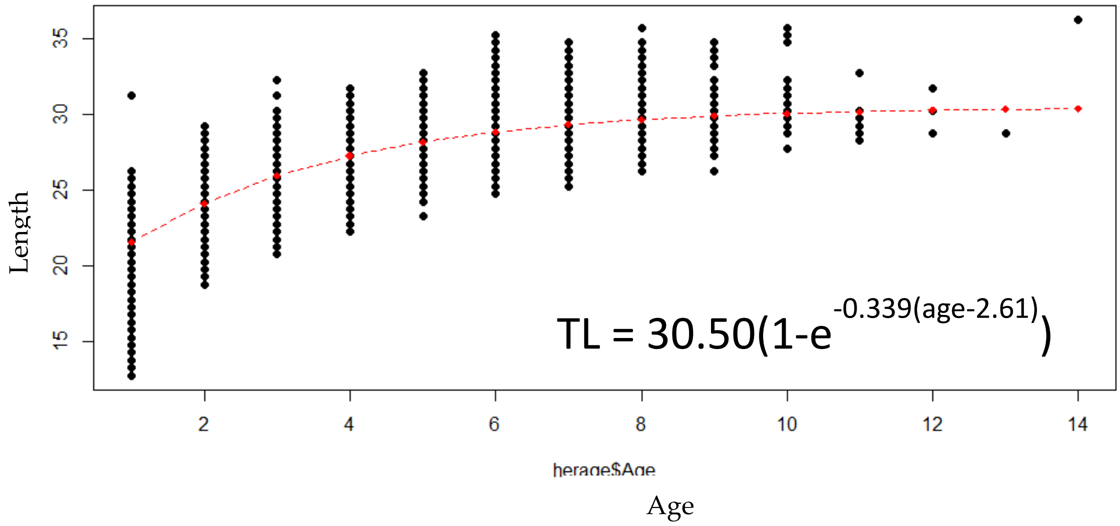


Figure 4.41. Fit of growth curve to length data from commercial catch of herring in 6aS and 7b. n = 594k.

As a further test, k was also calculated using length data from the genetically split MSHAS (6aS only). Due to sampling protocols, herring less than 23 cm were not routinely sampled for genetics prior to 2018 so only split data from 2018 onwards were included. The resulting k from this further analysis was ≈0.5, which is quite different to the other values presented and would place herring 6aS7bc in the short-lived species bracket. It is thought that this unusual growth estimate is due to the difference in timing of the survey versus the catch, which can be separated by up to 6 months. 1-ringed fish encountered during the summer survey would have recently turned 1 whereas 1 ringed fish in the catch would be approaching 2. Further work is required to understand the different survey k but nevertheless the most appropriate k to use for the category 3 flowchart and the chr calculation is that from the catch sampling (0.339) as far more data points exist over a much wider timeframe.

Calculation of Constant Harvest Rate (chr)

Method 2.2 of WKLIFEX is the constant harvest rate (chr), also called the F_{proxy} rule or the “Icelandic” rule. It applies a constant harvest rate ($F_{proxy,MSY}$) that is considered a proxy for an MSY harvest rate, and applies this to the biomass index. As per the WKLIFEX (2021) report, advised catch (C_{y+1}) is calculated as follows:

$$C_{y+1} = I_{y-1} \times F_{proxy,MSY} \times b \times m$$

Table 4.6. Definitions of the components used to calculate chr (from WKLIFEX, see table 3.4.2.1 of that report for a full description of how $F_{proxy,MSY}$ is calculated).

Component	Definition	Description and use
I_{y-1}		The index in year *y*−1.
$F_{proxy,MSY}$	$\frac{1}{u}\sum_{y\in U} C_y/I_y$	Is the mean of the ratio C_y/I_y for the set of historical years U for which the quantity *f* > 1, and u is the number of years in the set U. The quantity *f* is the ratio of the mean length in the observed catch that is above the length of first capture relative to the target reference length (mean length/target reference length). The target reference length is $L_{F=M} = 0.75L_c + 0.25L_\infty$, where L_c is defined as length at 50% of modal abundance (ICES, 2018b).
b	$\min\left\{1, \frac{I_{y-1}}{I_{\mathrm{trigger}}}\right\}$	Biomass safeguard. Adjustment to reduce catch when the most recent index data I_{y-1} is less than $I_{trigger} = 1.4I_{loss}$ such that *b* is set equal to $I_{y-1}/I_{\mathrm{trigger}}$. When the most recent index data I_{y-1} is greater than I_{trigger}, *b* is set equal to 1. I_{loss} is generally defined as the lowest observed index value for that stock.
m	[0,1]	Multiplier applied to the harvest control rule to maintain the probability of the biomass declining below B_{lim} to less than 5%. May range from 0 to 1.0.
Stability clause	$min\{max(0.7C_y, C_{y+1}), 1.2C_y\}$	Limits the amount the advised catch can change upwards or downwards between years. The recommended values are +20% and −30%; i.e. the catch would be limited to a 20% increase or a 30% decrease relative to the previous year's advised catch. The stability clause does not apply when *b* < 1.

Target Harvest Rate

The derivation of the target harvest rate, $F_{proxy,MSY}$, from length frequency data requires calculating the target reference length, $L_{F=M}$. Target reference length is calculated using the following equation:

$$L_{F=M} = (0.75 \times Lc_{(y)}) + (0.25 \times L_{inf})$$

where L_c refers to the length at first catch. This calculation assumes that the M/k ratio is equal to 1.5 (ICES 2018). The actual M/k ratio for 6aS7bc herring is 0.649, which is considerably different to the assumed value. ICES Technical Guidelines (2018) state that stock specific M/k values can be applied by using the following alternative $L_{F=M}$ equation from Jardim *et al*. (2015):

$$L_{F=\gamma M, K=\theta M} = \frac{\theta L_\infty + L_c(\gamma + 1)}{\theta + \gamma + 1}.$$

Table 4.7. Estimate of natural mortality (M) used in the exploratory assessments for herring in 6aS, 7bc and various M/k ratio calculations. Most appropriate M/k ratio highlighted in bold.

Age	1	2	3	4	5	6	7	8	9	1 to 9	2 to 9	3 to 6
M	0.528	0.303	0.255	0.225	0.207	0.193	0.186	0.180	0.180	0.251	0.216	0.220
k										0.339	0.339	0.339
M/k										0.740	0.637	0.649

Using the assumed M/k of 1.5 and the best estimate of k, 0.339, implies a natural mortality of 0.51, which differs substantially from that used in the exploratory SAM and ASAP runs: Average for ages 3-6 of 0.22. It was therefore deemed appropriate to use the stock specific M/k and the Jardim *et al*. (2015) equation to calculate $F_{proxy,MSY}$ for herring in 6aS,7bc.

All other calculations followed the WKLIFEX protocols.

Constant Harvest Rate Results

The split survey index is increasing since 2016 and the latest biomass estimate is above the trigger, which is 1.4 times the lowest observed survey biomass (Figure 4.40).

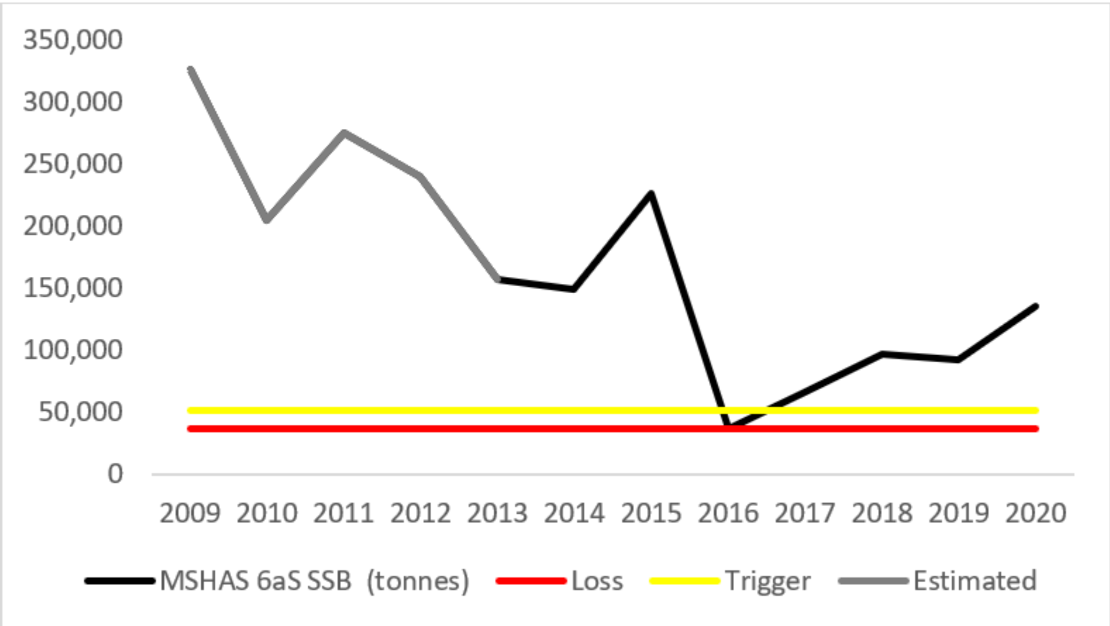


Figure 4.40. MSHAS 6aS Split Spawning Stock Biomass (tonnes) by year. Note: estimated values from 2008-2013 for comparison only; not used in assessment.

$F_{proxyMSY}$ is estimated at 0.034 and the target reference length for the latest year is 25.981cm. Length frequency distribution are presented in Figure 4.41. These values will update for each year of data added to the time-series.

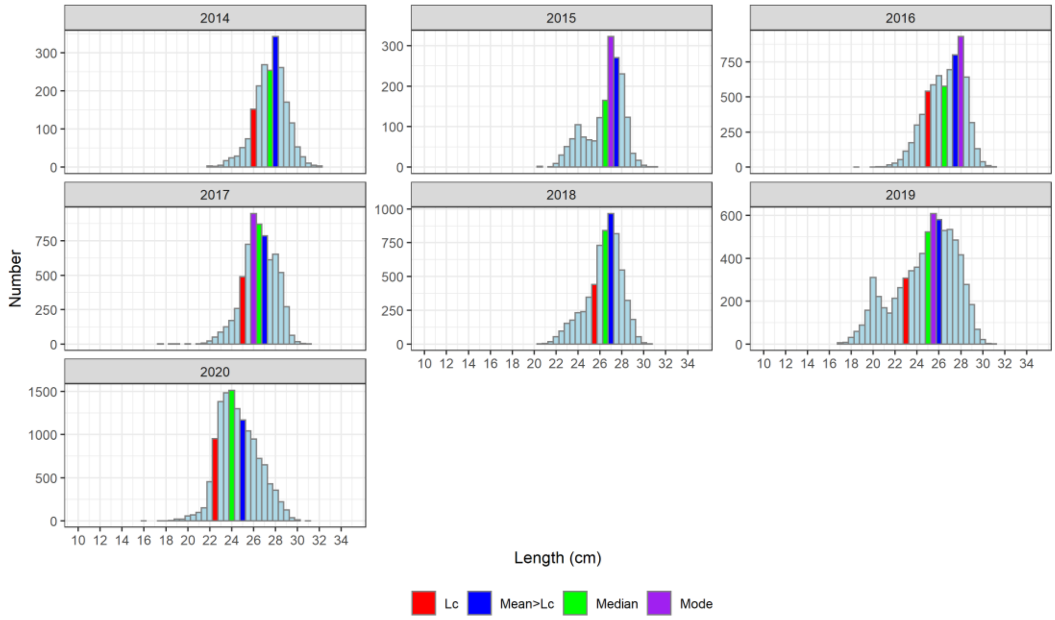


Figure 4.41. Length frequency distributions by year showing length at first capture (Lc), Mean length above Lc (Mean>Lc), the median and the mode from catch sampling data.

The multiplier, m, was set at 0.5 as per WKLIFEX guidelines for this method.

C_y/I_y was below 1 for all years except 2014; Table 4.8 details the constants and calculations used.

Table 4.8. Constants, lengths, survey index and catch data used in the calculation of Fproxy,MSY and target reference lengths.

Year	2014	2015	2016	2017	2018	2019	2020
Catch (t)	5096	1078	2213	2227	1495	1690	1220
Biomass estimates (I)	149 270	226 293	36 707	66 342	96 138	92 364	135 335
modal length in catch L	28.00	27.00	28.00	26.00	27.00	25.50	24.00
L_c (Length of first capture)	26.00	26.50	25.00	25.00	25.50	23.00	22.50
Mean length > L_c in catch	27.996	27.68	27.298	27.006	27.184	26.17	25.03
Target reference length ($L_{F=\gamma M,\ k=\theta M}$)	27.958	28.241	27.393	27.393	27.676	26.264	25.981
f	1.001	0.98	0.996	0.986	0.982	0.996	0.963
C_y / I_y where f > 1	0.034						
$F_{proxy,MSY}$	0.034						
L_∞	30.50						
M	0.220						
k	0.339						
γ	1.000						
θ (=k/M)	1.541						

Notes

Catch (t)	**Catch from 6aS7bc only**
Biomass estimates (I)	**MSHAS split 6aS7bc SSB**
modal length in catch L	**L = modal abundance (ICES, 2018).**
Lc	**Length of first capture = length at 50% of modal abundance (ICES,2018)**
Mean length > Lc in catch	**mean length (Ly-1) in the observed catch that is above the length of first capture relative to the target reference length (mean length/target reference length).**
Target reference length	**LF=γM, k= θM using Jardim et al. (2015) equation (see text)**
f	**The quantity f is the ratio of the mean length in the observed catch that is above the length of first capture relative to the target reference length (mean length/target reference length).**
Cy / Iy where f > 1	**Is the ratio Cy/Iy for the set of historical years U for which the quantity f > 1, and u is the number of years in the set.**
Fproxy,MSY	**Is the mean of the ratio Cy/Iy for the set of historical years U for which the quantity f > 1, and u is the number of years in the set.**
L∞	**L infinity estimated from catch sampled length data**
M	**Mean natural mortality ages 3-6**
k	**von Bertalannfy growth parameter estimated from catch sampled length data**
γ	**Gamma set to 1**
θ	**Theta =k/M**

Stability Clause

A stability clause constraining the change in advised catch to -30% or +20% is also included. ICES guidelines state the mean of the previous 3 years' catch should be used when calculating the stability clause for the first time, which in this case is appropriate given the uptake of the monitoring quota in those years. It was agreed at WKNSCS that the most appropriate starting value would be the average catch in the past three years (ICES 2021).

Summary

Category 3 method 2.2 chr rule using a stock specific M/k value was recommended by the benchmark group. Table 4.9 presents an example summary table and resultant advice based on a chr using length, survey and catch data from 2014 – 2020 (inclusive). Note that $F_{proxy,MSY}$ can change with each year of additional data. In conjunction with herring in 6aN, implementation of these calculations in R is being developed and will be uploaded to TAF.

Table 4.9. Example chr summary table and advice using length, survey and catch data from 2014 – 2020 (inclusive).

$Catch_{y-1}$ (mean of last 3 years catch)	1468 t
$Index_{y-1}$ (survey SSB)	135 335 t
$F_{proxy,MSY}$	0.034
b (biomass safeguard)	1
m (multiplier)	0.5
chr ($C_{y+1} = I_{y-1} \times F_{proxy,MSY} \times b \times m$)	2310 t
% Change (from previous 3yr catch)	+57%
Stability Clause Applied (-30% or +20%)	1,762 t
Advised Catch $_{y+1}$	1,762 t

4.5 Appropriate Reference Points

$F_{proxyMSY}$ is estimated at 0.034 for the years 2014-2020 (inclusive) and the target reference length for the latest year is 25.981 cm. These values will update for each year of data added to the time-series.

4.6 Future Research and data requirements

Although the her.27.6aS7bc stock assessment did not reach the required standard for a category 1 assessment on this occasion, significant improvements have been made since the last benchmark that have increased the understanding of the stock and should lay the groundwork for a higher category assessment in the future. Recommendations for future research and data requirements are outlined below.

Split Acoustic Survey

The genetically split MSHAS 6aS7bc abundance and biomass estimates for 2014-2020 (incl.) provide the most reliable index for this stock. Continuation of the genetic analysis of the survey is fundamental to the separate assessment of herring stocks in 6a. Specific recommendation to continue and improve the splitting work include:

- Genetic analysis of the MSHAS samples should be continued annually using at least the established 45 SNP panel detailed in Farrell *et al.* (2021).
- New baseline samples should be collected annually if possible and analysed at least with the established 45 SNP panel detailed in Farrell *et al.* (2021). Particular attention should be paid to building up the baseline samples of late spawning 6.a.S and the spring spawning 6aN fish.
- The assignment model should be updated regularly to incorporate new baseline samples. If the discrimination between the late spawning 6.a.S and 6.a.N spring groups is improved then the MSHAS samples should be re-analysed to reduce the number of assignments to the mixed 6aS/6aN_Sp group.
- The genetic assignment methods employed to update the baseline assignment model and to assign mixed survey and commercial samples should take account of further development of the genetic marker panel. In 2022 a new Axiom Array (SNP chip) comprising c.20,000 informative SNPs identified during the GENSINC project will become available. Widescale application of this tool would enable the development of a genetic assignment model incorporating all known populations of Atlantic Herring.

Catch Data

Since the introduction of the monitoring TAC for both 6a herring stocks in 2016, catches have been relatively easy to assign to their population of origin due to their location and timing, *e.g.* 6aS7bc catches mostly in winter in close proximity to spawning grounds around north-west Ireland. As the stocks rebuild and TACs increase however, fishing effort is likely to once again expand onto the Malin Shelf and mixed catches become an issue. Therefore, the genetic stock ID technique should also be applied to commercial catch samples. This should happen as soon as practically possible to maximize the number of years in the split catch time-series. An analysis of the appropriate catch sampling rate will be required.

Other Survey Indices

An IBTS Q4 index has been developed for 6aS7bc using a GAM based Delta LogNormal model (as for the combined 6a7bc assessment). While it was not appropriate to include this index in the final chr calculation for this stock, the fact that the series begins in 2003 means it could be an important element to include in future analytical assessments at the next benchmark.

Since the last benchmark of herring in 6a7bc a new Industry/Science acoustic survey of pre-spawning aggregations has also been developed. As this survey occurs when at a time of year when the stocks are separated geographically for spawning there is little need for stock ID methods. The time-series is relatively short and the methodology has been evolving so the index was ultimately not included. However, with four or five more years of data using a consistent survey design, this could prove to an important index of 6aS7bc herring. It may also be the best platform for collecting future baseline spawning samples to inform the genetic split of the large, summer Malin Shelf acoustic survey. Serious consideration should therefore be given to the continuation of the industry/science acoustic survey in 6aS7bc.

Assessment Models

Category 1 assessments were tried using SAM and ASAP. SAM had issues with survey catchability and model convergence as well as with the SSB and F trajectories. ASAP was very sensitive to the assumptions about fishery selectivity. Both models had poor retrospective performance with Mohns Rho values outside acceptable limits. While neither model reached the standard for a category 1 or 2 assessment, significant progress has been made with both approaches showing good promise for the future when more split data (survey and catch) is available.

Overall, there is future potential for an improved 6aS7bc stock assessment that utilizes the full range of data available.

Category 3 Method 2.2. chr

For the recommended Category 3 constant harvest rate it is vitally important to continue the genetic split of the MSHAS (including gradual improvements outlined above) and to accurately assign catches of herring in 6a to their respective populations of origin. Further work to understand the different k value obtained from the split MSHAS length data is also warranted.

4.7 External Reviewers Comments

The comments presented below are from experts involved in WKLIFE who reviewed this work after the benchmark meeting.

General comments

The chr rule ("constant harvest rate rule") was applied to her.27.6aN and her.27.6aS7bc following the draft guidelines of Annex 3 of ICES (2020). This short review is based on two working documents and Excel spreadsheets with calculations, one for each stock.

The general form of the chr rule is:

$$A_{y+1} = I_{y-1}\, F_{\text{proxy MSY}}\, b\, m,$$

where A_{y+1} is the new catch advice, based on multiplying the most recent biomass index value I_{y-1} with a target harvest rate $F_{\text{proxy MSY}}$, a biomass safeguard b reducing the catch advice when the biomass index falls below a trigger value (I_{trigger}), and a precautionary multiplier m (set generically to $m = 0.5$ in the absence of stock-specific simulations) to ensure long-term precautionary exploitation, and in combination with an uncertainty cap, restricting changes in catch advice relative to the previous catch advice (+20%/-30%).

Biomass index

The application of the chr relies on an abundance of stock biomass. An acoustic survey is used for both stocks and this is likely to be appropriate because the acoustic survey should cover the entire stock biomass.

It would be useful to have a description of the survey index and how the biomass value used in the chr rule is derived (raw data or aggregated values at age, is this a total or exploitable biomass index, etc).

Length considerations

For both stocks, the MSY proxy reference length has been estimated according to Appendix A of Jardim et al. (2015):

$$L_{F=\gamma M, K=\theta M} = \frac{\theta L_\infty + L_c(\gamma + 1)}{\theta + \gamma + 1}. \tag{A.3}$$

This requires knowledge about the natural mortality of the stocks, which is stated as $M = 0.22$ for both stocks.

Where does M come from, and if M at age values were used in previous assessments, how were they combined into a single age-independent M?

For both stocks, the length at first capture (L_c) and the MSY proxy length were calculated independently for every year of data. However, if there are no substantial changes in the fishery or selectivity, this might not be necessary, and these values could be defined once (e.g. combining length frequencies from several historical years) and then kept constant. Such an approach could possibly better handle issues with data in certain years or reduce the impact of bimodality in length distributions, e.g. due to large recruitment events.

Herring in 27.6aS7bc

Von Bertalanffy growth parameters

Von Bertalanffy growth parameters were calculated with data from commercial catch sampling. This is a different approach compared to her.27.6aN, for which survey data were used. However, despite the different data sources, the individual growth rate was similar ($k = 0.339$ year^{-1}) and did not cause concerns.

Survey index

Figure 4 in the WD labels the acoustic survey as an SSB index. Is this survey really a spawning stock biomass (i.e. mature individuals only) index and not a total biomass index?

The derivation of index reference levels (I_{loss}, I_{trigger}) appears correct given the provided biomass index values.

Conclusion

The implementation of the chr rule appears appropriate and the elements of the chr rule were calculated correctly.

General considerations

The application of the chr rule currently relies on the biomass index from the year before the assessment year. Depending on the timing of the survey and the availability of the data during the assessment, more recent index data could be used for providing advice.

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5 Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak) - Ple.27.420

5.1 Stock ID and sub-stock structure

No changes were made.

5.2 Issue list

Table 5.10. Issues list, for update, check also https://sid.ices.dk/Manage/rollingissues.aspx

Type	Problem/Aim	Work Required
Assessment method	The current assessment showed strong year and age patterns in both catches and tuning indices	Adjusting the parameters in the current AAP model. Trying other stock assessment models
Assessment method	The current assessment yields high number of plus age, around 40% of total biomass comes from plus age	Validate the model
Tuning series	Age 0 (and to some extent age 1) has been migrating away from shallow coastal DYFS areas to more offshore SNS areas. Additionally, age 1 may have been migrating from SNS areas to even more offshore BTS areas. As a result, indices estimated from each survey individually will not provide the desired complete information on the stock, and may also provide contradictory information. Furthermore, we can no longer assume constant selectivity of each survey across years in assessment. A combined indices is desired.	A combined indices of SNS and DYFS (maybe even with BTS) using delta-gam method.
Tuning series	IBTS-Q3 while not targeting flatfish has got higher weight than BTS in recent years assessment. In the leave-one-out analysis, leaving out IBTS-Q3 indices has led to a 40% reduction in SSB over last 10 years. This implies inconsistencies between BTS and IBTS-Q3 in the last 10 years, possibly changes of catchability, natural mortality or even migration by (subarea) and time	investigate age reading accuracy, methods in borrowing age length key, investigate both survey indices by subarea, checking intra-/inter-survey consistencies. Combined indices
Data to be considered	The catch of plaice has been decreasing in recent years. Fishing industry has been complaining about not able to catch plaice as perceived from TAC. This partly due to a too high TAC being set in the previous few years, giving an over-optimistic perception of stock size. Additionally, spatial fishing effort does not fully match with stock area. Plaice has an unequal age distribution, where the NW-NS of older plaice are under-fished. The Ducth fishery has underwent a 10-year transition of tickler beamtrawler into electrical pulse trawler, leading to a shift of fishing area (towards south), target species (plaice-> sole) and catchability.	spatial temporal patterns in LPUE, possibly compared to spatial temporal exploitable biomass
Biological parameters	The mean stock weight and catch weight used in SSB and catch calculation are individual point estimate per year. The large uncertainties in older ages plus a high abundance of older ages in the current estimated stock could lead to large uncertainties in the estimated total SSB and catches.	sensitivity analysis on using unsmoothed and smoothed weight in SSB and (forecasted) catches. Not done in the benchmark.

Type	Problem/Aim	Work Required
Biological parameters	Plaice has always had an unequal spatial age distribution. The change of climate and (density-dependent) habitat conditions has led to a reduced growth rate in last 20 years. Could this also lead to temporal (also spatial) changes in maturity , sex rate and natural mortality? especially for the older ages around Scottish coast.	estimate maturity,
Stock identity	BTS and IBTS-Q3 surveys showed reduced ability in tracking cohort in roundfish area 3 (Scottish coastal area) in recent years. Given that the targeted fishing intensity is low in that area, it is interesting to see whether plaice could migrate into the west coast of Scotland (Irish sea).	checking survey indices in Irish sea. Tagging studies
Biological reference points		update reference point in benchmark

5.3 Scorecard on data quality

No scorecard evaluation was conducted.

5.4 Multispecies and mixed fisheries issues

No changes were made.

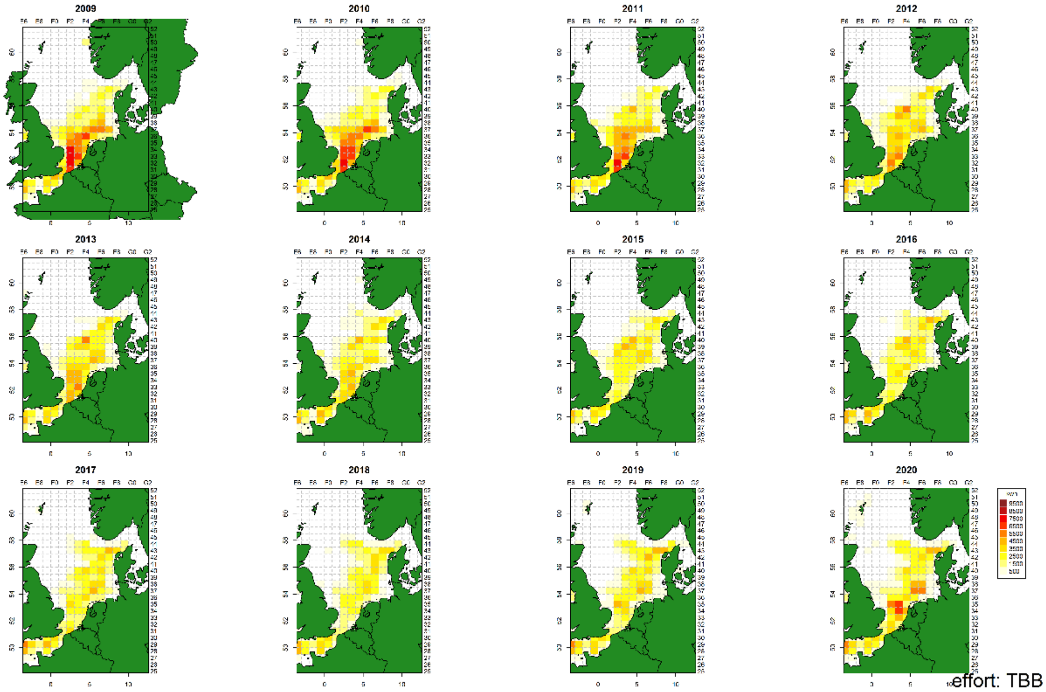
5.5 Ecosystem drivers

No changes were made.

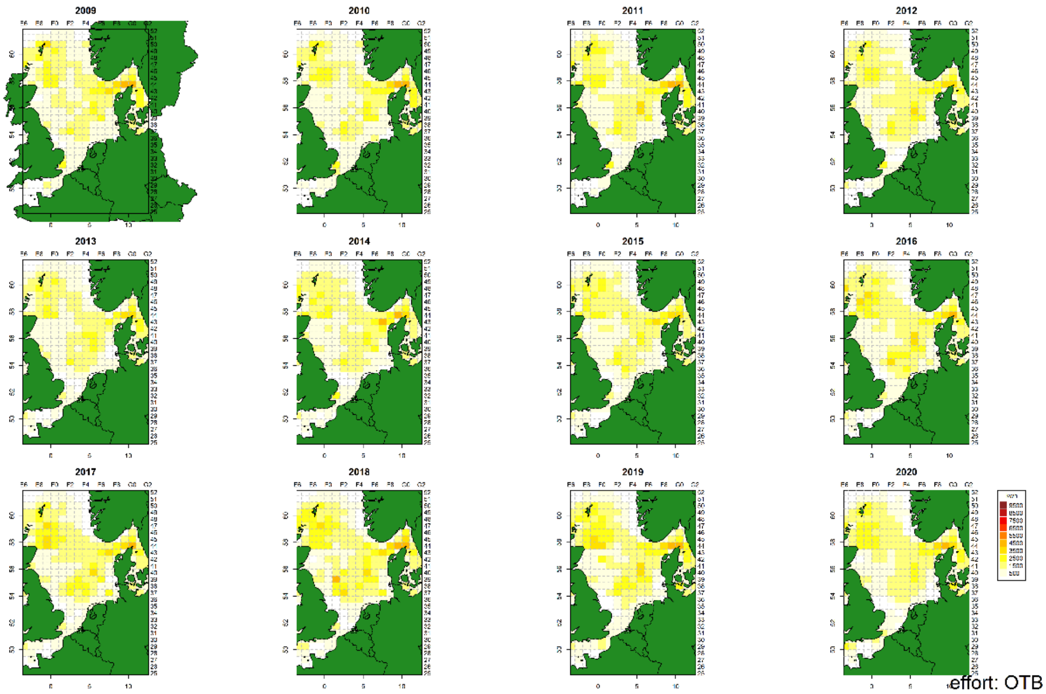
5.6 Stock assessment

5.6.1 Fisheries

Beamtrawler (TBB) and ottertrawler (OTB) are the two major fleets catching plaice. TBB fleets (majority Ducth fisheries) are fishing around the east part of the North Sea (Figure 5.1), while the OTB fleets covers a relatively larger part of NS. 1). Overall the fishing area does not fully cover older aged plaice which are located in the north-west area of the NS (Figure 5.4). This is likely leading to a dome shaped fishing selectivity. 2) Plaice is not the major targeted species: LPUE subarea analysis showed that in subareas where the fisheries had the highest effort does not give highest LPUE of plaice; Some feedback from fisheries are in the east area sole is the targeted species and in the north-west area cod is the targeted species; Although the total fishing efforts remained similar over time, since 2009 Dutch Beamtrawlers have been switching into pulse trawler which facilitates the catch of sole. In 2019 the EU Parliament decided to ban pulse fisheries, and a total ban has been applied since 1 July 2021. The switching of the two gears within beamtrawler fleet are illustrated in Figure 5.2.



(a)



(b)

Figure 5.1. Spatial distribution of annual fishing kwh efforts (2009-2020) for the two major plaice fleets in the North Sea: a) Beamtrawler TBB; b) ottertrawler OTB.

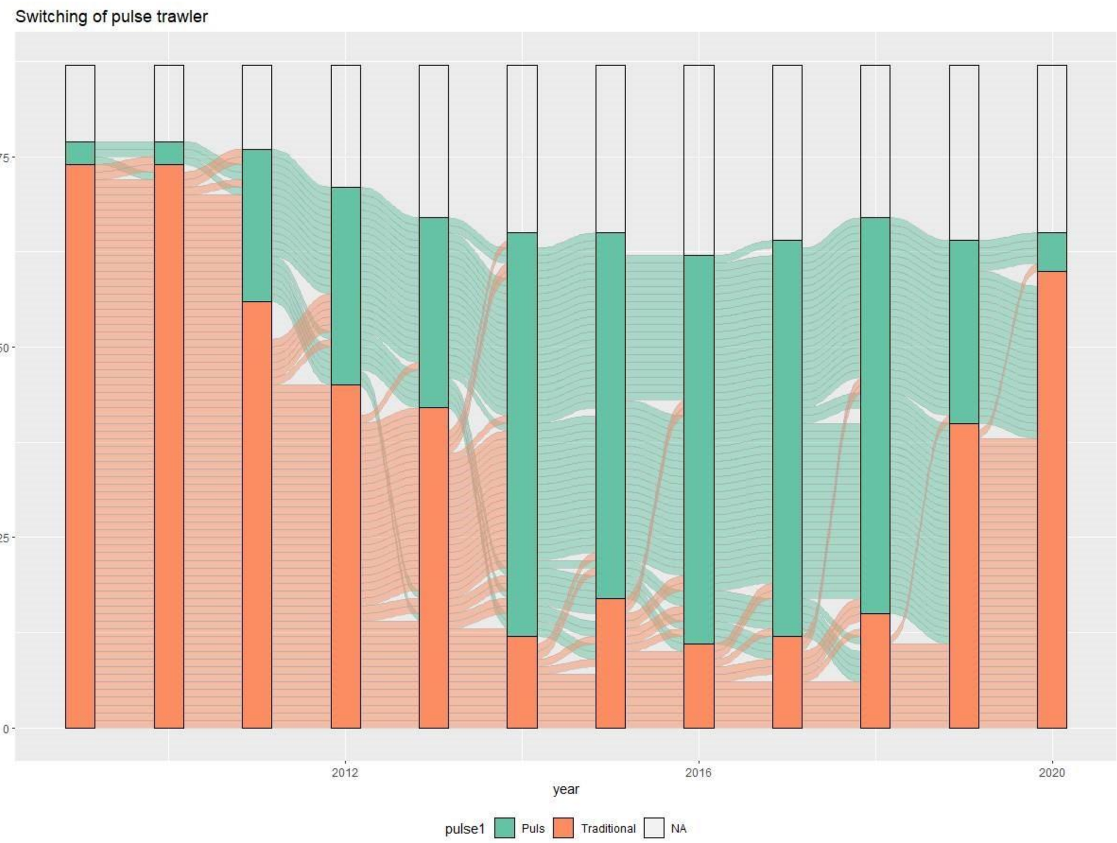


Figure 5.2. Switching between traditional beamtrawler and pulse trawler in Dutch fisheries from 2009 to 2020. Y-axis indicates the number of vessels.

5.6.2 Catch – quality, misreporting, discards

The following updates were made in catch data before benchmark (Table 5.2). None of the major plaice fisheries countries has updated catch data and majority of the changes were converting landing weight by Subarea into Division. The stock coordinator has contacted each national data submitter and concluded that the update has minor impact on the current catch status relating to the assessment issues list. Additionally, re-raising one year of data in Intercatch costs a full working day, due to the combined area and inclusion of plaice 7d. Therefore, the catch data was not updated during this benchmark. Instead, the catch data are expected to be updated when RDBES is applicable.

Table 5.2. Changes made to catch data before benchmark

country	changes
IRE	2003-2004, total less than 1t
SCO	2017-2018 BMS; 2018 raising from length to age composition
BEL	Update of age composition in 2006, 2008, 2011, 2015, 2016 and 2016
ENG	Landing from Subarea into Division
DE	Age composition from Subarea into Division
FRA	Discards raised using new method. French landing contributes to less than 0.5% of total landing.

5.6.3 Surveys

BTS-ISIS early (1985-1995, age 1-8)

No changes were made.

BTS+IBTSQ3 (1996-2020, age 1-10+)

International BTS survey has been the most important survey targeting plaice in the North sea. IBTSQ3, while targeting round fish, has shown high internal consistency in tracking plaice cohort and high correlation with BTS, thus it has been introduced in plaice assessment since last benchmark. During this benchmark, a combined indices was calculated using delta-GAM method (Berg *et al*., 2014). This compensates the incomplete spatial/age coverage of an individual survey and the different catchability of survey gears. It is known that plaice has age-specific spatial distribution, therefore time-varying spatial random effect was chosen for observed shift of age 1-3. The configuration of the model was:

Year + s(Ship) + s(spatial coordinates,time)+ s(depth)

The model had a time varying spatial effect and a lognormal model P with a cutoff at 0.15 and offset on log swept area.

The estimated indices are illustrated in Figure 5.3. The estimated abundance from age 0 to 10+ in 2020 are illustrated in Figure 5.4.

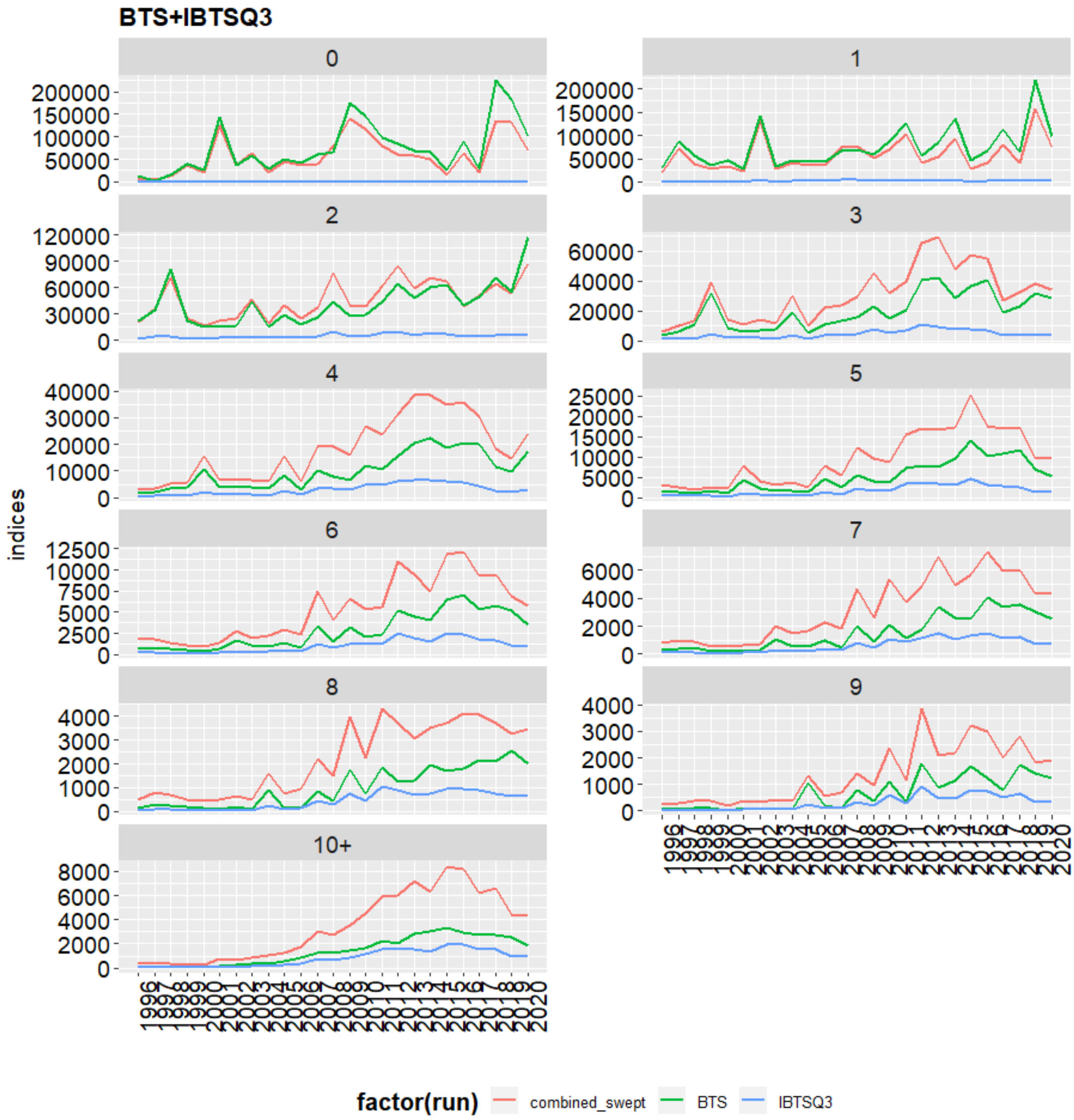


Figure 5.3. Estimated BTS+IBTSQ3 indices.

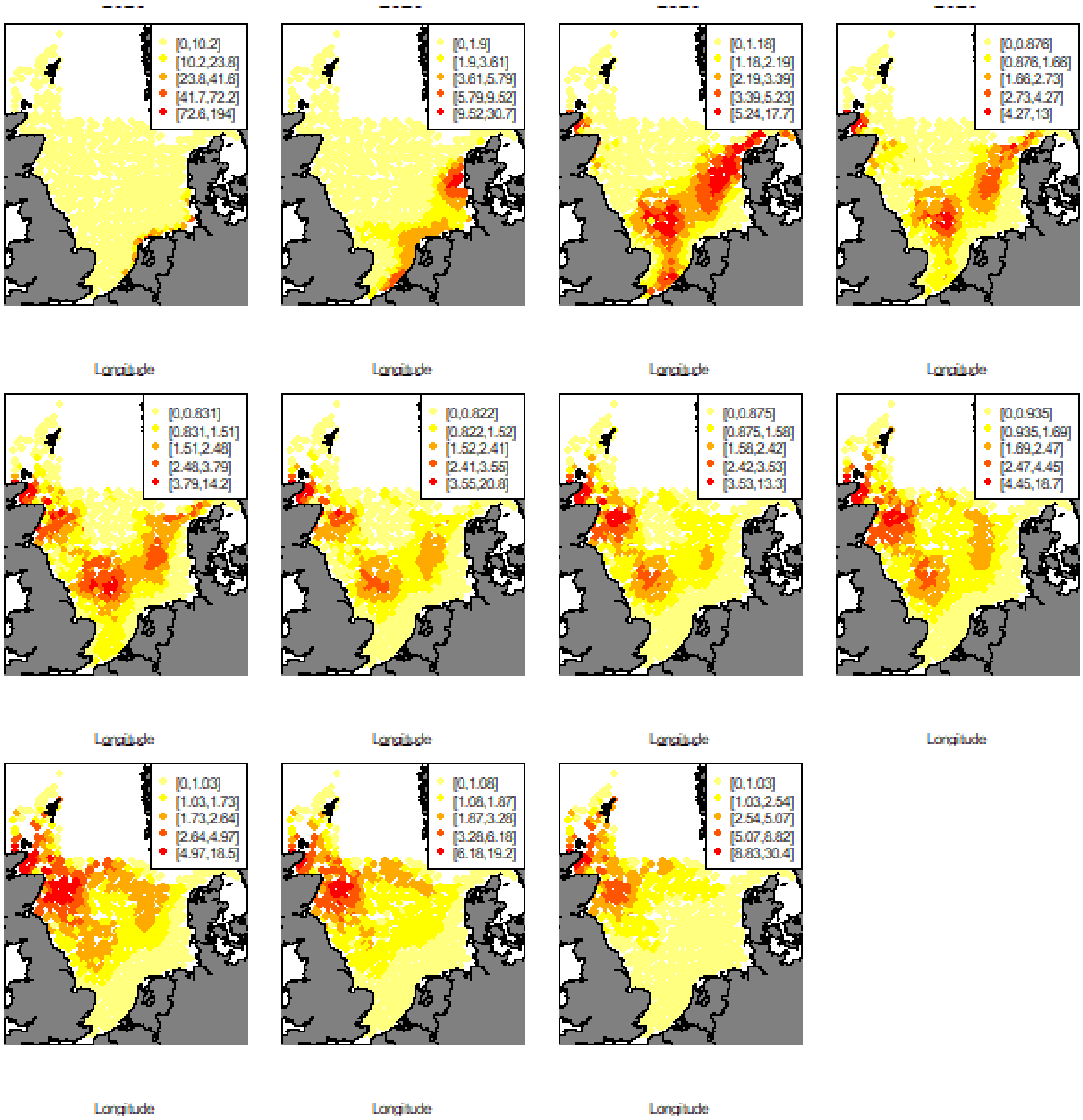


Figure 5.4. Estimated BTS+IBTSQ3 indices in 2020 for age 0 to 10+.

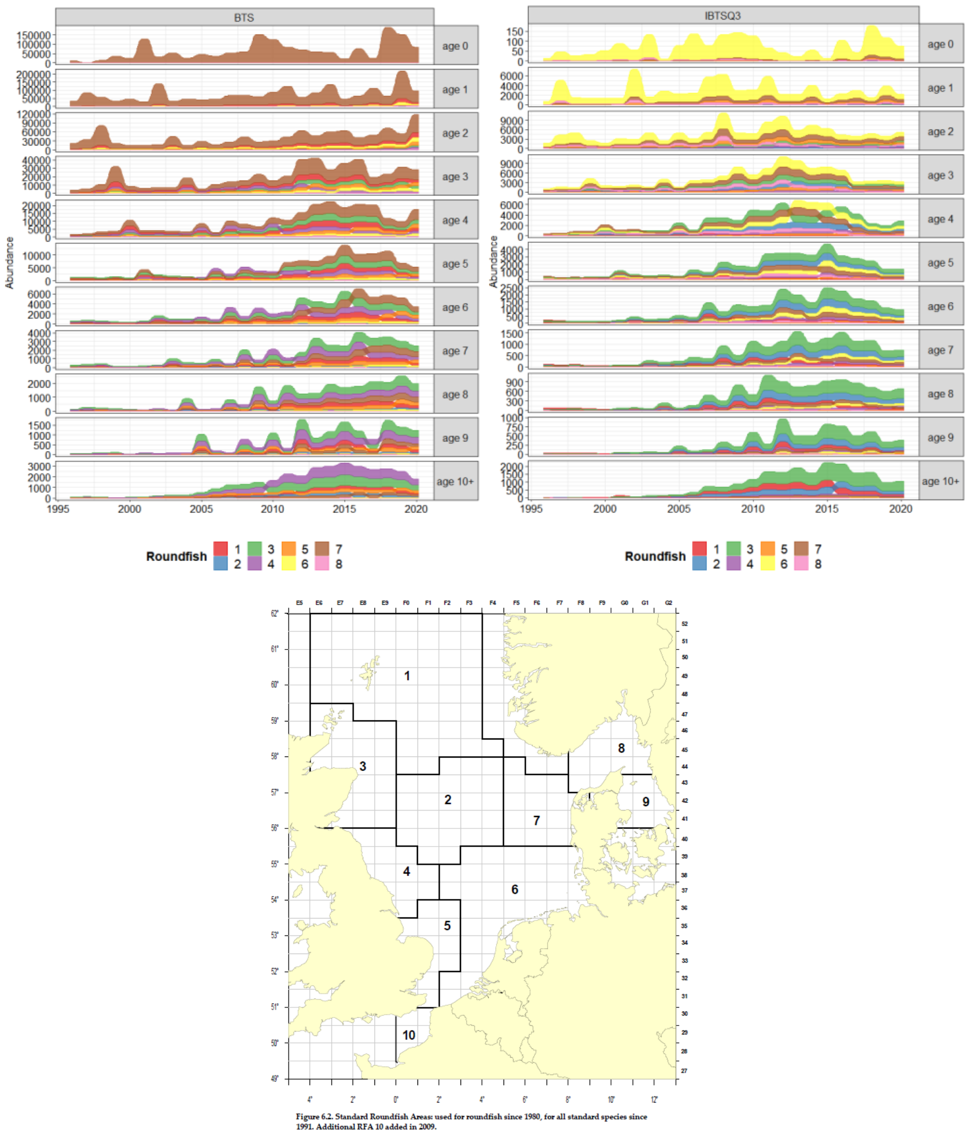


Figure 5.5. Contribution of estimated abundance by round fish area per age for BTS and IBTSQ3

Figure 5.5 illustrates the contribution of estimated abundance by round fish area per age for BTS and IBTSQ3. Although the indices are highly correlated between the 2 surveys, their major contributions of indices comes from different subareas: BTS has a better catchability for age 0-1 in RA6; IBTSQ3 has a better coverage of northern area RA3 where older ages are located. Therefore, a combined index takes advantage of both surveys.

To better quantify the between survey consistency, we computed the Pearson correlation coefficients between BTS-IBTSQ3 and BTS (prior to benchmark) in Figure 5.6. The BTS and IBTSQ3 have shown a reduced correlation (between survey consistency) in 2010-2020. Figure 5.7 shows that the internal consistency for the 3 indices are similar. A reduced internal consistency was observed in last 10 years.

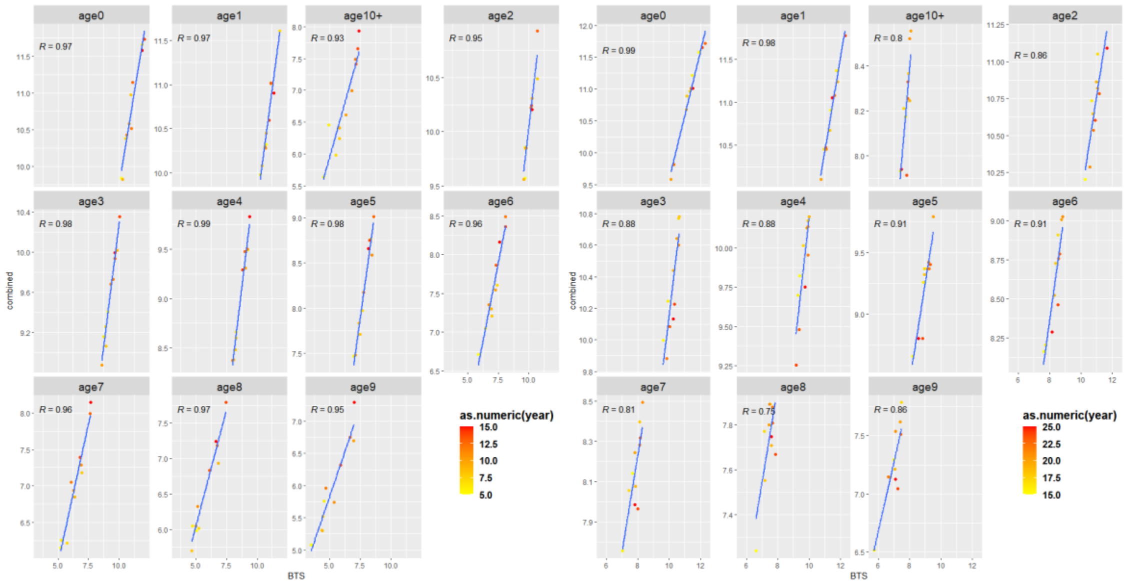


Figure 5.6. Linear correlation between log BTS and log BTS+IBTSQ3 indices in period 2000-2010 (left panel) and period 2010-2020 (right panel).

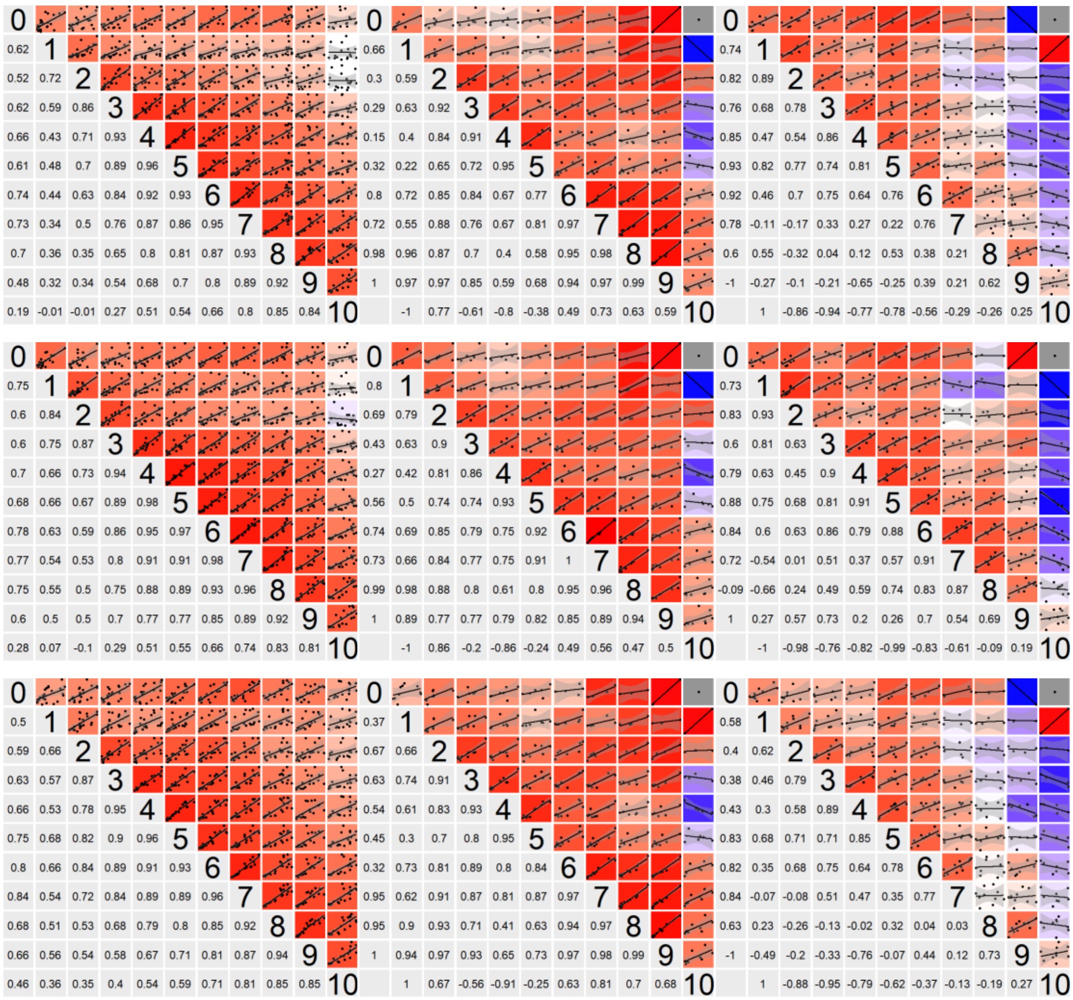


Figure 5.7. Internal consistency of combined indices (1st row), BTS (2nd row) and IBTSQ3 (3rd row), the left, middle and right panels refer to periods 1996-2020, 2000-2010 and 2010-2020.

IBTSQ1 (2007-2020, age 1-8+)

IBTSQ1 (Figure 5.8) index was updated. The configuration of the model was the same as above but without a time variying spatial effect and a cuttoff on log swept area of 0.01 instead of 0.15. The internal consistency is illustrated in Figure 5.9. Details are described in the working document.

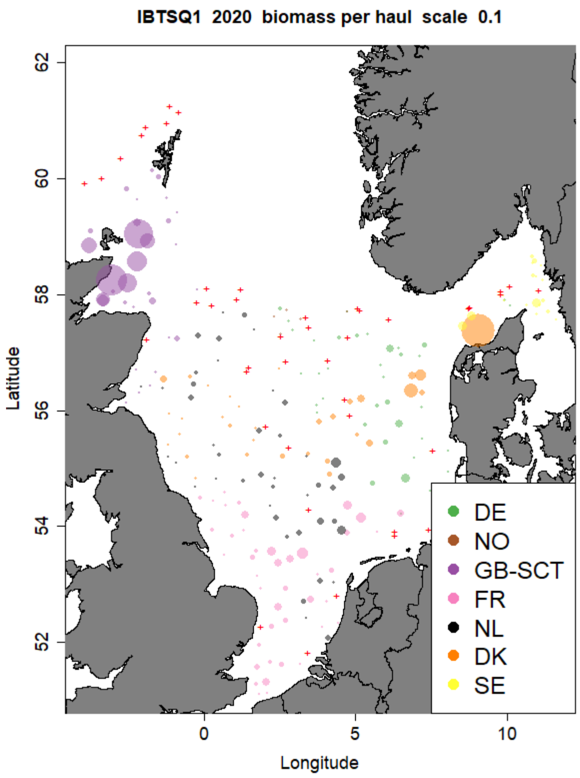


Figure5.8. Spatial distribution of hauls by country in IBTSQ1 in 2020, the size of the bubble is proportional to the square root of the biomass per haul.

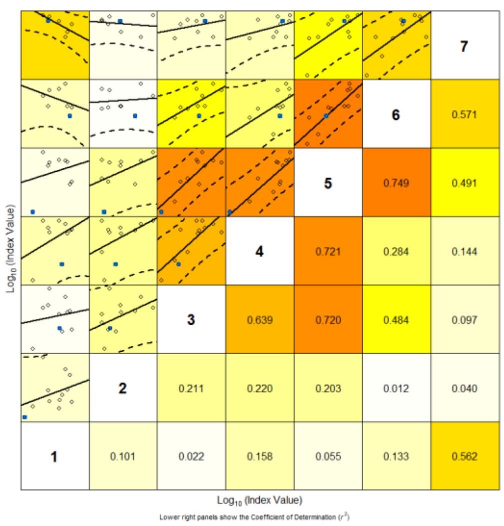


Figure 5.9. Internal consistency of IBTSQ1.

SNS (1970-1999, 2000-2020, age 1-6)

SNS (further from coast, targeting age 1-3) and DYFS (closer to coast, targeting age 0) are the two coastal surveys targeting plaice and sole at young ages (Figure 5.10). It has been observed that age 0 (and to some extent age 1) has been migrating away from shallow coastal DYFS areas to more offshore SNS areas. Additionally, age 1 may have been migrating from SNS areas to even more offshore than BTS areas. During the data compilation workshop (DEWK 2021), attempts were made to calculate delta-gam indices for each survey respectively. The delta-gam model-based indices were consistent to the in-house design based estimators, except for the 2018 large year-class where hotspots were shown in few hauls. Detailed information are described in the working document.

Unfortunately, we were not able to calculate a SNS+DYFS combined indices as desired in issue list, due to the incomplete SNS data in DATRAS format. As a result, the SNS indices prior to the benchmark were continuously being used in the assessment. The internal consistency is illustrated in Figure 5.11.

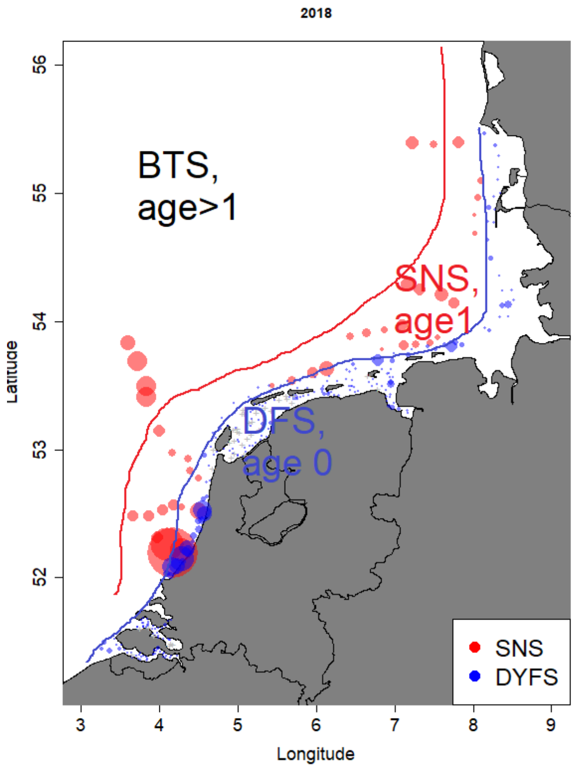


Figure 5.10. Spatial coverage of DYFS, SNS and BTS.

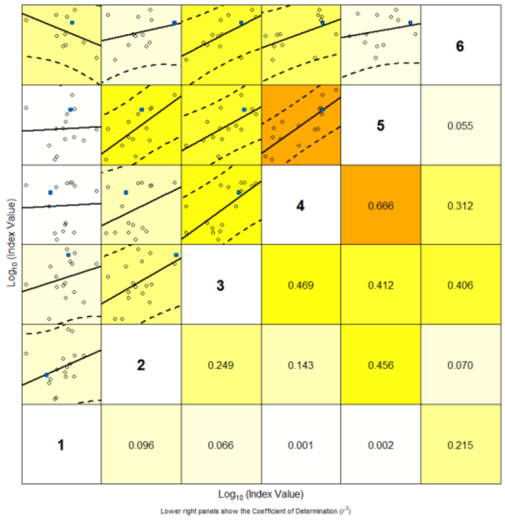


Figure 5.11. Internal consistency of SNS (2000-2020).

DYFS (1990-2020, age 0)

No changes were made. This survey is only used in the short term forecast.

5.6.4 Weights, maturities

No changes to catch, stock, discards weight and maturities were made.

5.6.5 Natural mortality

1. The current estimate for natural mortality (M) is assumed to be 0.1 year-1 for all ages and years. This is based on Beverton back to 1963 and is likely to be outdated.
2. Mean weight and growth rate of age 7+ plaice has been strongly declining in the last 20 years. This was accompanied by a substantial increase of abundance in these older ages, as indicated by the surveys. The older age plaice have been clustered in the north west area of the North Sea, where the fishing mortality was low. The high density and reduced growth is likely to cause an increased M for older ages, due to food competition.
3. Additionally, studies showed that the biggest predator of plaice, seal, has increased consumption of plaice in last 20 years.
4. A sensitivity analysis was conducted by fitting a decent SAM assessment model with varying magnitude of time-age invariant M. The profile of loglikelihood indicates a magnitude around 0.3 of M gives the best fit on the observed data. All these evidences imply that the original fixed 0.1 M might be lower than the actual level of M, and the M of older ages might increase strongly in last few years.

We estimated M using the method of Peterson and Wroblewski (1984), which relies on the allometric relationship between M and body weight:

$$M_W = 1.29 year^{-1} W^{-0.25}$$

The Peterson and Wroblewski estimates (Figure 5.12.a) were consistent with the profile loglikelihood fits from the observed data. During the benchmark, a time-invariant M was also calculated by averaging Peterson-Wroblewski M across years for each age (Figure 5.12.b). It was decided during the benchmark to choose the time-invariant estimates of M for the final assessment.

It was decided in the benchmark that the calculated M per age is kept fixed and not to be updated in future assessment years.

Detailed information are described in the working document.

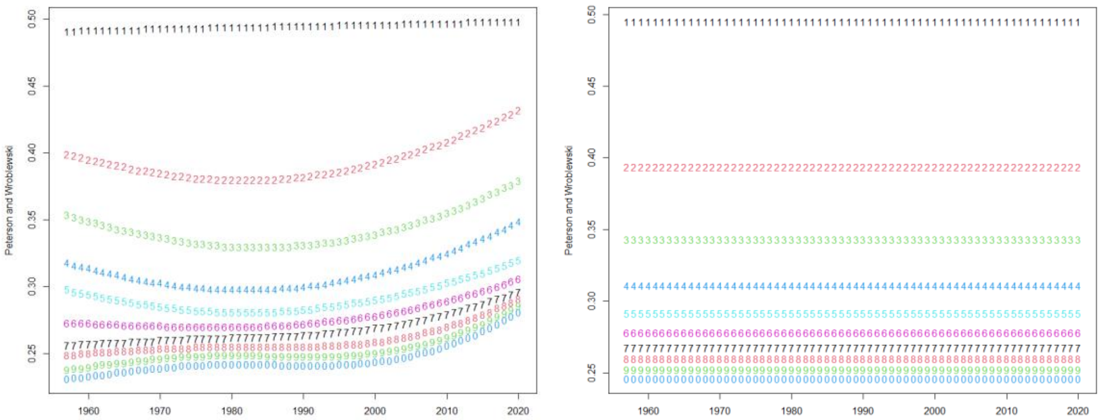


Figure 5.12. (a) Peterson and Wroblewski M computed from smoothed stock weight. (b) Peterson and Wroblewski M averaged over time for each age.

5.6.6 Assessment model

Due to lack of maintenance and flexibility in AAP model, it was decided to directly switch from smoother based AAP model (Aarts and Poos 2009) to state-space SAM model (Nielsen and Berg, 2014).

5.6.6.1 Input data

Table 5.3: survey indices and catch series used to fit the models

type	name	year	age
survey	BTS+IBTSQ3	1996-2020	1-10+
	BTS-Isis early	1985-1995	1-8
	IBTSQ1	2007-2020	1-8+
	SNS1	1970-1999	1-6
	SNS2	2000-2020	1-6
catch		1957-2020	1-10+

Discards in 1957-1999 were reconstructed (Van Keeken *et.al* 2004).

Table 5.4 :Time-invariant Peterson and Wroblewski natural mortality used in model fitting.

1	2	3	4	5	6	7	8	9	10+

0.495	0.394	0.343	0.311	0.292	0.278	0.268	0.260	0.252	0.246

Table 5.5: Proportion mature at the start of the year by age

1	2	3	4	5	6	7	8	9	10+
0	0.5	0.5	1	1	1	1	1	1	1

Both F and M before spawning are zero. Stock weights were estimated as the quarter 1 catch weight obtained from Intercatch.

5.6.6.2 Model tuning and selection process

The quality of survey indices were evaluated using the internal consistency and the between survey correlations. In selecting the best assessment model, we used the following metrics:

1) A low AIC, but not necessarily to be the minimum to avoid overfitting
2) Lower magnitude of observational and (especially) process residual; no residual pattern
3) Robust model towards change of data: no retrospective pattern
4) Robust towards small change of parameters

Prior to the benchmark, assessment model was smoother-based age structured stock assessment, (Aarts and Poos, 2009), while the F-at-age matrix is generated using a tensor spline. Survey catchability at age was modeled as polynomial spline and fixed since age 6. Note that the major issues with this assessment are 1) large number of plus age which needs to be validated and 2) residual patterns in both survey and catches.

We first tried to build a SAM model with similar configurations as the AAP model. SAM showed better ability of following the large drop of fishing mortality since 2000, as a result, the large number of plus ages in the last 10 years has already been substantially decreased. Afterwards, we tried further playing with different parameter configurations in SAM, aiming to resolve the residual patterns, e.g. the age patterns in IBTSQ1 and SNS can be suppressed by assigning AR1 correlated structure across ages. In the meantime, the assessment turned out to be unstable (retro pattern, over-fitting) when the catchability parameters are set to be free for each age. The survey experts have indicated that the catchability should follow a sigmoid shape where older fishes have a constant and little chance of escaping the gear. Therefore, we decided to fix the catchability for BTS+IBTSQ3 survey from age 5. The model then became much more robust, although still with some residual patterns. In the end, we tried to update the assessment using Peterson-Wroblewski natural mortality. The rationales are described in Section 5.4. Both the time-varying and time-invariant Peterson-Wroblewski M has showed significant improvement of the model fitting. Additionally, the two models showed almost no differences in terms of the parameter estimates, and both models do not resolve the residual patterns. Although it is violated the weight based M assumption in Peterson and Wroblewski M, it was decided during the benchmark to use time-invariant estimates of M by age (Figure 5.12.b) by averaging M across years for each age, as there were only very minor differences in SAM model fit between time-variant and time-invariant estimates. In addition, in order to utilize time varying estimates of M, that currently do not have any independent verification methods, it would be important to better explain the factors contributing to M, e.g. via inclusion in the North Sea multispecies model.

5.6.6.3 Final model

The major parameter configurations of the final SAM model is given below.

```
$minAge
1
$maxAge
10
$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 0 1 1 0 0
$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
  0  1  2  3  4  5  6  7  8  8
 -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 -1 -1 -1
 -1 -1 -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).
 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 -1
  0  1  2  3  4  5  6  7 -1 -1
  8  9 10 11 12 12 12 12 12 12
 13 14 15 15 15 15 16 17 -1 -1
 18 19 20 21 22 23 -1 -1 -1 -1
 24 25 26 27 28 29 -1 -1 -1 -1
$keyVarF
# Coupling of process variance parameters for log(F)-process (nomally only first row is used)
  0  1  2  2  2  2  2  3  3  3
$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1 1 1 1 1
$keyVarObs
# Coupling of the variance parameters for the observations.
```

```
 0  1  1  1  1  1  1  2  2  2
 3  4  4  4  4  4  5  5 -1 -1
 6  7  7  7  7  7  7  8  9 10
11 12 12 12 12 12 13 13 -1 -1
14 15 16 17 17 17 -1 -1 -1 -1
18 19 20 21 22 22 -1 -1 -1 -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" "AR" "AR" "AR"
$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).
#1-2 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 NA NA -1 -1
 NA NA NA NA NA NA NA NA NA
 0  0  0  0  0  0  0 -1 -1
 1  1  1  1  1 -1 -1 -1 -1
 2  2  2  2  2 -1 -1 -1 -1
$fbarRange
# lowest and higest age included in Fbar
 2 6
```

The final SAM assessment results are given in Figure 5.13. The model gives a low AIC value. The catch weights are fitted very well (Figure 5.14), which is also indicated by a very low observational variance for catch at age (Figure 5.19). The one-step-ahead observation residuals (Figure 5.15) do not show large residual pattern, except for the negative residuals in of the last 10 years in BTS+IBTSQ3 age 5-10+: The assessment expects to see higher indices of these older ages. These older ages correspond to the North-Western area where the fishing intensity is low, and BTS+IBTSQ3 is the only survey that targets these ages with relatively low sampling effort. In the meantime, there are not sufficient studies on how plaice reacts to high density, low-fishery, and climate change in this area, e.g. natural mortality, growth, and migration. This residual pattern is less likely to be improved by model configurations. Future research should be conducted to investigate the cause. Process residuals are shown in Figure 5.16. Retrospective analysis are illustrated in Figure 5.17.

Fittings of excluded surveys (leave-one-out analysis) are illustrated in Figure 5.18. BTS+IBTSQ3 turns out to be the dominant survey and leaving out other surveys does not make much impact on the assessment. This is also indicated in the survey weights (or SD of observational variance) as shown in Figure 5.19, that BTS+IBTSQ3 obtained the lowest weights in all ages. The result is consistent to the internally consistent BTS+IBTSQ3 age tracking. The AR1 correlation structure increased, to some extent, the SD and suppressed the weight of SNS especially for younger ages.

The estimated stock size, fishing selectivity, survey catchability and the comparison to the WGNSSK2021 assessment using AAP are given in Figure 5.20 to 5.23. Compared to the AAP-WGNSSK21 assessment, the new SAM model gives a better fit to the variable fishing mortality since the end of 1990s. This resulted in a substantially reduced number of plus ages in the new assessment. Additionally, updated M values, with a mean value of 0.31, has led to a upper-scaling of R, and down-scaling of F.

Despite the change of scaling caused by new M values, the new assessment is consistent to the perception of the stock from surveys and fisheries observations. Spatial mismatch of fishing ground has lead to a dome-shaped fishing selectivity as well as a strong increasing trend of older age plaice. The overall fishing mortality (Fbar) was kept low since 2010, likely due to plaice not being the targeted species.

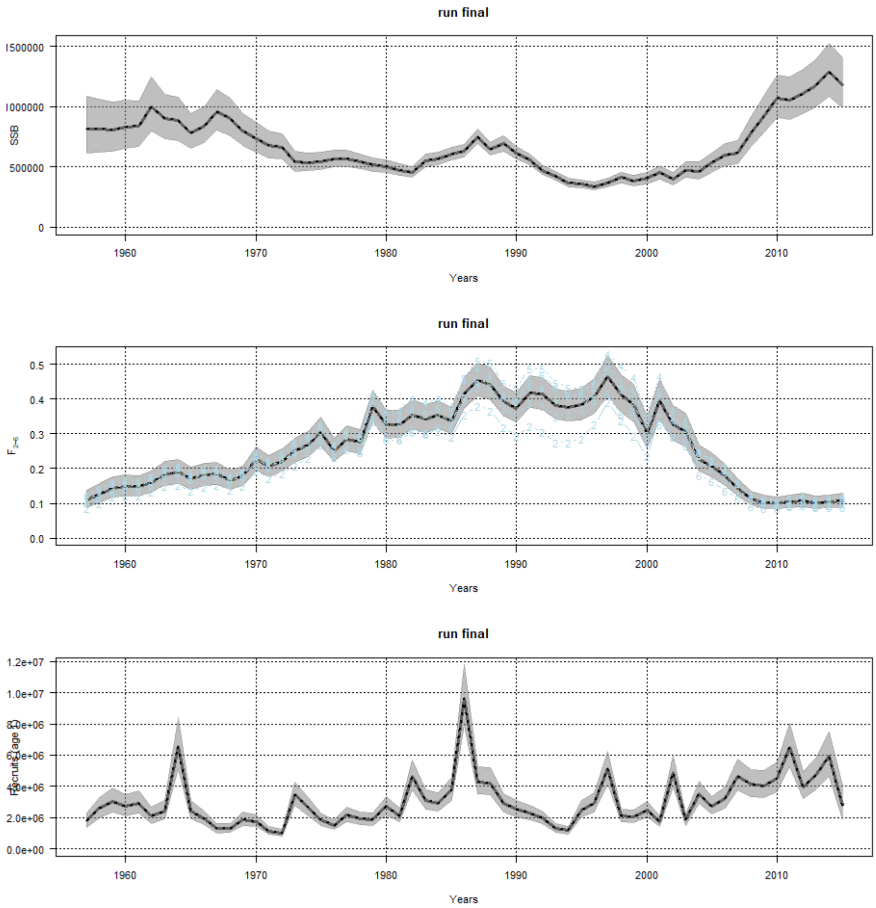


Figure 5.13. Estimated SSB, Fbar and recruitment

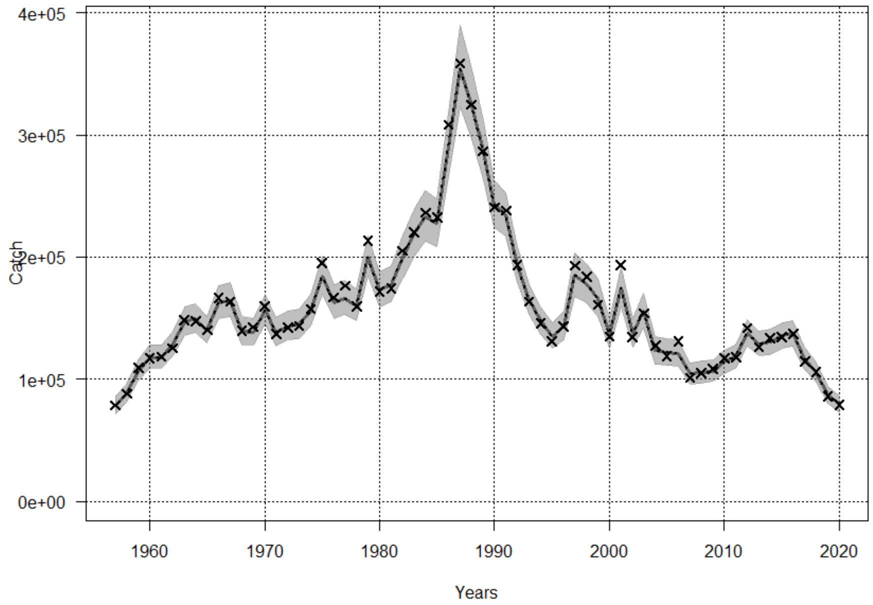


Figure 5.14. Model fit to the observed catch.

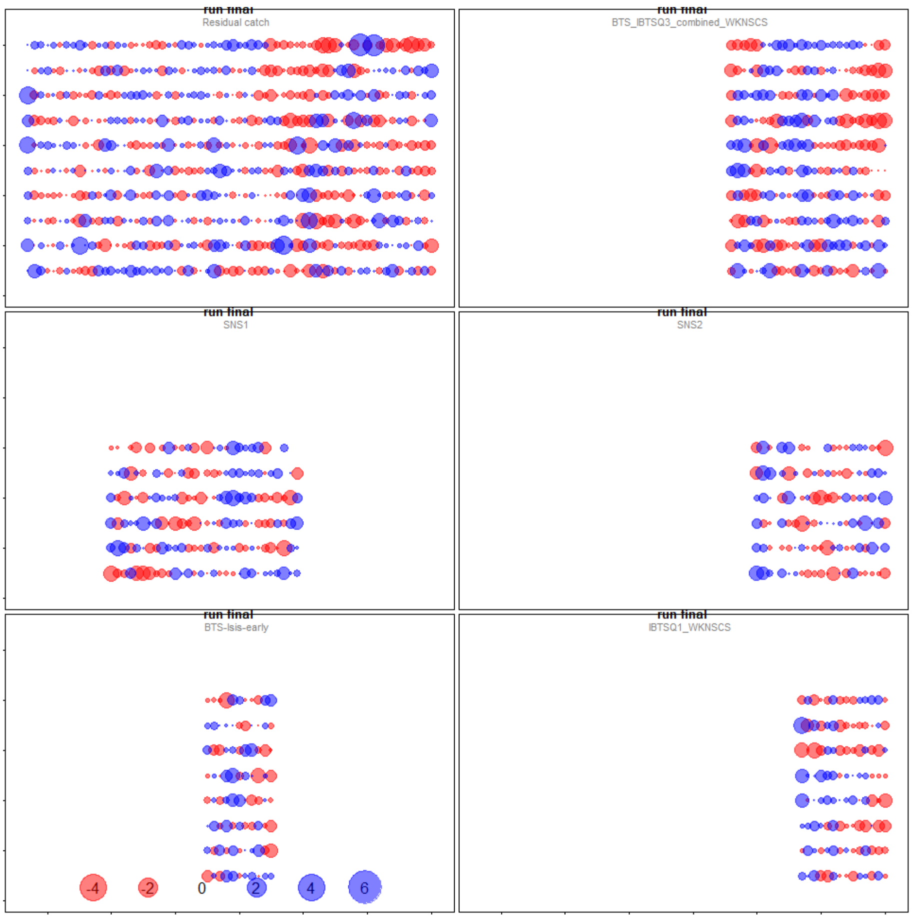


Figure 5.15. Standardized one-step ahead observational residuals.

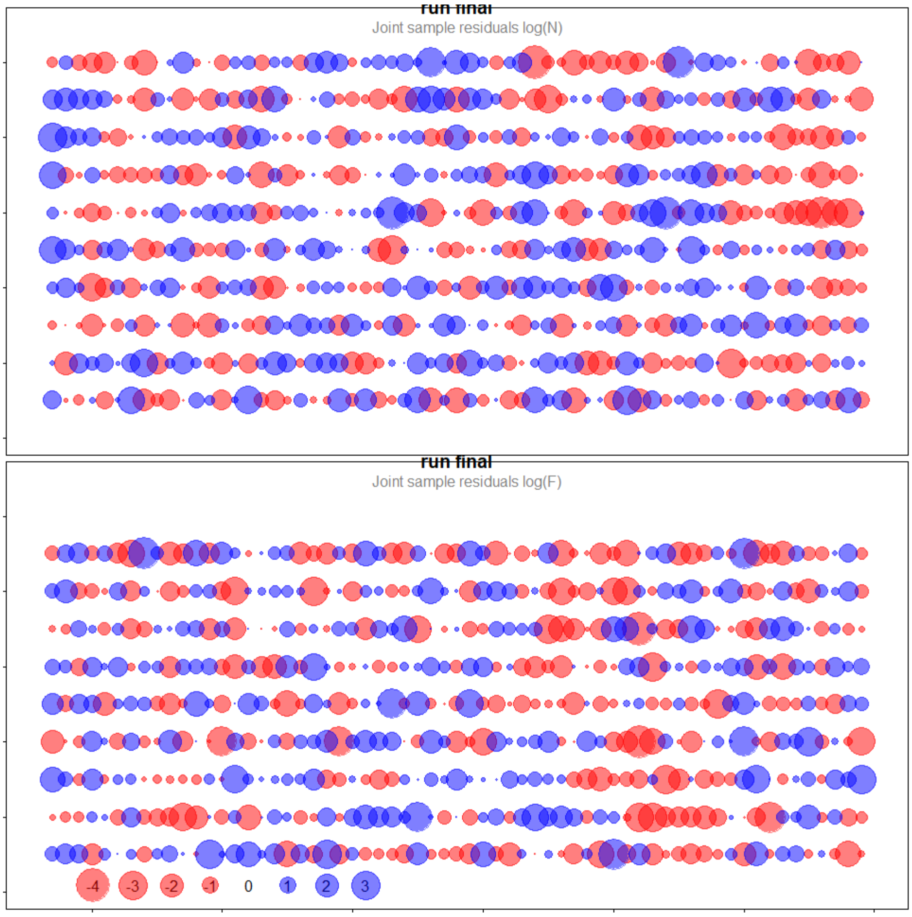


Figure 5.16. Residuals of the fitted model N (top panel) at age (vertical) over time (horizontal) and F (bottom panel) at age.

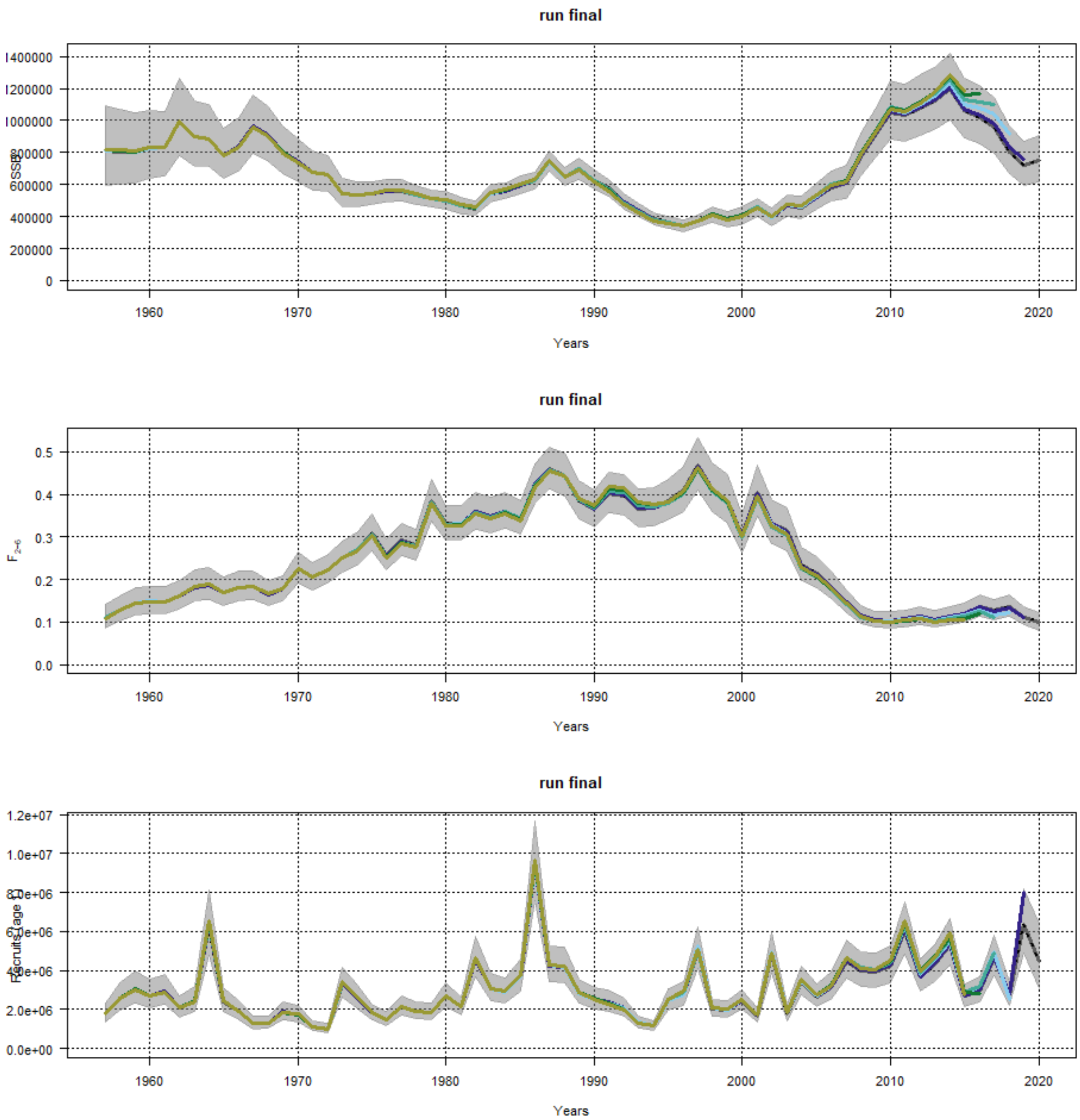


Figure 5.17. Retrospective analysis (up to 5 years) of SSB (upper, Mohn's rho = 0.120), Fbar (middle, Mohn's rho = -0.101), and recruitment (lower, Mohn's rho = 0.042).

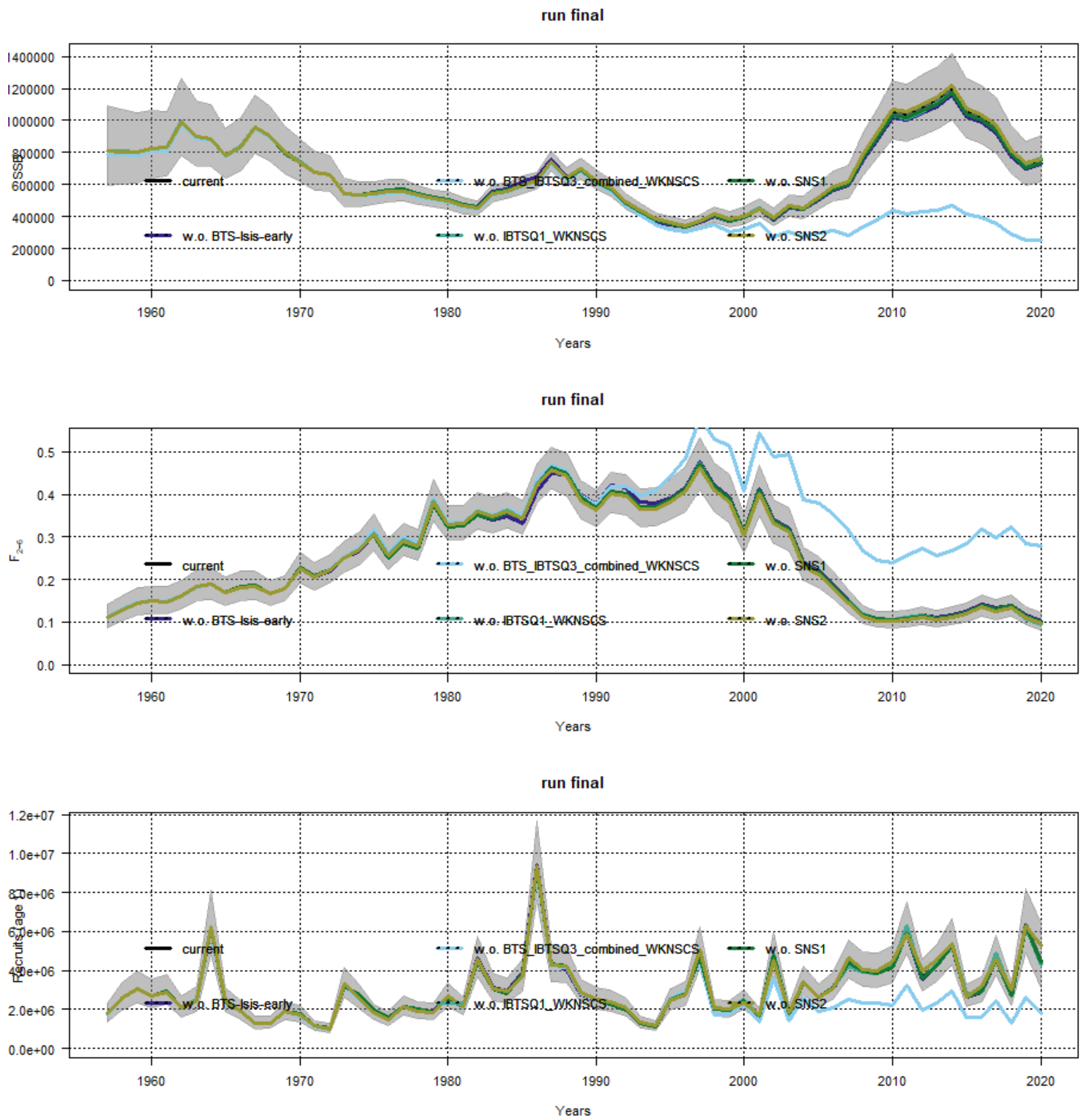


Figure 5.18. Model refits excluding surveys (leave-one-out analysis). The grey band indicates the 95% confidence intervals of the assessment model including all surveys.

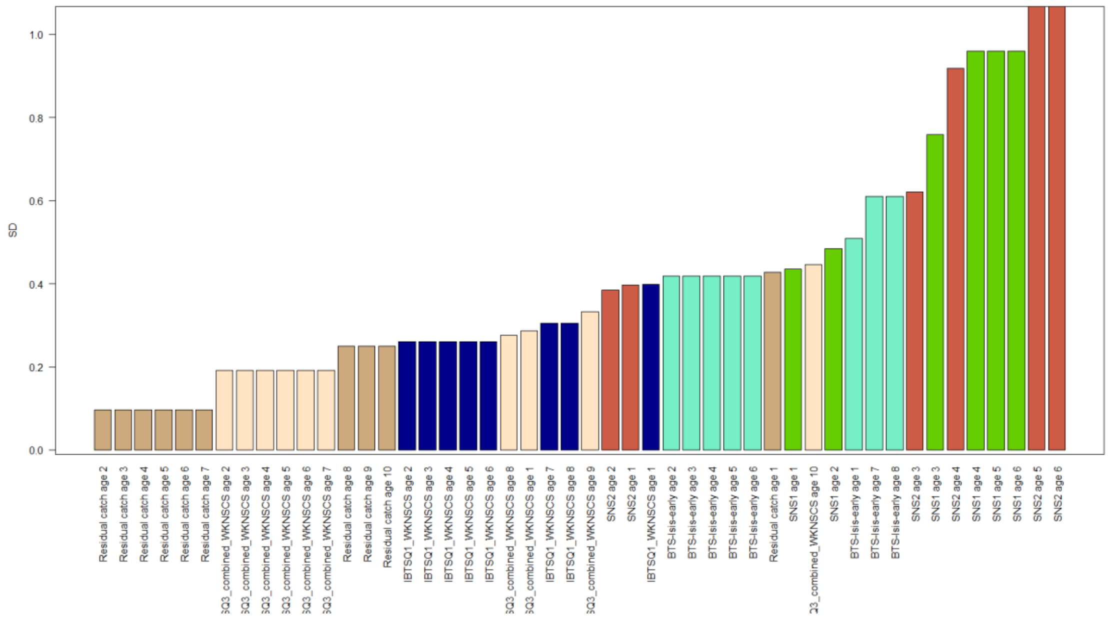


Figure 5.19. Estimated SD of observational error.

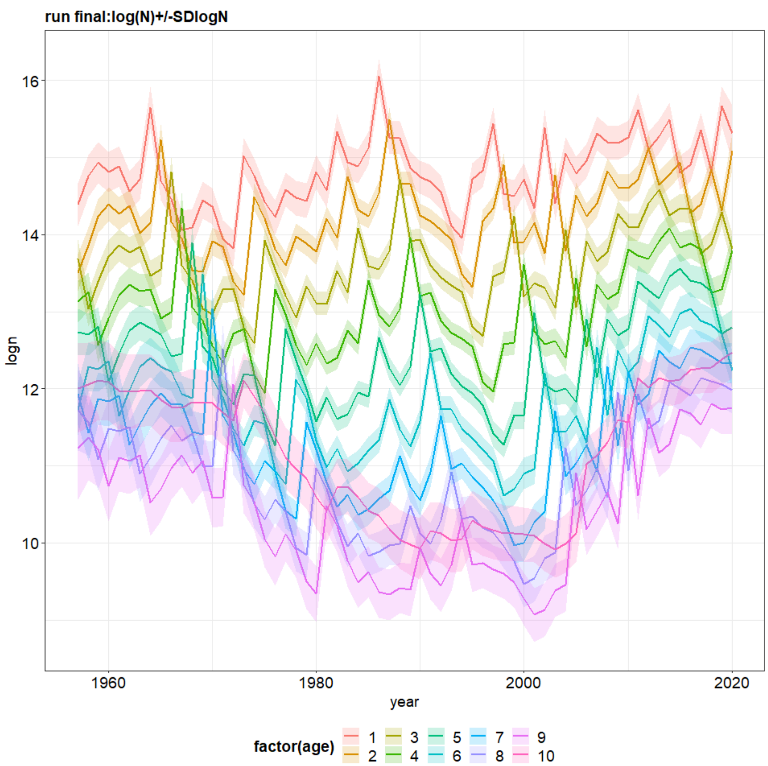


Figure 5.20. Estimated N at age in log scale with +/- SD.

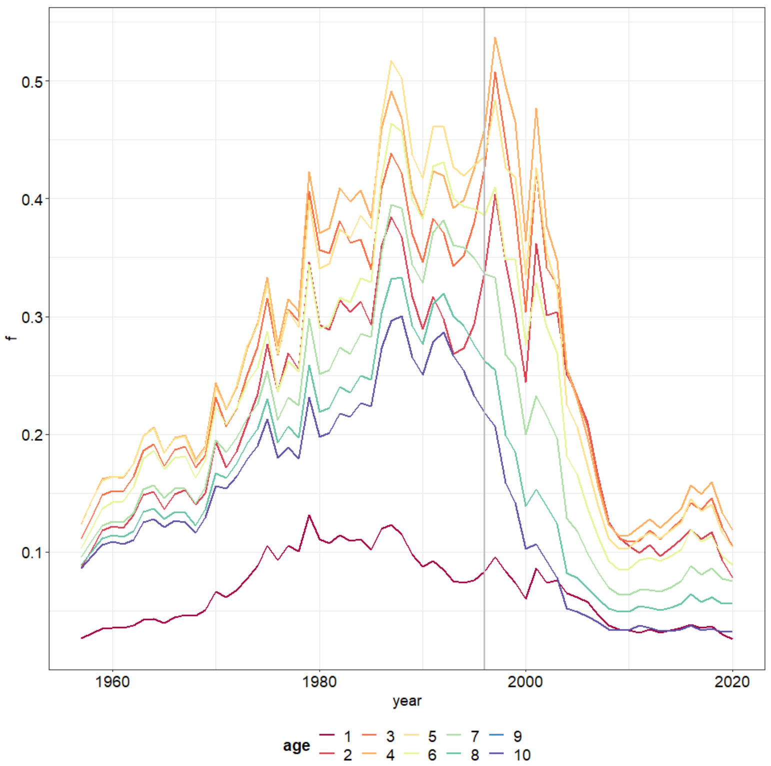


Figure 5.21. Estimated F at age over time.

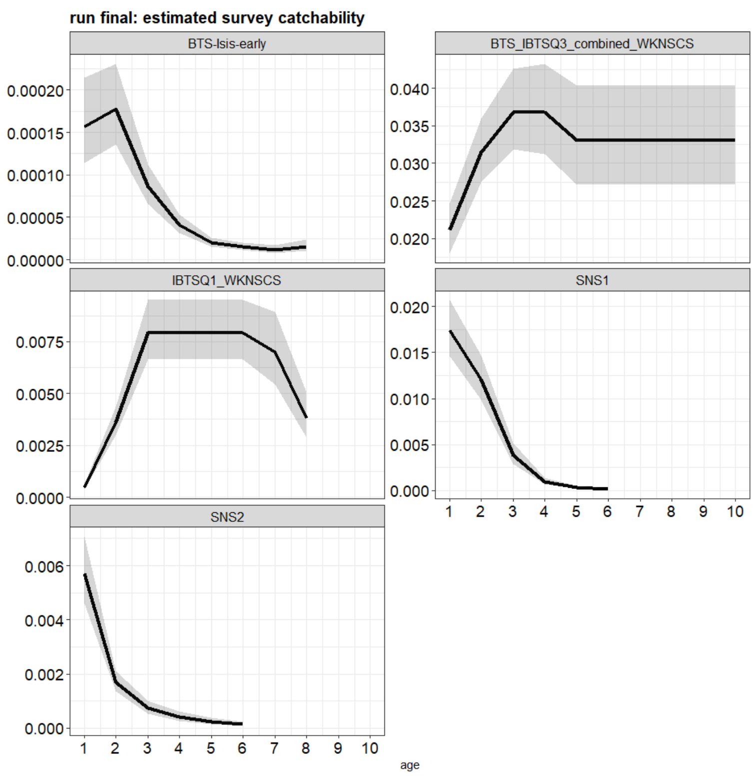


Figure 5.22. Estimated survey catchability.

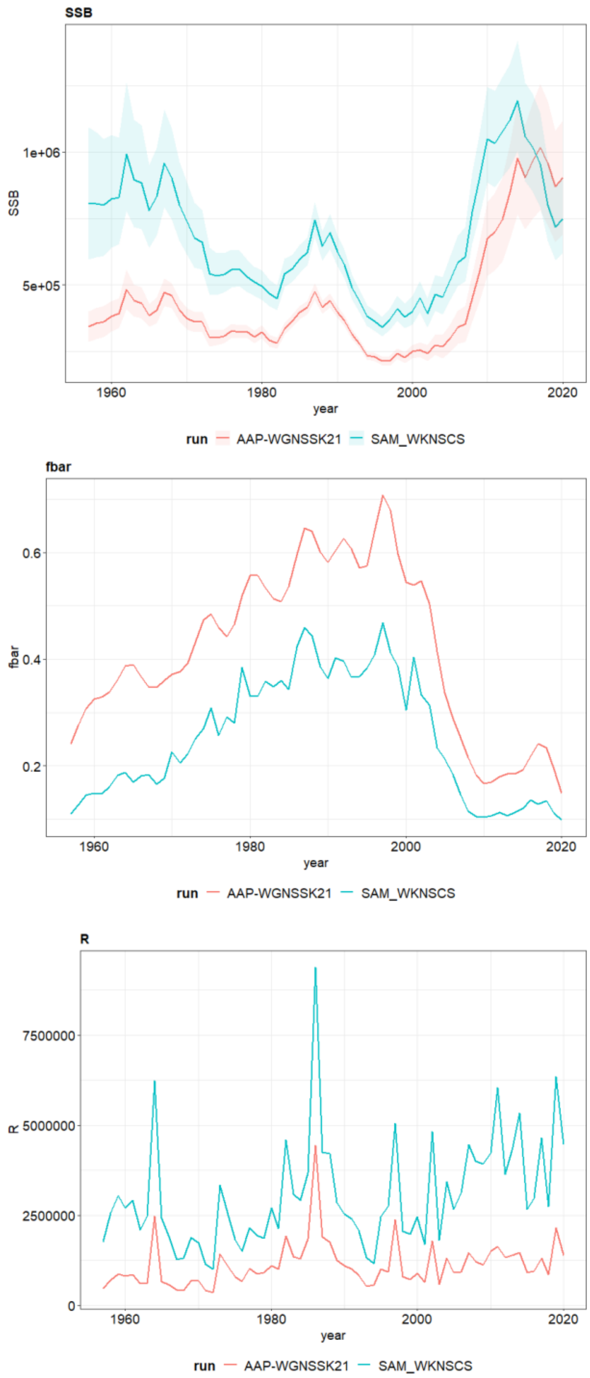


Figure 5.23 Estimates compared to WGNSSK2021 assessment using AAP model for spawning stock biomass (top), fishing mortality (middle) and recruitment (bottom).

5.7 Short term projections

The North sea plaice assessments include subarea 4, Skagerrak 320 and 50% of mature fishes coming from the 1st quarter of 7d, while the catch advice is exclusive of 7d. The solution is to run the short term projection of the entire stock and deduct the advised catch coming from the short term forecast of plaice 7d.

Weight-at-age in the stock and weight-at-age in the catch are taken to be the average over the last 3 years. If no trend of Fbar exists, the exploitation pattern was taken to be the mean value of the last three years; If Fbar shows a trend, the mean the exploitation pattern needs to be re-scaled to the last data year F. The proportion of landings at age was taken to be the mean of the last three years, this proportion was used for the calculation of the discard and human consumption partial fishing mortality.

It is recommended to move from deterministic forecasting into stochastic forecasting, by taking into account of the uncertainties in the parameters, e.g. recruitment in the intermediate year. Both FLR and stockassessment (from SAM) R packages provide such options.

Population numbers at ages 2 and older starting from the intermediate year are survivors from assessment.

For recruitment in the intermediate year, BTS-Q3 survey no longer updates recruitment indices (age 1) during Autumn, thus no re-opening of the advice is needed in Autumn. On the other hand, DYFS targets age 0. Both SNS and BTS survey provide age 0 indices as well. This allows a RCT3 analysis to predict the age 1 recruitment in the intermediate year. An alternative method is to sample with replacement from the log-transformed recruitments (follows a normal distribution) of last 10 years excluding recent 3 years, and take the median value.

Recruitment in the TAC year is estimated by sampling with replacement from the estimated recruitment of the entire time-series.

Table 5.6: assumptions used in the short term projection of SAM fitted model

Variable	Assumption
Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Fixed values, time-invariant
Natural mortality	Fixed values, time-invariant
F and M before spawning	zero
Weight at age in the catch	Average over the last 3 years
Weight at age in the stock	Average over the last 3 years
Exploitation pattern	Average over the last 3 years if no trend of Fbar, otherwise re-scaled to the last data year
Proportion of landing	Average over the last 3 years
Recruitment in intermediate year	RCT3 analysis, or median value from resampling of last 10 years excluding recent 3 years
Recruitment in TAC year	Sampling from the estimated recruitment of the entire time-series

5.8 Appropriate Reference Points (MSY)

Final assessment is named as “plaice_final_10fixIVM” in stockassessment.org.

5.8.1 Data selection

Since 2009, the major Dutch fisheries has been switching from traditional trawler to pulse trawler (Figure 5.2). This has led to a change of target species to sole (and sole area) and changing selectivity for plaice. In 2019, the pulse fisheries has been banned and Dutch fisheries are now in a transition phase to adapt such regulations. It is difficult to predict the selectivity pattern in coming years as the gear, target species and spatial coverage will change correspondingly . Therefore, we decide to use the last 10 years as the default value in eqsim.

There is a strong trend in mean weight and M in last 20 years (Figure 4), so we chose 2018-2020 data for biological parameters in eqsim. The estimates for 2020 recruitment does not have large CI. Therefore, we included all data years for SRR estimation/simulation.

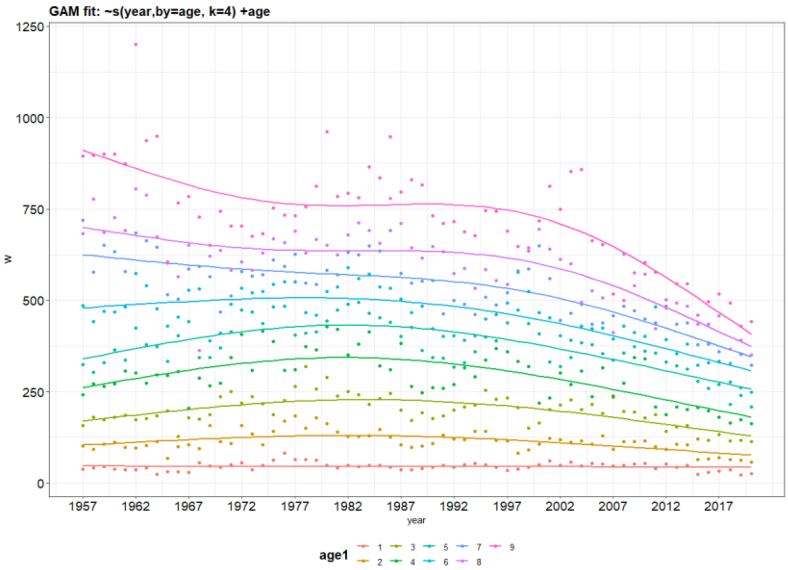


Figure 5.24. Weight at age over time for the stock

```
#### settings -----
Fs <- seq(0, 0.5, length=131)
nsamp <- 10000

# Step 1. data selection----
# USE 5 y for selex and biology: last 3 years
bio.years <- c(2018, 2020)
sel.years <- c(2011, 2020)

# REMOVE no years
# any years of uncertain R estimates?
remove.years <- NULL ## no removed years
## R 2020 estimate is OK, and I dont have R2021
```

5.8.2 Stock size and recruitment relationship

```
srfit00 <- eqsr_fit(ple4, nsamp = nsamp, models = c("Segreg", "Ricker","Bevh
olt"),
                    remove.years=remove.years)
#srfit00$sr.det
eqsr_plot(srfit00)
```

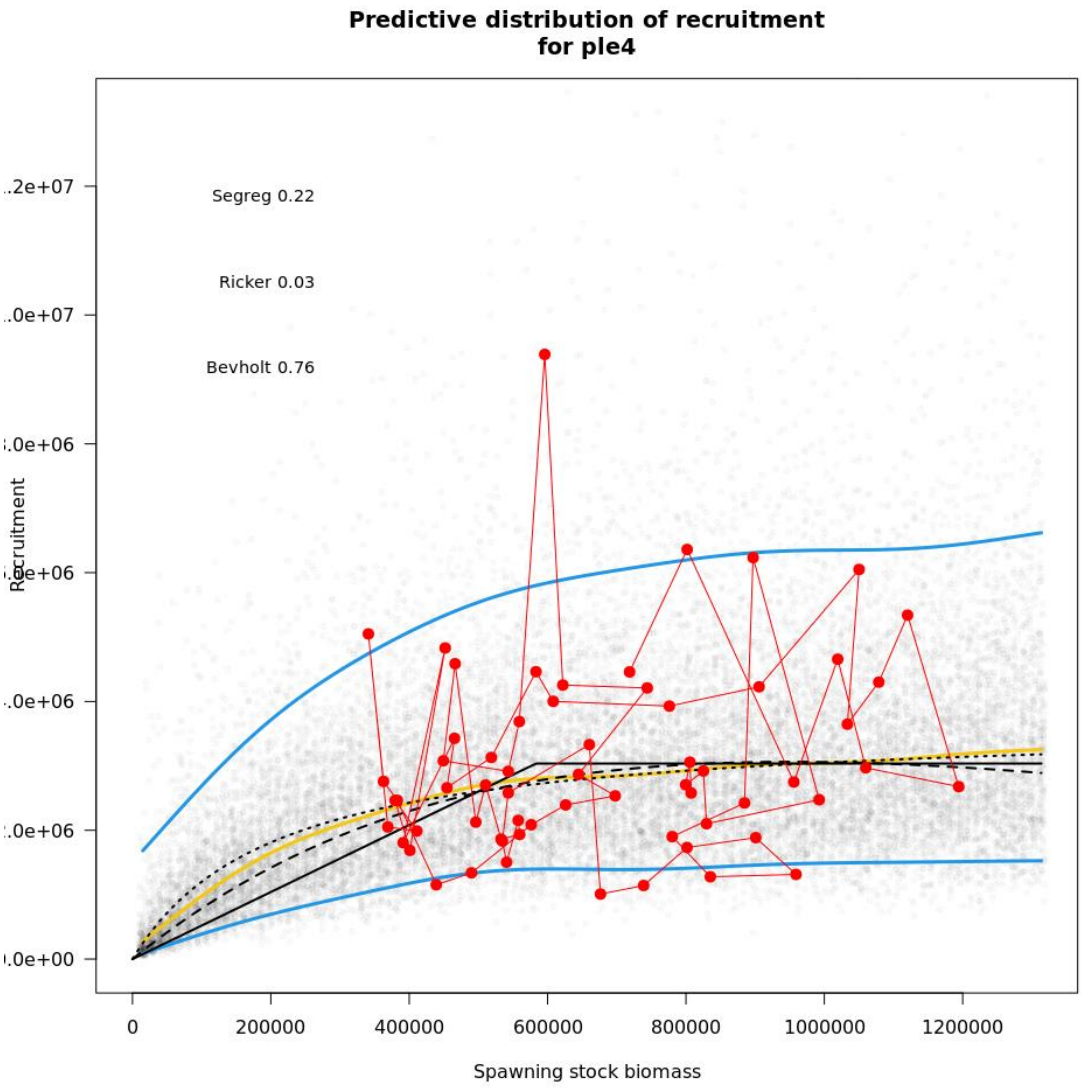


Figure 5.25. Stock recruitment relationship.

```
#eqsr_plot(srfit00,n=2e4,ggPlot=TRUE,Scale=1e3)
#srfit00$rby
```

5.8.3 Biomass limit reference points

```
########## if SSR type 2 ######### not selected
# Step 3. Blim----
# A deterministic biomass limit below which a stock is considered to have re
duced reproductive capacity.
# we do not see impaired recruitment, so SRR is type 5

# if type  2, not selected
#srfitsegreg<- eqsr_fit(ple4, nsamp = nsamp,
#  models = "Segreg", remove.years = remove.years)

#Blimsegreg <- srfitsegreg[["sr.det"]][,"b"]


#eqsr_plot(srfitsegreg)
#abline(v=Blimsegreg)
```

```
########## if SSR type 5 ######### selected!
# Step 3. Blim=Bloss
# we choose type 5
# determine Blim = Bloss
#Bloss should be taken from a stable part of the assessment and should not
# be from recent years if SSB is declining, since this could lead to a decli
ning Blim as the stock declines.
plot(ssb(ple4))
```

```
dimnames(ple4)$year[ssb(ple4)==min(ssb(ple4))]

[1] "1996"

## 1996 is the minimum year
Bloss <- min(ssb(ple4))

BlimBloss <- Bloss

BlimBloss

[1] 341002.7

#cat(paste0("Blim = Bloss = ", Blim,"\n"))

# determine Bpa

# Step 4. Bpa-----
# the 95th percentile of the distribution of the estimated SSB if the true S
SB equals Blim
# PA from sd(ssb)[,2020], too low
#sigma estimated from the assessment uncertainty in SSB in the terminal year
#(sigma is the estimated standard deviation of ln(SSB) in the final assessme
nt
#year). If sigma is unknown, 1.4 can be used as a default for "exp(1.645 × ?
?)", equivalent to sigma = 0.20.

# possible to get it from sam?
SD <- (stockassessment:::tableit(run333_P, "logssb")[,3]-stockassessment:::t
ableit(run333_P, "logssb")[,2])/4
SD[length(SD)]  ## last year, too small, use default value

      2020
0.09487264

# PA from cv=0.2, exp(1.645 * 0.2)
pa  <- exp(1.645 * 0.2)

## choose type 5
Bpa <- BlimBloss * pa
Bpa

[1] 473849.8
```

5.8.4 Fishing mortality reference points

```
####Create the Hockey stick SR with Blim
segreg3 <- function(ab, ssb) log(ifelse(ssb >= BlimBloss, ab$a * BlimBloss,
ab$a * ssb))

# still use SSR segreg to get the SSR
#srfitsegreg <- eqsr_fit(ple4, nsamp = nsamp,
 #                    models = "Segreg", remove.years = remove.years)

#Fit the SR data using only segreg3 model (HS at blim)
srfitsegreg1 <- eqsr_fit(ple4, nsamp = nsamp, models = c("segreg3"),remove.y
ears = remove.years)
eqsr_plot(srfitsegreg1)
```

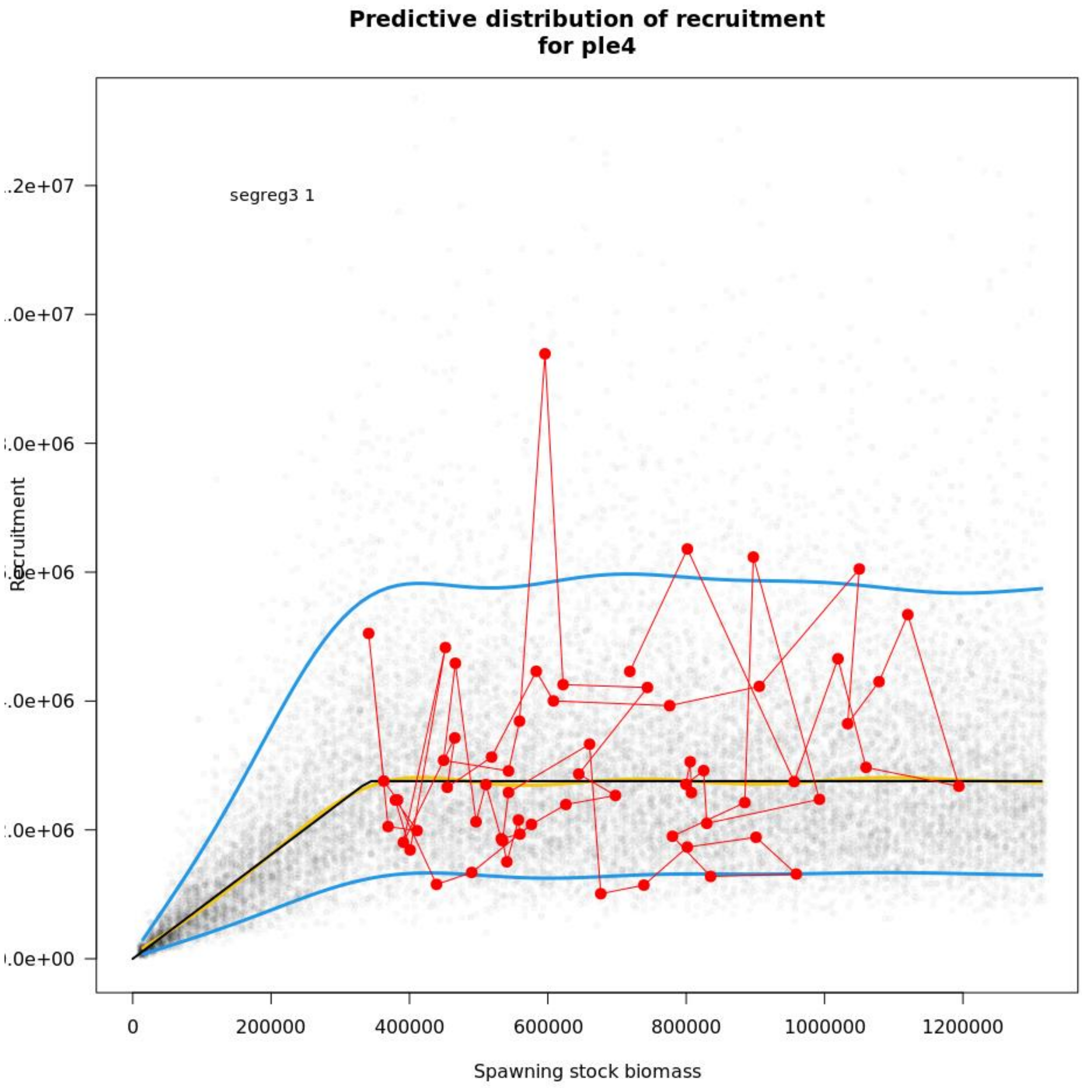


Figure 5.26. Stock recruitment relationship with break point at Blim.

```
srsim1 <- eqsim_run(srfitsegreg1,
  bio.years = bio.years, sel.years = sel.years,bio.const = FALSE,sel.const =
FALSE,
  Fcv = 0, Fphi = 0,
```

```
  Btrigger=0, Blim = BlimBloss, Bpa = NA,
  Fscan = Fs,
  verbose = FALSE)

print(srsim1$Refs2)

                 F05          F10          F50    medianMSY      meanMSY
catF          0.1957 2.136196e-01 2.703530e-01           NA 2.346154e-01
lanF              NA           NA           NA 2.267267e-01 2.230769e-01
catch    104583.9905 1.080207e+05 1.032795e+05           NA 1.102790e+05
landings          NA           NA           NA 6.256642e+04 6.251707e+04
catB     509536.1719 4.732834e+05 3.409148e+05           NA 4.311902e+05
lanB              NA           NA           NA 4.475111e+05 4.544407e+05
             Medlower    Meanlower     Medupper    Meanupper
catF               NA           NA           NA           NA
lanF     1.731732e-01 1.727073e-01 2.592593e-01 2.546547e-01
catch              NA           NA           NA           NA
landings 5.940744e+04 6.255933e+04 5.949005e+04 6.258703e+04
catB               NA           NA           NA           NA
lanB     5.585638e+05           NA 3.756435e+05           NA

# EXTRACT Flim and Fpa
FlimBloss <- srsim1$Refs2["catF", "F50"]
FlimBloss

[1] 0.270353
```

5.8.5 Initial F_{MSY}

```
## srr using 3 models, type 2
srfitmsy <- eqsr_fit(ple4, nsamp = nsamp,
                     models = c("Segreg", "Bevholt"), # exclude Ricker,
                     remove.years=remove.years)
eqsr_plot(srfitmsy)
```

```
eqsr_plot(srfitmsy,n=2e4,ggPlot=TRUE,Scale=1e3)
```

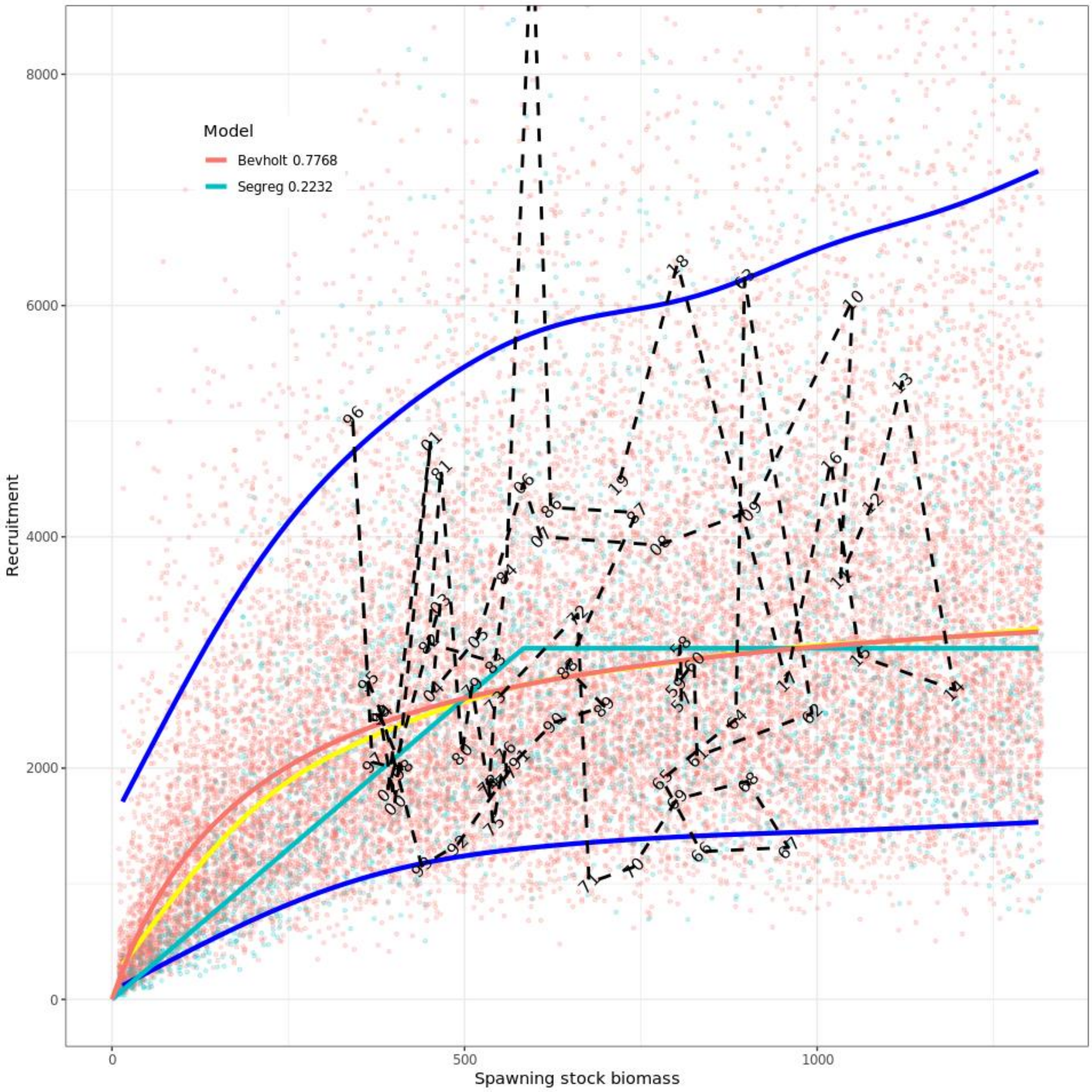


Figure 5.27. Stock and recruitment relationship with Segreg and Bevholt.

```
# SIMULATE, Fcv=0.212, Fphi=0.423 (WKMSYREF4)
srsim2 <- eqsim_run(srfitmsy,
  bio.years = bio.years, sel.years = sel.years,
  bio.const = FALSE, sel.const = FALSE,
  Fcv=0.212, Fphi=0.423,
  Btrigger=0, Blim = BlimBloss, Bpa = Bpa,
  Fscan = Fs,
  verbose = FALSE)

print(srsim2$Refs2)
```

```
                  F05          F10          F50    medianMSY      meanMSY
catF     1.500790e-01 1.635031e-01 2.254697e-01           NA 1.615385e-01
lanF               NA           NA           NA 1.521522e-01 1.500000e-01
catch    8.781225e+04 8.859745e+04 8.191299e+04           NA 8.857771e+04
landings           NA           NA           NA 5.359270e+04 5.361593e+04
catB     5.863586e+05 5.360852e+05 3.410088e+05           NA 5.434355e+05
lanB               NA           NA           NA 5.782566e+05 5.866582e+05
             Medlower    Meanlower     Medupper    Meanupper
```

```
catF                NA           NA           NA           NA
lanF      1.171171e-01 1.160892e-01 1.906907e-01     0.183137
catch               NA           NA           NA           NA
landings 5.099292e+04 5.483389e+04 5.100099e+04 54872.952756
catB                NA           NA           NA           NA
lanB      7.181282e+05           NA 4.413966e+05           NA

# ini Fmsy
Fmsy        <- srsim2$Refs2["lanF", "medianMSY"]
Fmsy

[1] 0.1521522

# Fmsy range without Brigger
Fmsy_low_WO_Btrigger   <- srsim2$Refs2["lanF", "Medlower"]
Fmsy_high_WO_Btrigger  <- srsim2$Refs2["lanF", "Medupper"]
Fmsy_low_WO_Btrigger

[1] 0.1171171

Fmsy_high_WO_Btrigger

[1] 0.1906907

# Fp05 without AR
#F05msy_WOAR <- srsim2$Refs2["catF", "F05"]
#F05msy_WOAR
#eqsim_plot_range(srsim2, type="mean")
eqsim_plot_range(srsim2, type="median")
```

```
## BFmsy
eqsim_plot_range(srsim2, type="ssb")
```

```
BFmsy        <- srsim2$Refs2["lanB", "medianMSY"]
BFmsy

[1] 578256.6

## 5% percentile of Bmsy
BFmsy_5perc <- srsim2$Refs2["lanB", "Medupper"]
BFmsy_5perc

[1] 441396.6
```

5.8.6 MSY $B_{trigger}$

```
# fishing around Fmsy for last 5 years? Yes
colMeans(ple4@harvest[2:6])[as.numeric(dimnames(ple4@harvest)$year) %in% c(2
016:2020)]

[1] 0.13636912 0.12779911 0.13517351 0.11203519 0.09876994

aa<- colMeans(ple4@harvest[2:6])
plot(1957:2020, aa, typ="l", ylab="fbar")
abline(h=Fmsy)
abline(v=2016)
```

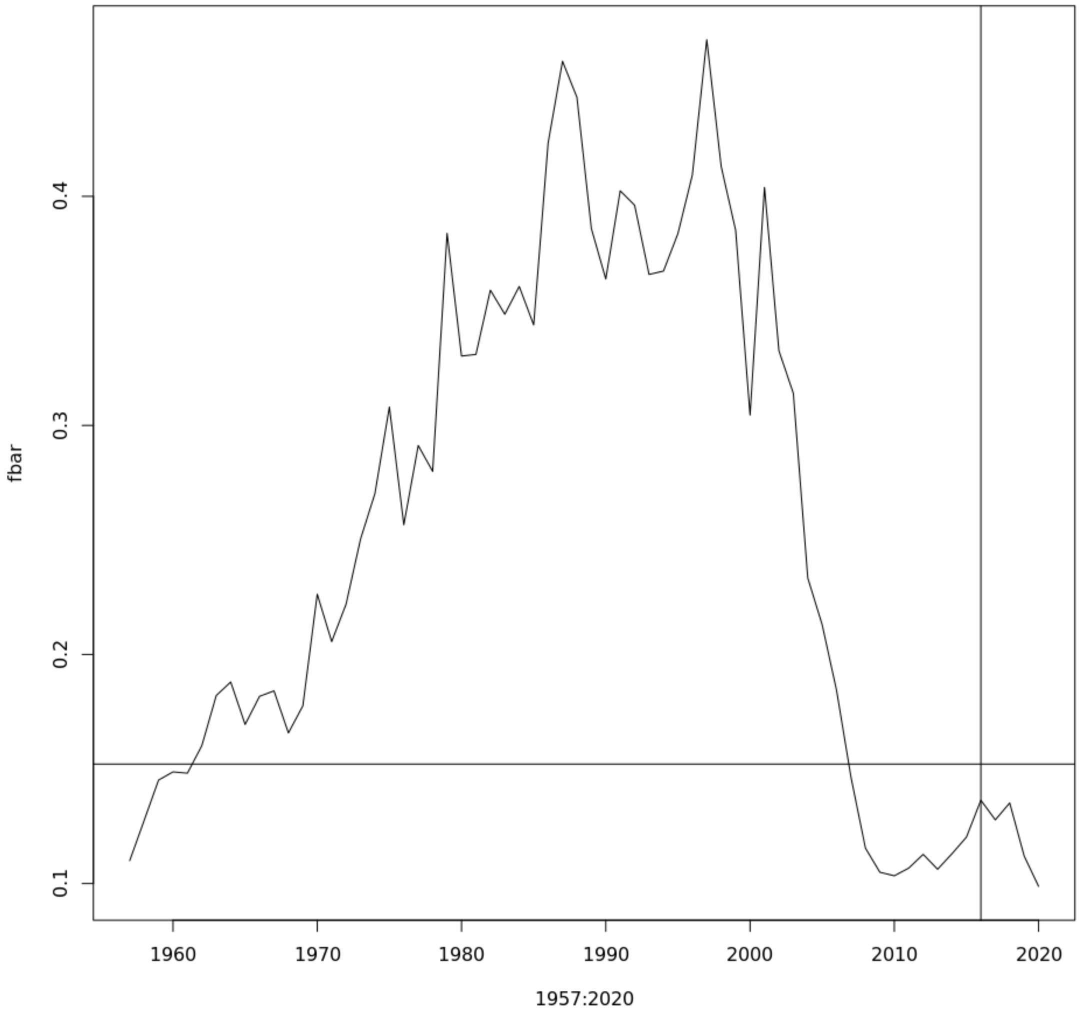


Figure 5.28. Checking last 5 year Fbar relative to initial F_{MSY}.

```
# is the 5% of BFmsy > Bpa? no
BFmsy_5perc > Bpa

[1] FALSE

# MSYBtrigger=Bpa
Btrigger <- Bpa
Btrigger

[1] 473849.8
```

5.8.7 Evaluate the ICES MSY AR

```
#run again EqSim, this time including the selected MSY Btrigger value
srsim3 <- eqsim_run(srfitmsy,
                    bio.years = bio.years, sel.years = sel.years,
                    bio.const = FALSE, sel.const = FALSE,
                    Fcv=0.212, Fphi=0.423,
                    Btrigger=Btrigger, Blim = BlimBloss, Bpa = Bpa,
                    Fscan = seq(0, 1.2, len = 40),
```

```
                    verbose = FALSE)

print(srsim3$Refs2)

                  F05          F10          F50    medianMSY      meanMSY
catF     1.818801e-01 2.035250e-01 3.139386e-01           NA 2.153846e-01
lanF               NA           NA           NA 1.669670e-01 1.846154e-01
catch    9.225669e+04 9.203726e+04 8.499107e+04           NA 9.175124e+04
landings           NA           NA           NA 5.507966e+04 5.496117e+04
catB     5.056839e+05 4.622638e+05 3.411563e+05           NA 4.398427e+05
lanB               NA           NA           NA 5.456982e+05 4.980132e+05
             Medlower    Meanlower     Medupper    Meanupper
catF               NA           NA           NA           NA
lanF     1.249249e-01 1.232309e-01 2.378378e-01 2.543159e-01
catch              NA           NA           NA           NA
landings 5.234574e+04 5.605707e+04 5.225720e+04 5.610325e+04
catB               NA           NA           NA           NA
lanB     6.873790e+05           NA 4.092215e+05           NA

#get new Fp05
F05msy_AR <- srsim3$Refs2["catF", "F05"]
F05msy_AR

[1] 0.1818801

#If the FMSY calculated in Step 1 is > EqSim output Fp.05 , then FMSY is red
uced to
#Fp.05 (i.e. Fp.05 becomes the final choice of FMSY)
Fmsy

[1] 0.1521522

Fmsy > F05msy_AR

[1] FALSE

#Fmsy <- F05msy_AR ## dont need to change Fmsy
Fmsy

[1] 0.1521522

## Fmsy_high_WO_Btrigger < F05msy_AR? No
## Fmsy_high_WO_Btrigger reduced to F05msy_AR
Fmsy_high_WO_Btrigger < F05msy_AR

[1] FALSE

Fmsy_high_WO_Btrigger <- F05msy_AR
```

5.8.8 Final reference points

Table 5.7: the reference points prior to the present benchmark.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	564 599	(Fifth percentile of the SSB as estimated at the benchmark = SSB_{2015})/1.4	ICES (2017)
	F_{MSY}	0.21	EqSim analysis based on the recruitment period 1958–2012.	ICES (2017)
Precautionaryap-proach	B_{lim}	207 288	Break-point of hockey stick stock–recruit relationship, based on the recruitment period 1958–2012.	ICES (2017)
	B_{pa}	290 203	$B_{lim} \times \exp(1.645 \times 0.2) \approx 1.4 \times B_{lim}$	ICES (2017)
	F_{lim}		F_{lim} (0.516) is no longer considered appropriate given the estimate of F_{pa}	ICES (2017, 2021)
	Fpa	0.769	$F_{p.05}$ with AR: The F that provides a 95% probability for SSB to be above B_{lim}.	ICES (2017, 2021)
EU Management plan (MAP) *	MAP MSY $B_{trig-ger}$r	564 599	MSY $B_{trigger}$	ICES (2017)
	MAP B_{lim}	207 288	B_{lim}	ICES (2017)
	MAP F_{MSY}	0.21	F_{MSY}	ICES (2017)
	MAP target range F_{lower}	0.146–0.21	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.	ICES (2017)
	MAP target range F_{upper}	0.21–0.30	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.	ICES (2017)

Table 5.8: The reference points resulting from the present benchmark process

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	473 850	Bpa	ICES (2021)
	F_{MSY}	0.152	EqSim analysis based on the recruitment period 1957–2020.	ICES (2021)
	F_{MSY_upper}	0.182	$F_{p.05}$ with AR	ICES (2021)
	F_{MSY_lower}	0.117	Lower range of F_{MSY}	ICES (2021)
Precautionaryap-proach	B_{lim}	341 003	Bloss: the lowest estimated SSB in the time-series, which equals the SSB of year 1996.	ICES (2021)
	B_{pa}	473 850	$B_{lim} \times \exp(1.645 \times 0.2) \approx 1.4 \times B_{lim}$	ICES (2021)
	F_{lim}	0.270	EqSim analysis based on the recruitment period 1957–2020.	ICES (2021)
	F_{pa}	0.182	$F_{p.05}$ with AR: The F that provides a 95% probability for SSB to be above B_{lim}.	ICES (2021)

5.8.9 Current stock status

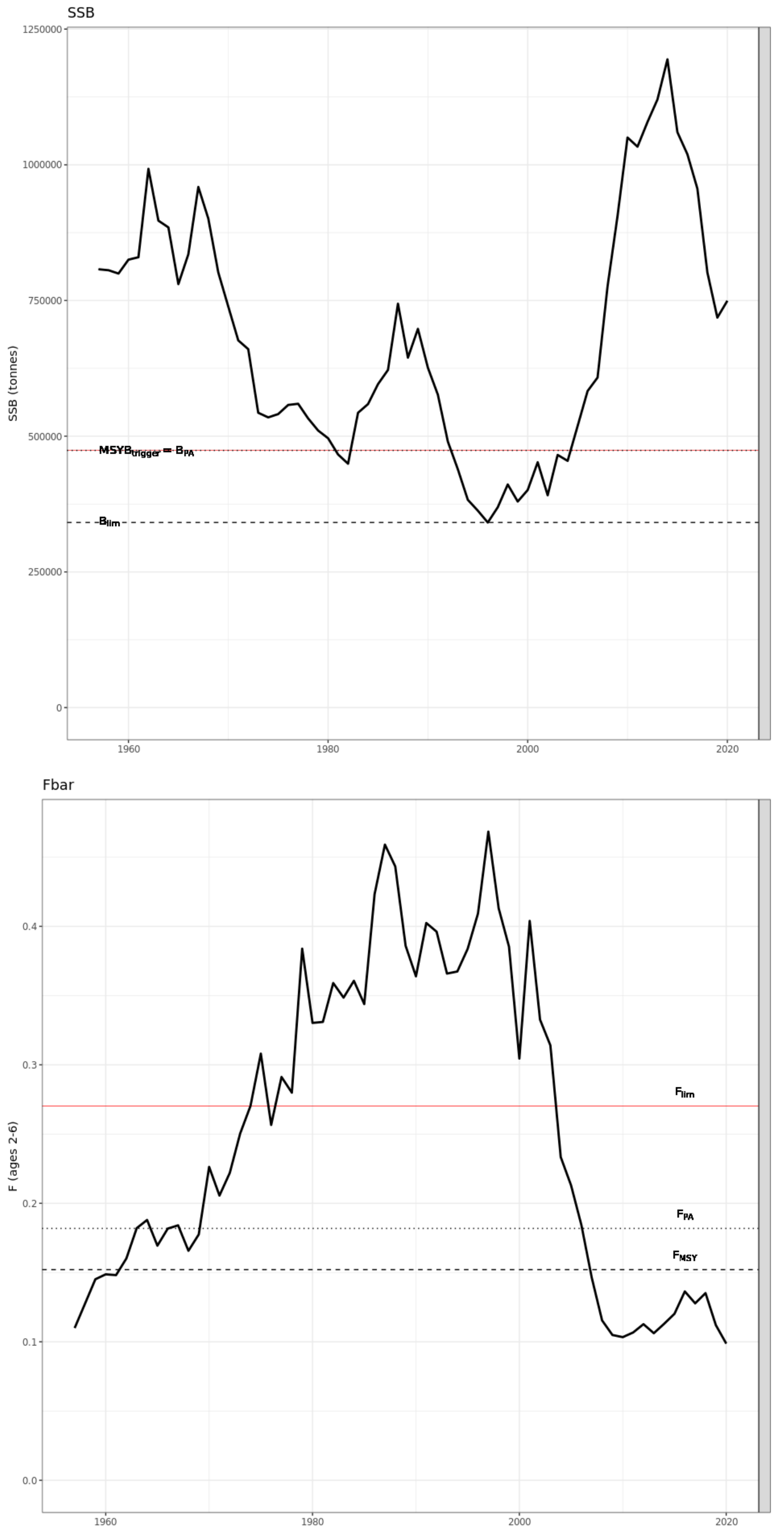


Figure 5.29. Stock status relative to the new reference points for spawner biomass (top) and fishing mortality (bottom).

Future research and data requirements

It is recommended to explore the causing factors and validate the time varying natural mortality in WGSAM using multi-species assessment models (ICES 2018).

Age reading errors in plaice has been extensively studied (WKARP2 2021). Additionally, the stock composition of older plaice has been increasing. It is interesting to investigate the inclusion of age reading errors and its impact on the assessment.

Research in discards survival have shown survival rate around 14% (van der Reijden *et.al.*, 2017). It is interesting to investigate the inclusion of discards survival and its impact on the assessment.

The biology and habitat of plaice has been adapted swiftly by changing of environmental factors and fisheries, which has been observed in several plaice stocks in North Sea, Celtic Sea, as well as Baltic Sea. It would be interesting to conduct some collective research to investigate the shared factors and stock ID.

5.9 References

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6 Plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)

6.1 Stock ID and sub-stock structure

The degree of separation between the stocks of plaice in the Celtic Sea and the Irish Sea is unclear. Juvenile fish do not move far away from local nursery grounds (Mariott *et al.*, 2016), so there is likely no redistribution of recruitment and only adults migrate.

Historical tagging studies indicate a southerly movement of mature fish (or fish maturing for the first time) from the southeast Irish Sea, off North Wales, into the Bristol Channel and Celtic Sea during the spawning season. While some of these migrant spawning fish will remain in the Bristol Channel and Celtic Sea, the majority are expected to return to summer feeding grounds in the Irish Sea (Dunn and Pawson, 2002).

Very little mixing is considered to occur between the stocks (Pawson, 1995). Nevertheless, time-series of recruitment estimates for all stocks in waters around the UK (Irish Sea, Celtic Sea, western and eastern Channel, North Sea) show a significant level of synchrony (Fox *et al.*, 2000) and generally stock trends are very similar (Dutz *et al.*, 2016). This possibly could indicate that the stocks are subject to similar large-scale environmental forces and respond similarly to them and recruitment strength is "shaped" at the larval and early post-larval stages prior to settlement.

6.2 Issue list

The evaluation of the status of the stock is currently based on an SPiCT assessment using two commercial CPUE indices, and two survey indices. The commercial time-series are LPUE of both E&W beam and otter trawlers from 1989 to 2010. Survey indices are coming from the UK-BTS-Q3 beam trawl survey (1993-now) in 7.f and the Irish IBTS survey Q4 (2003-now) in 7.g. Despite that age-structured information on landings and discards is available from many metiers including the most important Belgian fleets, the use of Aaart-Poos (AP) model used since the last benchmark 10 years ago has not converged or had unacceptable residuals since 2015. The likely problem comes from assumption on discard prior 2004 when discard data collection began. Notably in years where discards exceed landings, and the assessed species is a part of the mixed fishery (sole+plaice) and is is not the main target species, discard reconstructions are problematic.

A new benchmark for this stock is overdue, and the need in this event is aggaravated by the current assessment using either survey trends or a production model for a stock seemingly well supported by data (at least in the last 17 years). There is also need to revise maturation and growth rates as during last decades due to climate changes and fisheries impact they might change to an important extent.

6.3 Scorecard on data quality

The scorecard as recommended by ICES (2008) was compiled below (Table 6.1).

Table 6.1. Scorecard of the Celtic Sea plaice.

WKACCU Scorecard	**No bias**	**Potential Bias**	**Confirmed Bias**	**Comment**
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				The species is dissimilar to other and might not be confused
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				
Final indicator		**All green**		
B. LANDINGS WEIGHT				ICES estimates of landing data are considered
1. Missing part				to be a fair reflection of the actual catches
2. Area misreporting				
3. Quantity misreporting				
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				
8. Damaged fish landed				
Final indicator		**All green**		
C. DISCARDS WEIGHT				
1. Sampling allocation scheme				Discard practices widely vary with metier, and

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
2. Raising variable				likely with individual fishers' attitude as the species
3. Size of the catch effect				is generally a bycatch in targeted fishery for sole.
4. Damaged fish discarded				Survivability exemption for plaice landings by beam trawlers
5. Non response rate				also depends on engine power, vessel length, and distance from shore
6. Temporal coverage				and tow duration. Belgium beam trawlers have also daily
7. Spatial coverage				catch limit imposed.
8. High grading				
9. Slipping behaviour				
10. Management measures leading to discarding behaviour				
11. Working conditions	NA			
12. Species replacement	NA			
Final indicator		**Orange related to numerous uncertainties with discard evaluation**		
D. EFFORT				
1. Unit definition				
2. Area misreporting				
3. Effort misreporting				
4. Source of information				
Final indicator		**All green**		
E. LENGTH STRUCTURE				Length structure is not used in the assessment
1. Sampling protocol	NA			

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
2. Temporal coverage	NA			
3. Spatial coverage	NA			
4. Random sampling of boxes/trips	NA			
5. Availability of all the landings/discards	NA			
6. Non sampled strata	NA			
7. Raising to the trip	NA			
8. Change in selectivity	NA			
9. Sampled weight	NA			
Final indicator		**NA**		
F. AGE STRUCTURE				Otolith exchange analysis for plaice 7.f.g took place in 2019
1. Quality insurance protocol				The average percentage agreement of 72% was achieved for
2. Conventional/actual age validity				whole otoliths and average percentage agreement
3. Calibration workshop				for sectioned otoliths was 63% (experienced readers).
4. International exchange				Comparative analysis of size-at-age as estimated from Irish data
5. International reference set				(whole otoliths) and UK data (sectioned otoliths) did not reveal
6. Species/stock reading easiness				consistent differences between methods.
7. Staff trained for age readings				
8. Age reading method				

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
9. Statistical processing				
10. Temporal coverage				
11. Spatial coverage				
12. Plus group				
13. Incomplete ALK				
Final indicator		**Green as difficulties with age readings seemingly do not impact final judgement on size-at-age.**		
G. MEAN WEIGHT				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor	NA			
8. Final indicator		**All green**		
H. SEX RATIO	NA			Sex ratio is not used in the assessment
1. Sampling protocol	NA			
2. Temporal coverage	NA			
3. Spatial coverage	NA			
4. Staff trained	NA			
5.Size/maturity effect NA	NA			
6. Catchability effect NA	NA			
Final indicator				
I. MATURITY STAGE				Belgium, Ireland and UK used different maturity scales

WKACCU Scorecard	No bias	Potential Bias	Confirmed Bias	Comment
1. Sampling protocol				throughout the assessed period
2. Appropriate time period all along the year				
3. Spatial coverage				
4. Staff trained				
5. International reference set				Not available
6. Size/maturity				
7. Histological reference				
8. Skipped spawning				Not taken into account in all scales though a rare event
Final indicator				**Green as for assessment of maturity only data collected during appropriate period and using appropriate scale**

6.4 Multispecies and mixed fisheries issues

Plaice are caught mostly by beam trawl (52-69% of landings in 2016-2020) and otter trawl (29-42% of landings in 2016-2020) in mixed fisheries with sole, which generates high discards of plaice due to the mismatch in the selectivity properties of the gear and the plaice minimum landings size. To catch of sole of MLS of 24 cm, a vessel needs no use smaller mesh size than if it would target only adult plaice in which MLS is 27 cm. Sole also is much more valuable fish: mean price of landings into the UK and abroad by UK vessels between 2015 to 2019 was £9.4 per kg, in contrast to £1.5/kg for plaice (Annex B in MMO 2020). Therefore, both in the past and nowadays fishers often discard not only undersized plaice but also fish of commercial size to save effort and space in fish hold if sole are available to be caught. Discards always were at the level of landings occasionally even higher and were opportunistically reported, sampled and aged from 2004 onwards.

A half of the landings (46-58% in 2016-2020) is taken by Belgian fishers, and about 1/5 each by Irish (12-30%) and French (11-30%) fleet. The remaining of 6-10% was landed by fishers from the UK.

The discard ban did not solve the problem of discards as the species has generally high survival, at least from catches of otter trawls (Revill *et al.*, 2013; Depestele *et al.*, 2014; Uhlmann *et al.*, 2016 a,b). Following the recent discard policy (EU 2020, MMO 2021) there are exemptions from discarding ban for some beam trawlers depending on combination of their length, engine power, gear configuration and distance from shore as well as for all otter trawlers. Therefore, discarding practice will continue into future with difficulties to use LPUE as a potential tuning series.

6.5 Ecosystem drivers

Plaice are preyed upon and consume a variety of species through their life history,.As juveniles in shallow waters, it is intensively preyed upon by a shrimp *Crangon crangon* (Albaina *et al.*, 2012). As a predator, plaice typically consume high proportions of polychaetes and molluscs. In spite its important place in the ecosystem, plaice have not as yet been explicitly included multi-species assessment methods for the Celtic Sea (e.g. ICES, WGSAM 2008).

Plaice spawning in the Celtic Sea occurs in spring, peaking in March (Ellis, Nash, 1997). Eggs are pelagic so their survival highly depend on environmental variability. Other than statistical correlations between recruitment and temperature (Fox *et al.*, 2000), little is known about the effects of the environment on the stock dynamics of plaice in the Irish and Celtic Seas. Negative correlations between year-class strength of plaice (in either the Irish Sea, Celtic Sea, Channel and North Sea) and sea surface temperature are generally strongest for the period February–June. However, eastern (North Sea and Channel) and western (Irish Sea and Celtic Sea) stocks have been found to respond to different time-scales of temperature variability, which might imply that different mechanisms are operating in these stocks and/or that the Irish Sea and Celtic Sea share common spawning (Fox *et al*., 2000). Stock is increasing from between 2008 and 2017 after a period of low abundance in ~1995–2007 as some other plaice stocks around the UK, like in divisions 7.e and 7.h–k (ICES, 2017) and in the North Sea (Dutz *et al*., 2016) that possibly might be caused by some global processes.

6.6 Stock Assessment

6.6.1 Catch – quality, misreporting, discards

International landings-at-age data are based on quarterly market sampling and annual landings figures are available from 1977. Catches rose to a maximum in the late 1980s (Figure 6.1), declined during the early 1990s, and then fluctuated around 1000 t. The decline in landings reached a low at 386 t in 2005 after which they fluctuated between 381 and 642 t. Estimates of the level of discarding have been collected since 2004 and have shown fluctuation with a substantial increase occurred in 2007 and in 2011-2013 by all fleets, followed by a gradual return to the previously lower levels and further decrease in 2018-2020 probably due to discarding ban impact. Landings' data are available from all fishing countries. The misreporting of landings of this stock is not considered to be a problem.

Prior to 2010 indications were that discard rates, although variable, were substantial in some fleets/periods. At the ICES WKFLAT (2010) meeting discard data from the countries participating in the fishery were raised and collated to the total international level for first time, a process that is continued annually. Not all fleet provide information about discards, and data on discard age structure is particularly sparse and varying from year to year. Wherever this information was absent, discards were raised based on similarity of gear and quarter/annual type of data. Estimates of the level of discards available from 2004. Discarded fish is smaller and younger than landed, but age-specific proportions varied from year to year likely depending on recruitment strength as well as on discarding practices of fishers driven by market demand as fish above MLS was often discarded, particularly after 2011.

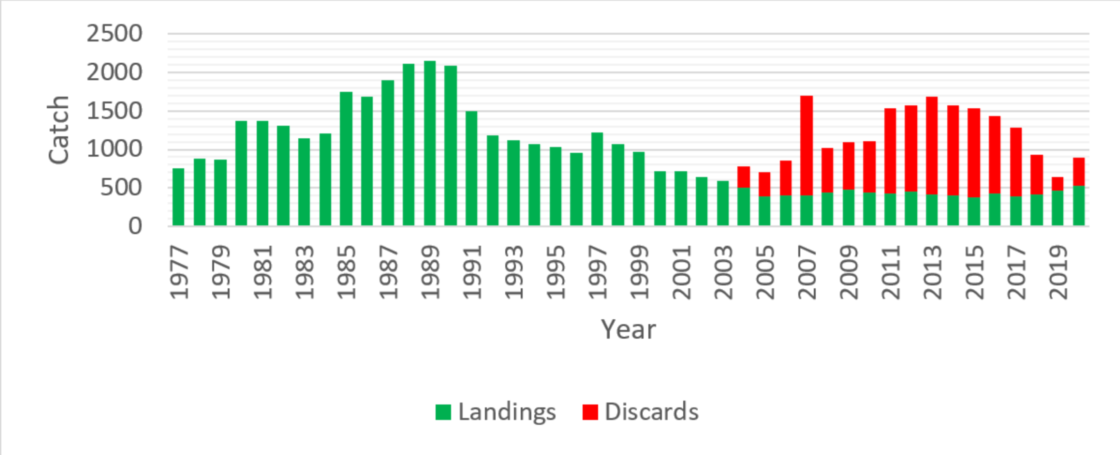


Figure 6.1. Landings and discards throughout the history of fishery of the plaice in Celtic Sea and Bristol Channel

Because the discarded fish was generally smaller, in numerical aspects in always strongly predominated (Figure 6.2). Recent research on discard survival in the English Channel revealed that discard mortality of adult plaice captured by beam trawl varied with season, fish size and other factors like vessel type (Revill et al., 2013; Depestele et al., 2014; Uhlmann *et al*., 2016 a,b). Therefore, significant amounts (4 to 93%, mostly <50% in Belgian beam trawlers and mean 48% in French beam trawlers) might survive discarding (Depestele *et al*., 2014; Uhlmann *et al*., 2016 a). The survival estimate for the UK otter trawl fishery in the Western Channel was 47–63% and for the trammelnet fishery 71–72%. The discarded fish survival was also estimated as 19–20% for the North Sea UK otter trawl fishery and 4–15% in the Western Channel UK beam trawl fishery (Catchpole et al., 2015). However, bulk of discards are represented by small plaice that has relatively high mortality as with other flatfish species (review: Hendrikson, Nies, 2007) so real survival might be even lower. Sensitivity runs taking into account 50% discard survival when applying the SAM model lead to its worse performance, and particular retrospective problems , so this phenomenon was not considered further in the assessment.

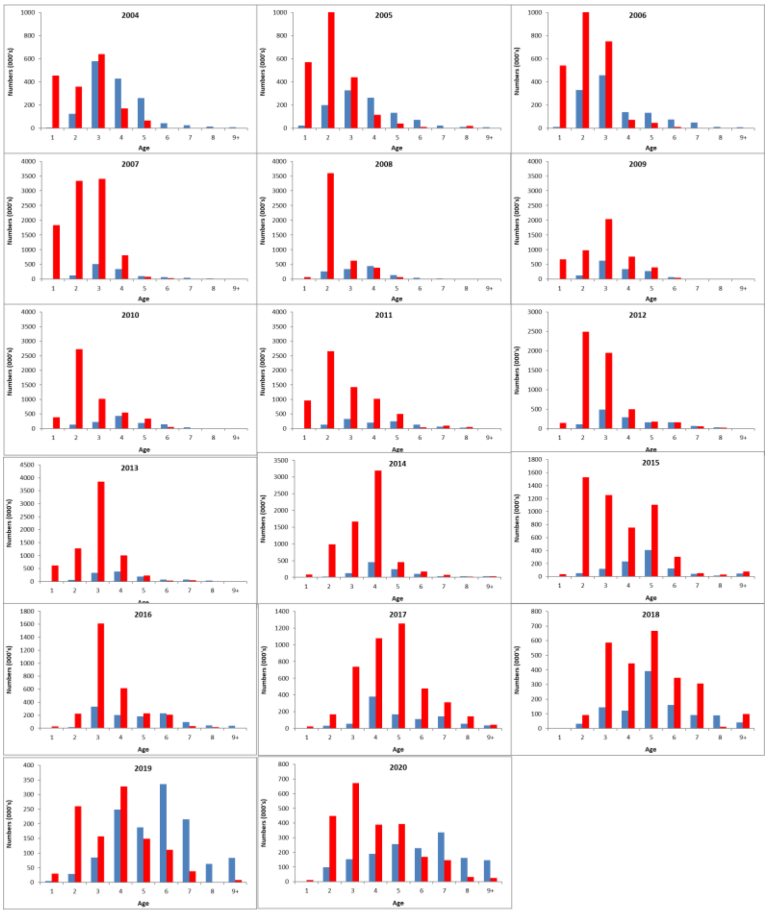


Figure 6.2. Landings (blue) and discards (red) composition by age.

6.6.2 Surveys

Indices of abundance from the UK(E&W)-BTS-Q3 beam trawl survey in 7.f and the Irish IBTS survey (IGFS-WIBTS-Q4) in 7.g are were historically used for this assessment. Surfaces covered by these surveys does not coincide (Figure 6.3), with Q3 survey covering mostly area 7.f and Q4 survey mostly 7.g. Data from UK(E&W)-BTS-Q3 are available from 1993 onwards, and IGFS-WIBTS-Q4 – from 2003.

The UK(E&W)-BTS-Q3 started in 1993 and was always used for tuning the AP model. The Irish Celtic Explorer IBTS survey (IGFS-WIBTS-Q4) time-series started in 2003 and was not used in earlier years. The both survey time-series were used for the stock trends-based advice in the years 2015, 2016 and 2017 and for SPiCT in 2018 -2021.

Aside of these two surveys, LPUEs of commercial fleets of UK beam trawlers and otter trawlers have been used for tuning of Aart-Poos model, which was used for ICES advice up to 2015. However, commercial indices of abundance from the different fisheries provided contradictory trends during the recent 10 years or so. It occurred because of varying discarding practices from after 2011 onwards, when fishermen began to discard substantial numbers of elder and larger fish of commercial size. Therefore, these LPUE could not be considered as proxies for adult fish abundance after ~2010-2011, and was used in assessment only for a period 1989-2010 (otter trawlers) and 1990-2010 (beam trawlers).

Belgium fleet is the most important stakeholder in this fishery taking most of the catch. Therefore, it potentially might be the most reliable source of LPUE data to be used in an age-structured model. However, the Belgian landings and effort data are influenced by policy decisions, particularly often changing limits of how much plaice might be taken per fishing day depending on season, year and boat size. The resulting LPUE therefore should only be used for indicative purposes and be considered qualitatively (Nimmegeers *et al.*, 2021).

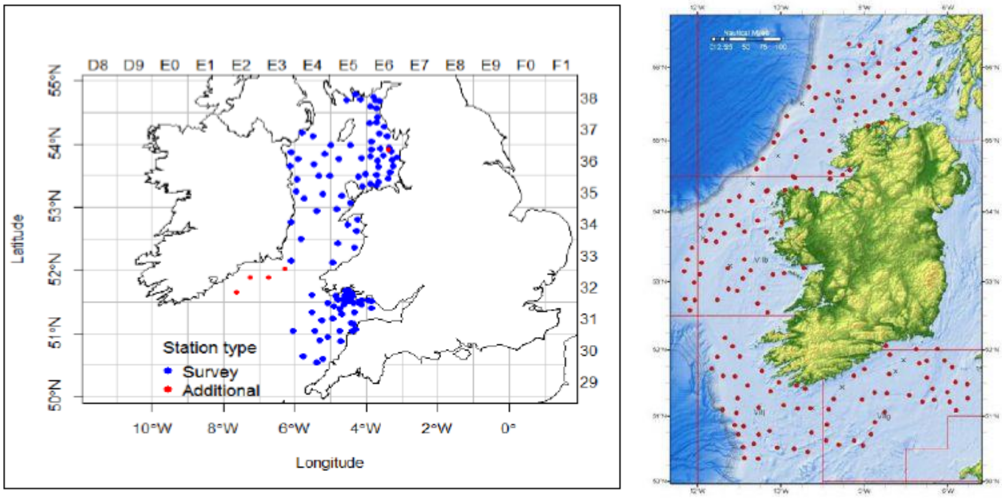


Figure 6.3. Areas covered by surveys UK(E&W)-BTS-Q3 (left, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043958/20211220_UK_WorkPlan_for_data_collection_in_the_fisheries_and_aquaculture_sectors_AC.pdf) and IGFS-WIBTS-Q4 (right, https://www.marine.ie/Home/site-area/areas-activity/fisheries-ecosystems/irish-groundfish-survey) including waters outside of the assessment area

Consistency of these four different indices of plaice abundance is presented on Figure 6.4. and time-series -specific age selectivity on Figure 6.5.

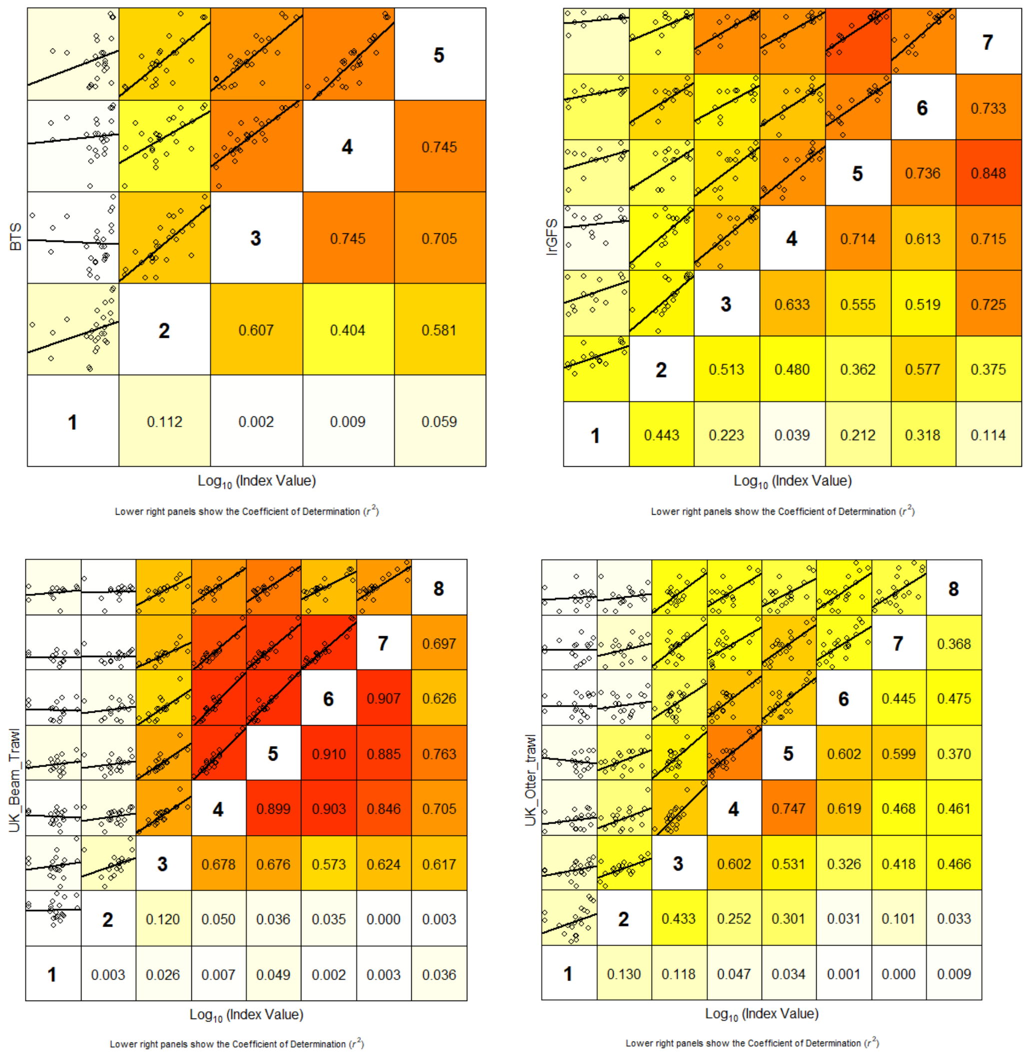


Figure 6.4 Consistency of survey and LPUE data.

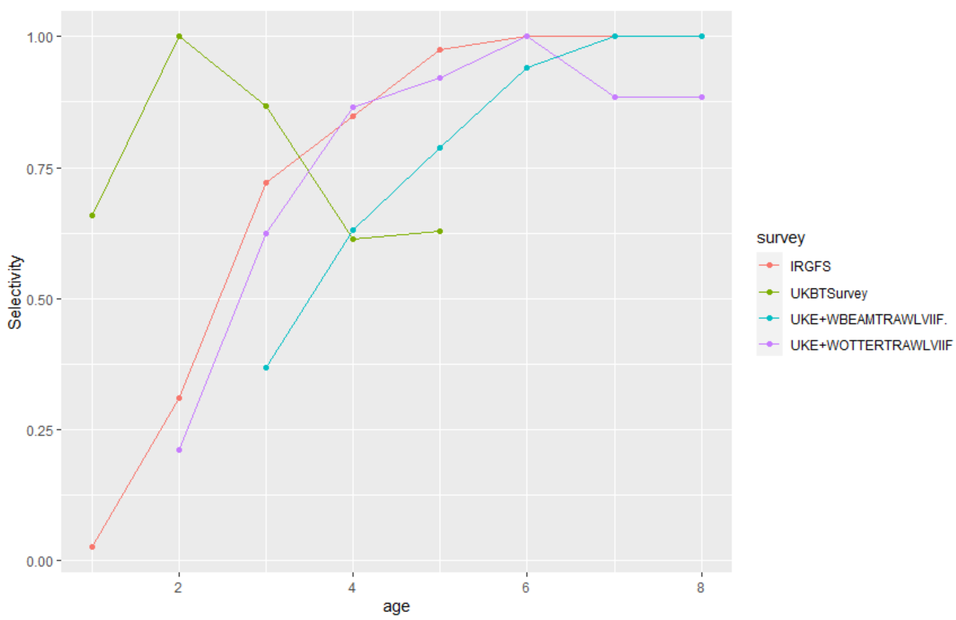


Figure 6.5 Time-series – specific age selectivity.

6.6.3 Weights, maturities, growth

6.6.3.1 Weights

Landings' age compositions and weights-at-age are provided on quarterly basis for some fleets of the UK, France and Belgium, and on annual basis – for Ireland, the rest of Belgium and UK (Scotland). Landings weights-at-age fluctuated historically and in most of age groups did show a declining trend since ~2000-2003 (Figure 6.6).

Discards weight-at-age are available from 2004 onwards, and during the period of the study did not exhibit any unambiguous trend. For the assessment purposes, these weights in 1989-2003 were taken as average for a period 2004-2010.

Catch weight-at-age for a period when discards were unknown were reconstructed using aforementioned averaged weight of discards (2004-2010) and based on the assumption that discarded proportion of fish of the same age was stable during this period, and equal to average for 2004-2010. For example, mean 11.214% of 2 y.o. fish were landed in 2004 -2010. As ~426 thousand of 2.y.o fish were landed in 1998, the total catch of this age group in this year was estimated as ~3799 thousand and discards as ~3373 (catch minus landings).

Because both assessment surveys occurred in the second half of the year (Q3 and Q4) and combination of commercial data on catches and landings from Q1 was prone to bias as larger fish of the same age will go into landings while slow-growing smaller might be discarded, there was no option to provide reliable stock weights in Q1 for SAM model. Therefore, they were assumed to be equal to catch weights-at-age.

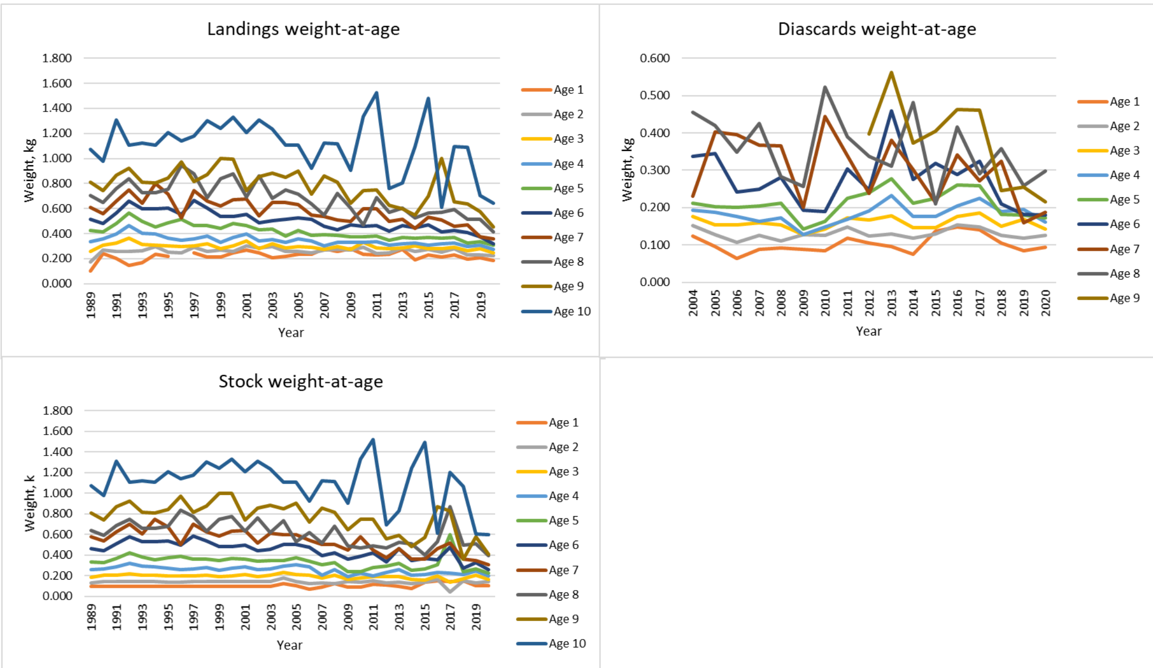


Figure 6. 6 Landings, stocks and discards weight-at-age.

6.6.3.2 Maturities

Historically, different institutions used different maturity scales and their use changed with time. The UK used 6-stage Cefas maturity scale up to 2011, and then the ICES 6-stage scale for flatfish was applied. The Ireland used 9-stage scale throughout while the Belgium initially used 7-stage scale, and from 2012- the ICES 6-stage scale for flatfish (Table 6.2).

Table 6.2. Maturity scales recently used for plaice 7.f.g. by different institutions

Physiological condition related to maturity	Stages		
	Ireland (from Witthames 2003)	Cefas 2002-2011 (Cefas universal scale)	Cefas 2013-2021 and Belgium 2004-2020 (ICES flatfish scale)
Virgin / Immature (never spawned before)	1	I (Immature)	1
Developing virgin or inactive adult	2	I (Immature)	1
Early maturing	3	M (Maturing)	2
Mature	4	M (Maturing)	2
Ripe	5	H (Hyaline)	3
Spawning	6	R (Running)	3
Spent	7	S (Spent)	4
Resting /inative adult	8	I (Immature)	1
Skipped spawning (only during the spawning period)	Similar to stage 2 or 3	Similar to stage 2 or early M	5
Abnormal	9	A (Abnormal)	6

The plaice spawning in Celtic Sea occurs in February - March to early April and spawned eggs take between 16 and 20 days to hatch. Therefore, the optimal sampling time to estimate proportion of mature fish per year is the first quarter though the end of fourth quarter can be used, too (ICES 2010).

To calibrate size-at-maturity from data collected by the different institutions, the survey data from Ireland (IGFS, November – December), survey data from the UK (DRCDC, Q1SWBEAM, Q1SWOTTER, WCGFS, February – April), and commercial data from Belgium fleet (January – April), were used. Data from commercial samplings (landings and discards) were directly combined based on the assumption that maturity does not impact fisher's choice between landing/discarding of an individual fish. Resulting data turned out to be not entirely compatible (Figure 6.7), possibly due to subtle differences in maturity scales or rather timing of data collection.

Among three datasets, the UK data were chosen to estimate proportion of mature fish at age as chosen surveys occur in the optimal time and materials are collected randomly irrespective of the fish aggregations. Irish data were collected out of the optimum season (mostly November) so potentially might show lower proportion of mature fish, a supposition consistent with observed curve (Figure 6.5). Commercial data from the Belgian trawlers were sampled in the optimal time but materials were collected from aggregations targeted by fishers, so potentially these data might be impacted by differential distribution of foraging and spawning fish.

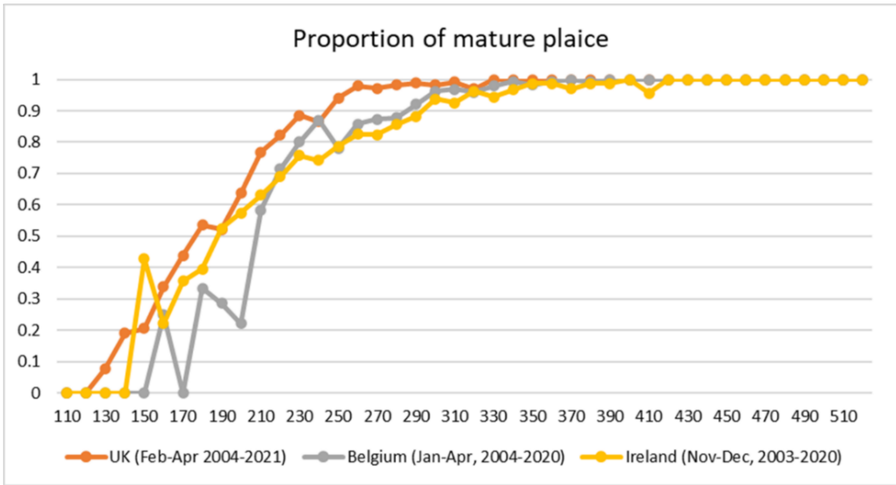


Figure 6.7. Size-at-maturity estimated from the different datasets

The proportion of mature fish in UK Q1 surveys gradually increased from 1993-1994 (as used in the previous assessments) and was relatively unchanged in 2004-2020 (Figure 6.8).

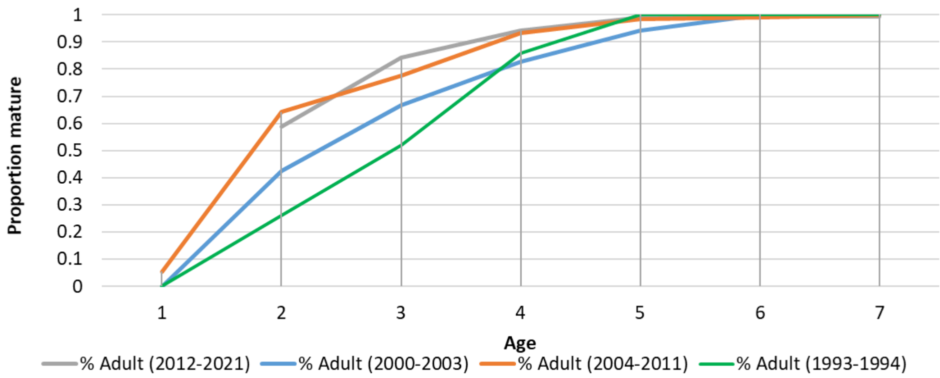


Figure 6.8. Proportion of mature plaice in February – April UK surveys (UK (DRCDC, Q1SWBEAM, Q1SWOTTER, WCGFS) in divisions 7.f-g.

As data were very similar between 2004-2011 and 2012-2020 and unfortunately were too scarce for estimation separate proportions of mature fish for the different years, the maturity ogive for combined data of 2004-2020 was suggested (Table 6.3).

Table 6.3. Proportion of mature plaice at age

Proportion mature	Age				
	1	2	3	4	5+
Previous assessments (based on 1993-1994)	0	0.26	0.52	0.86	1
New data (based on 2004-2021)	0	0.62	0.81	0.94	1

6.6.3.3 Growth

There are two methods applied for otoliths aging: reading of sectioned otolith (Cefas) and reading whole otoliths (other institutions). Otolith exchange analysis for plaice in divisions 7.f-g was organised in May-June 2019. Preliminary work on otolith of North Sea plaice established the target statistics as percentage agreement between readers (PA) = 85% and CV = 5% and the same values are expected to be applicable to other plaice stocks (ICES, 2010). These thresholds were not reached during the recent plaice 7.f-g otolith exchange. Overall PA for sectioned otoliths was 56%, CV=28%. For whole otoliths PA= 72% and CV=19%; When only advanced 7f-g readers were combined: PA=75%; CV=18% (whole otoliths); latter values (75% and 18%) were in line with plaice otolith reading from other areas (4, 3a, and 7hk). During WKARP (2010), threshold and target statistics were presented (agreement = 85% and CV = 5%) for North Sea plaice readers (whole). These thresholds could not be reached for the recent plaice 7.f-g exchange.

As fish grow during the year, size-at-age readings should be compared only between samples collected in the same season, desirably the same month. A comparison of outputs of otolith reading by two different methods did not reveal a consistent difference between Irish (whole otolith, November) and UK (sectioned otolith, September) readers (Figure 6.9). In 2015 and 2018 fish of the same age were estimated to be larger in Irish samples but it might had different causes (including fast growth between September and November in these years as Irish samples were collected two months later). As there were no consistent differences between two methods (institutions), it was concluded that despite low agreement in otolith readings between individual readers and necessity to improve precision, the existing age data are compatible, are at the same level of reliability as for plaice of other stocks, and might be used for age-based model assessment.

Survey / Country	1	2	3	4	5	6	7		1	2	3	4	5	6	7
2003IR		0.91	1.08	1.12	1.23	1.34	1.64	2012IR		0.90	1.04	1.12	1.22	1.29	1.40
2003UK	0.89	1.02	1.15	1.16	1.23	1.45	1.86	2012UK	0.86	0.95	1.07	1.09	1.26	1.22	1.39
2004IR	0.93	0.76	1.01	1.20	1.21	1.28	1.41	2013IR	0.68	0.85	1.01	1.11	1.21	1.24	1.35
2004UK	0.85	0.98	1.14	1.20	1.24	1.23	1.23	2013UK	0.82	0.98	1.04	1.14	1.19	1.23	1.41
2005IR				1.12	1.33		1.51	2014IR	0.78	0.94	1.01	1.11	1.15	1.23	1.31
2005UK	0.85	1.00	1.06	1.18	1.27	1.31	1.30	2014UK	0.81	0.93	1.03	1.11	1.20	1.32	1.52
2006IR	0.72	0.91	1.07	1.19	1.22	1.39	1.34	2015IR	0.80	0.92	1.05	1.18	1.25	1.33	1.45
2006UK	0.87	0.98	1.06	1.13	1.21	1.28		2015UK	0.79	0.90	0.97	1.02	1.11	1.11	1.08
2007IR	0.85	0.94	1.03	1.12	1.21	1.17	1.12	2016IR		0.88	1.01	1.13	1.05	1.21	1.33
2007UK	0.87	0.97	1.07	1.08	1.31	1.38	1.04	2016UK	0.75	0.85	0.97	1.04	1.12	1.21	1.30
2008IR	1.00	0.98	1.05	1.17	1.15	1.39	1.25	2017IR	0.63	0.79	0.99	1.12	1.14	1.12	1.36
2008UK	0.80	0.94	1.06	1.16	1.15	1.23	1.36	2017UK	0.71	0.85	0.95	1.06	1.08	1.15	1.26
2009IR	0.67	0.89	0.99	1.09	1.19	1.30	1.08	2018IR		0.94	1.26	1.21	1.52		
2009UK	0.85	0.97	1.03	1.15	1.20	1.31	1.39	2018UK	0.76	0.85	0.94	1.02	1.09	1.10	1.14
2010IR	0.69	0.84	0.98	1.05	1.19	1.23	1.19	2019IR	0.79	0.87	1.00	1.01	1.11	1.16	1.17
2010UK	0.87	1.00	1.09	1.16	1.21	1.32	1.31	2019UK	0.81	0.87	1.00	0.99	1.12	1.12	1.08
2011IR	0.71	0.88	1.01	1.05	1.11	1.26	1.29	2020IR	0.83	0.89	0.95	1.01	1.07	1.11	1.24
2011UK	0.81	0.94	0.99	1.11	1.20	1.13	1.29	2020UK	0.77	0.89	0.94	1.01	1.17	1.03	1.28

Figure 6.9. Standardised (to average plaice size in a combined sample) annual size-at-age data collected in autumn research surveys

Possibility to use this survey dataset on plaice age for estimation of parameters of von Bertalanffy equation was discussed at meetings of WKNSCS prior the Benchmark and among other colleagues. There were concern that survey data are nor fully adequate for the task as containing little information on large fish, which is rarely captured. Using of commercial data was problematic as both discards and landing contained unrepresentative samples for the entire stock, and there is no agreed protocol how there two datasets might be combined as landings always were sampled wider than discards. Question of using of surveys data for estimation of growth parameters is under further discussion and is not considered thereafter as irrelevant to the current assessment.

6.6.4 Assessment models

6.6.4.1 Historical assessments

WKFLAT (2011) agreed that the model that will be used as a temporary basis for the assessment and provision of advice for the Celtic Sea plaice is AP model (Aarts and Poos, 2009). This was selected on the basis that it was the only model available to WKFLAT which reconstructs the historic discarding rates (derived from the survey data series).

In 2013, no assessment was presented for this stock given that the "preferred" Aarts and Poos (2009) model failed to converge and other model variants could not provide realistic representations of observed landings and discards. Consequently, WGCSE 2013 decided to avoid the use of the "preferred" TV_PTVS AP model variant and instead focus on assessing the stock using trends derived from the fishery-independent UK(E&W) beam trawl survey. Trends derived from the UK(E&W) beam trawl survey were selected for the basis of advice given that this survey most appropriately covered the spatial extent of the stock and well represented ages landed in the fishery. The UK(E&W) beam trawl survey was used to infer trends in recruitment, stock size (spawning–stock biomass) and fishing mortality.

In 2014 corrected TV_PTVS Aarts and Poos (2009) model converged and produced realistic results and confirmed conclusions derived in 2013 from the fishery-independent UK(E&W) beam trawl survey. In 2015–2017 all three model variants converged, but only of the "preferred" TV_PTVS AP variant provided estimations consistent with the previous run, observed catches and landings. However, trends of both UK(E&W)-BTS-Q3 beam trawl and IGFS-WIBTS-Q4 surveys on one hand and data on LPUEs of commercial fleets produced conflicting signal that resulted in asymmetrical distribution of residuals. Because of this, the ICES stock advice was based on both surveys' CPUE trends.

Independently of WGCSE, the stock status was explored in 2015 by WKProxy using a biomass dynamic model (SPiCT) (ICES, 2016 a). As discard data were not available prior 2004, the group approximated the total catch values from 1977 to 2003. An adjustment was made to the data by applying the 2004 discard ratio back in time (landings prior to 2004 were multiplied by K=1.54). These total catch data were combined with CPUE trends of both surveys expressed in two mean-standardized biomass index series of +3-year-old plaice, which were considered to reflect "exploitable biomass" for this stock.

6.6.4.2 Current assessment (as for 2021)

In 2017 the ICES framework for category 3.2 stocks was applied (ICES, 2012; 2016 b–d). As the previous ICES advice used both catch/landings and biomass index series, the stock was investigated by applying SPiCT. The SPiCT results were chosen to support the basis for advice using comparison of the two latest biomass index (B/ B_{MSY}) values (index A) with the three preceding values (index B), multiplied by the recent advised catch. The same approach was used later in both 2018-2021 (Table 6.5).

Table 6.5. Parameters of SPiCT used in the current assessment

Assessment year	Time-series	2017-2021
Assessment model		SPiCT
Catch data		Including discards 1977–2019 (reported and raised discards for 2004–2019, and estimated discards for 1977–2003)
Discard rate		Average (proportion by number) 2004–2010. Calculated as discards/(landings + discards).
Tuning fleets	UK(E&W)-BTS-Q3	1995–2019 ages 3+
	IGFS-WIBTS-Q4	2003–2019 ages 3+
	UK commercial beam trawl	1995–2010 ages 4–8
	UK commercial otter trawl	1995–2010 ages 4–8

All recent assessment ended up in conclusion that $B>B_{MSY}$ and $F<F_{MSY}$ (Figure 6.10).

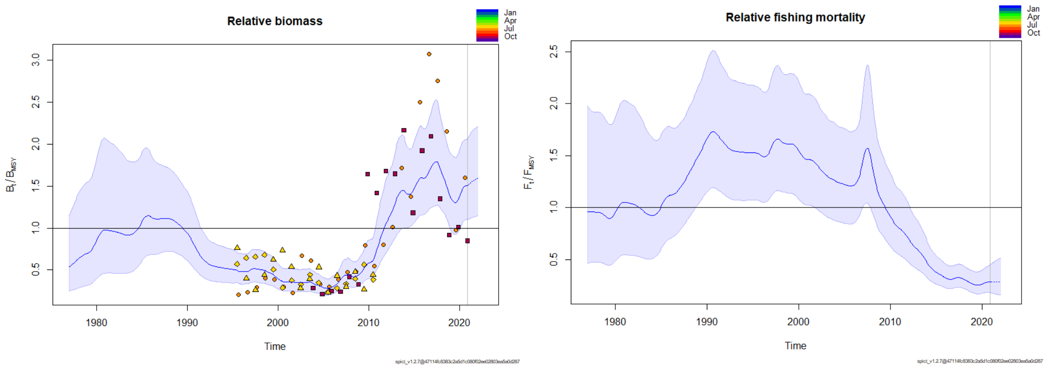


Figure 6.10. Results of the recent (2021) assessment of plaice 7.f.g.

6.6.4.3 Suggested assessment

As plaice assessment in the Bristol Channel and Celtic Sea is supported by abundant age data, it is expected that an application of an age-based model to evaluate the status of this resource might be possible. The state-space assessment model (SAM) (Nielsen, Berg, 2014) from R-library *stockassessment*. This model, with many useful extensions, is implemented in the flexible R package SAM (https://github.com/fishfollower/SAM).

As discard information was available only from the year 2004, and their numbers before that might be only guessed, the original intention was to use only data series for 2004-2020 as containing only reliable data with little of extrapolation. The model itself converged but retro was unacceptable as well as Mohn's Rho (R -0.01408473, SSB 0.47544137, Fbar(3-6), -0.39211535).

Changing M from low values as in plaice of the Irish Sea to higher values as estimated by Gislason (*Gislason* et al., 2010) formula for plaice in the eastern Channel did the output only worse. Both model and retrospective converged, but retro was unacceptable as well as Mohn's Rho (R -0.2651199, SSB 0.3098683, Fbar(3-6), -0.3159965).

To simulate discard survival, the discard proportion was taken as 50% of the average observed values per age class in 2004-2020 assuming that other 50% would survive as never captured. Retro runs did not converge. Results of the assessment as well as Mohn's Rho was still unsatisfactory (R -0.1926721, SSB 0.4688292, Fbar(3-6), -0.3806196)

Therefore, it was decided to run the model for a wider range of years that would include decline in catches from the highest level in late 1980s to the lowest at ~2003-2006 with following stock increase up to 2017 and consequent less noticeable decrease between 2018 and now.

It required reconstruction of discard numbers for a period when they were not recorded and based on the assumption that discarded proportion of fish of the same age was stable during this period, and equal to average for 2004 -2010. For example, mean 11.214% of 2 y.o. fish were landed in 2004-2010. As ~426 thousand of 2.y.o fish were landed in 1998, the total catch of this age group in this year was estimated as ~3799 thousand and discards as ~3373 (catch minus landings).

The assessment was carried using the following input parameters (Table 6.6). Input data files and input configuration files are provided in the Appendix A (Tables A1-A12). Output results with uncertainty intervals are presented in Tables A13-A14 for two different natural mortalities used.

Table 6.6. Biological and fisheries information used in the SAM assessment.

Years of assessment	2022	
Assessment model	SAM	
Assessment software	stockassessment library	
Fleets		
Survey		
UK(E&W)-BTS-Q3	**Age range**	1-5
	Year range	1993-2020
IGFS-WIBTS-Q4	**Age range**	1-7
	Year range	2003-2020
UK commercial beam trawl	**Age range**	3-8
	Year range	1990-2010
UK commercial otter trawl	**Age range**	2-8
	Year range	1989-2010
Catch/Landings		
Age range	1–10+	
Landings data:	1989-2020	
Discards data	2004-2020	
Model settings		
Fbar:	3–6	

	Selectivity model	Correlated random walk
	Mortality	Fixed across years, different across ages. Two variants explored: mortality of plaice of Irish Sea with relatively low values (0.107-0.139) similar to previously used 0.12 mortality as estimated by Gislason (Gislason et al., 2010) equation for plaice in the Eastern Channel (0.244-0.685) (ICES 2015)
	Maturity	Fixed across years, different across ages. For a period 1989-2000 the previous values (based on data of 1993-1994) were used. For a period 2001-2020 new values (based on data of 2004-2020) were used
	discards survival	0

6.6.4.4 Diagnostics and comparative performance of the model with the different assumptions about natural mortality.

Convergence and Akaike Criteria

The model converged at both assumptions about natural mortality. The AIC was 1338.53 for the run low M and 1317.763 for the run using high M.

Residuals

The difference in residuals between two runs (Figure 6.11) was hardly distinguishable so a preferred run could not be selected based on residual diagnostics.

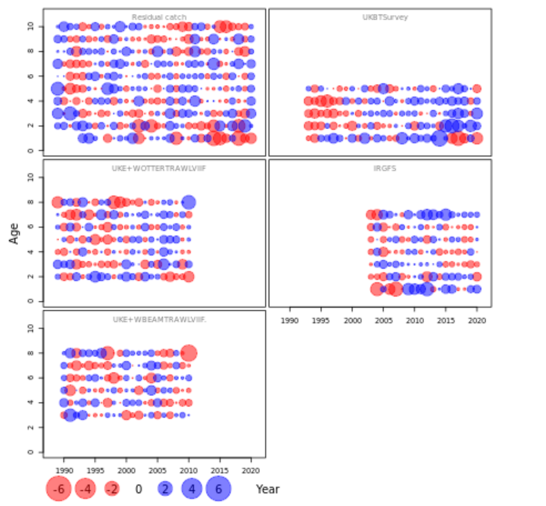
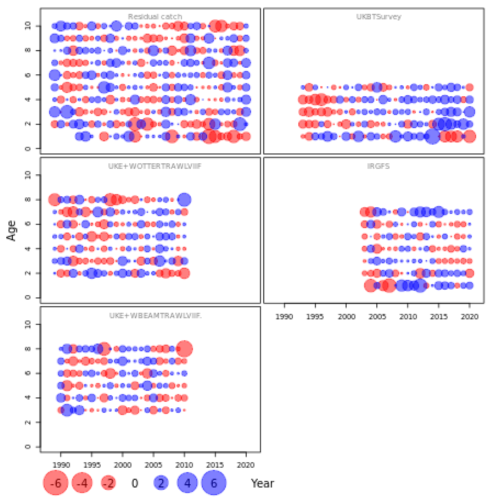
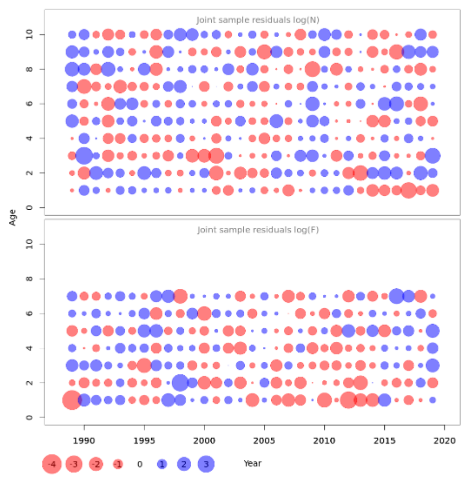
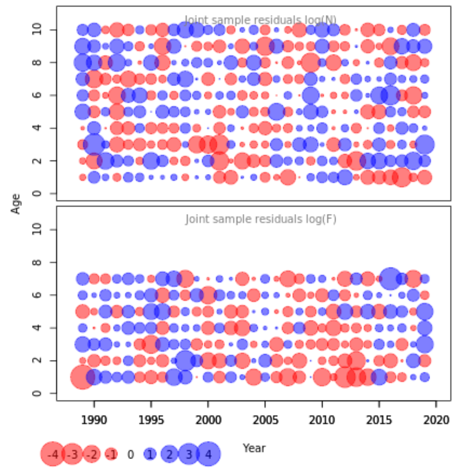
M as in plaice of Irish Sea (low)	M as estimated by Gislason equation for the Eastern Channel (high)
	
	

Figure 6.11 Residuals for two different mortalities used (series-specific on the top and joint residuals on the bottom)

Retrospective

Both retrospective runs converged with satisfactory reconstructions laying within confidence intervals of the original assessment (Figure 6.12) and similar Mohn's Rho values (Table 6.7). As discussed at the Benchmark, high values of Mohn's Rho in respect to recruitment might be not entirely relevant as dynamics of the spawning biomass and F_{BAR} are of importance for the advice. If only values for SSB and F_{BAR} are considered, usage of higher M demonstrated better retrospective.

Table 6.7. Mohn's Rho in retrospective with two different mortalities used

Mortality	R	SSB	F_{BAR}
M as in plaice of Irish Sea (low)	-0.371	-0.092	0.101
M as estimated by Gislason equation for the Eastern Channel (high)	-0.442	-0.041	-0.06

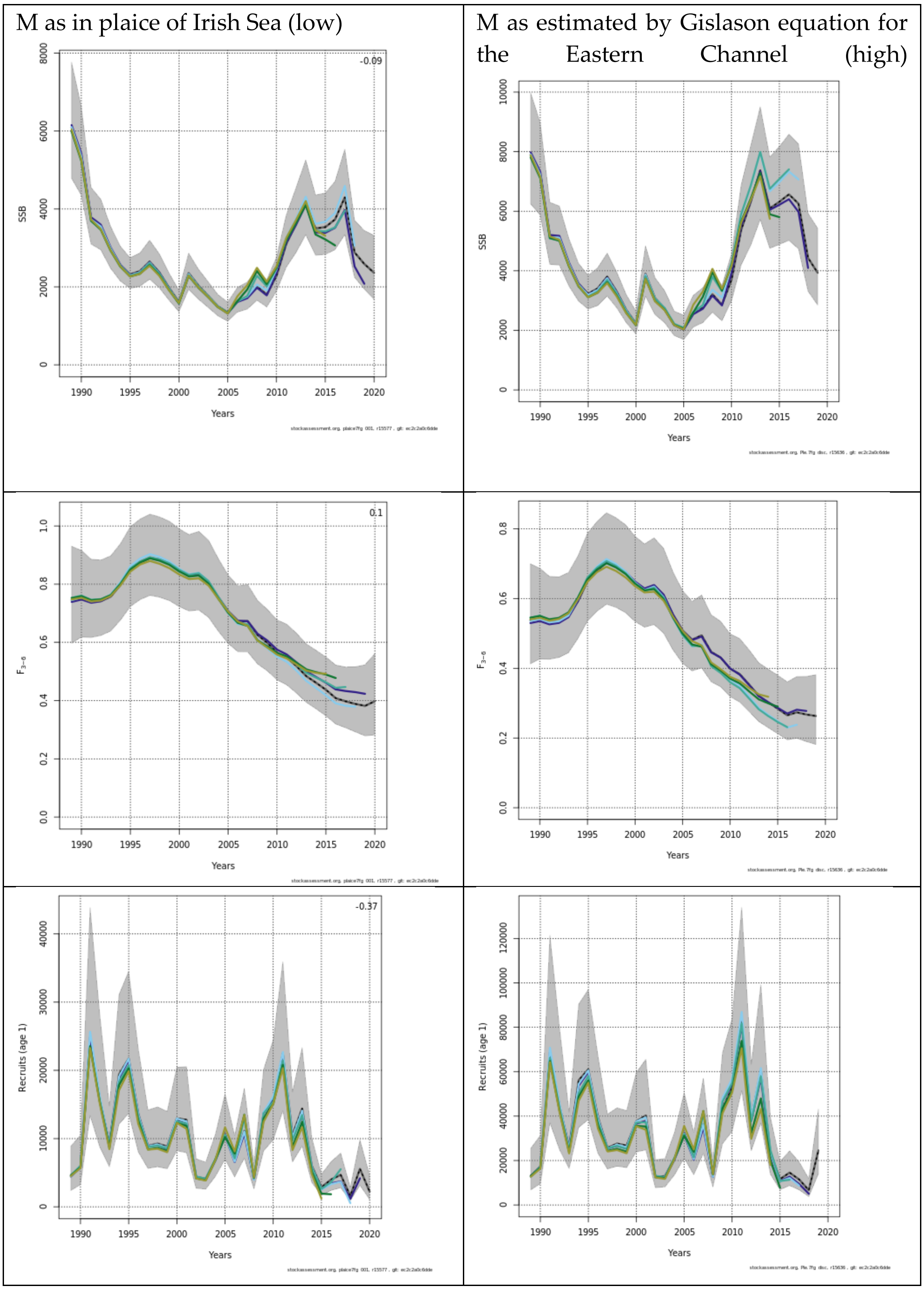
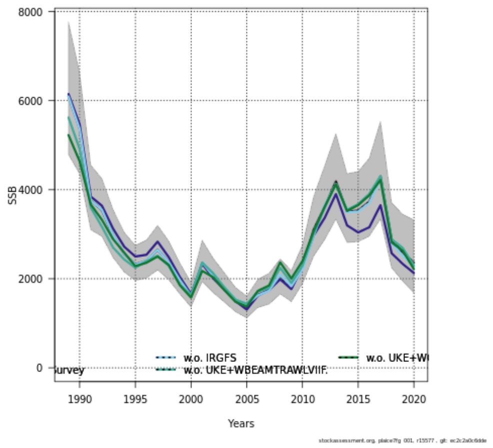


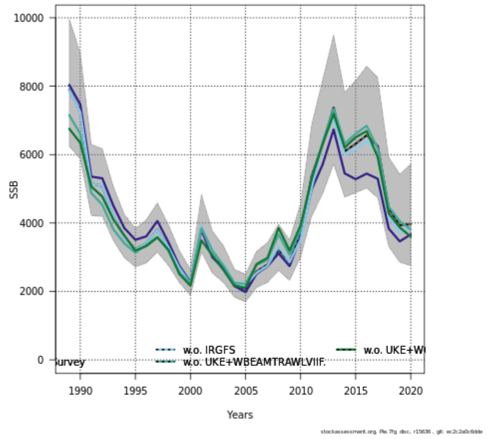
Figure 6.12 Retrospective of model runs for two different mortalities used (SSB, F_{BAR} and R from top to the bottom).

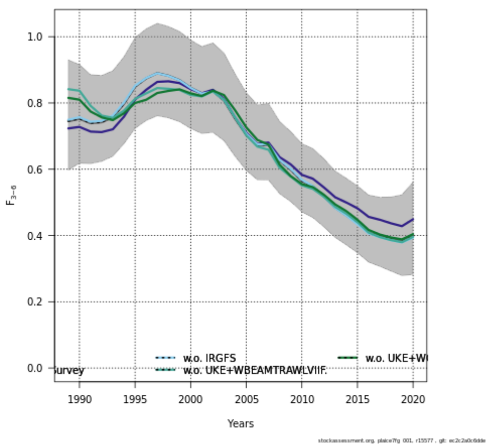
Leave one out

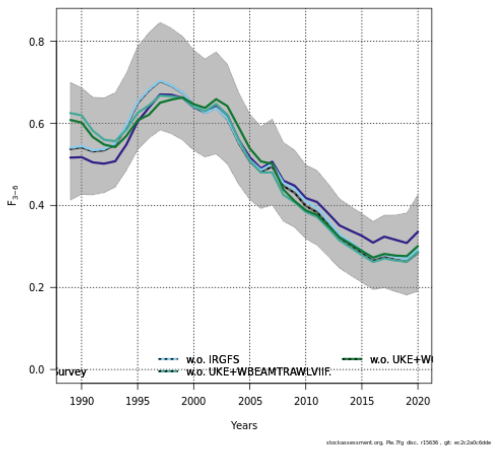
Leave one out run of both versions converged and demonstrated similarly satisfactory performance (Figure 6.13).

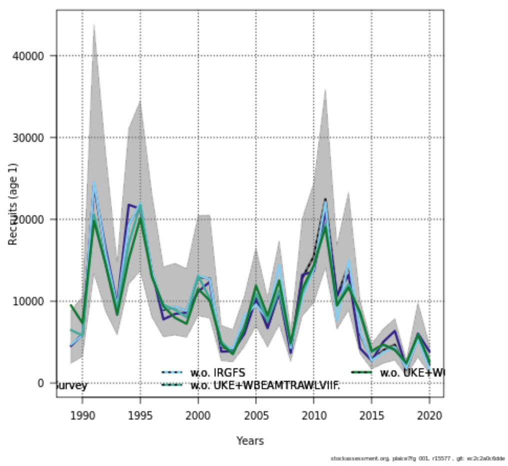
M as in plaice of Irish Sea (low)	M as estimated by Gislason equation for the Eastern Channel (high)











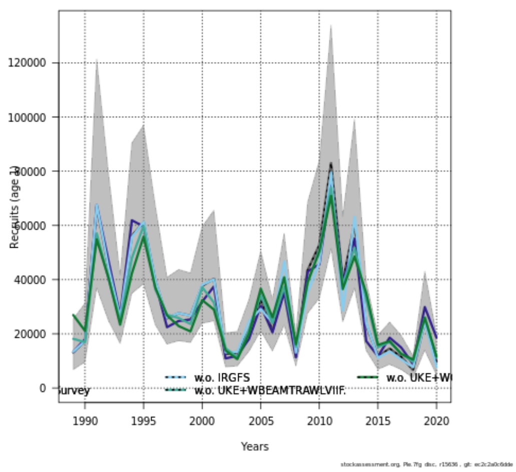


Figure 6.13. Leave one out of model runs for two different mortalities used (SSB, F_{BAR} and R from top to the bottom).

Fitting primary data

Fitplots of the model (Figures 6.14 and 6.15) using different M turned out to be virtually indistinguishable making neither run preferable.

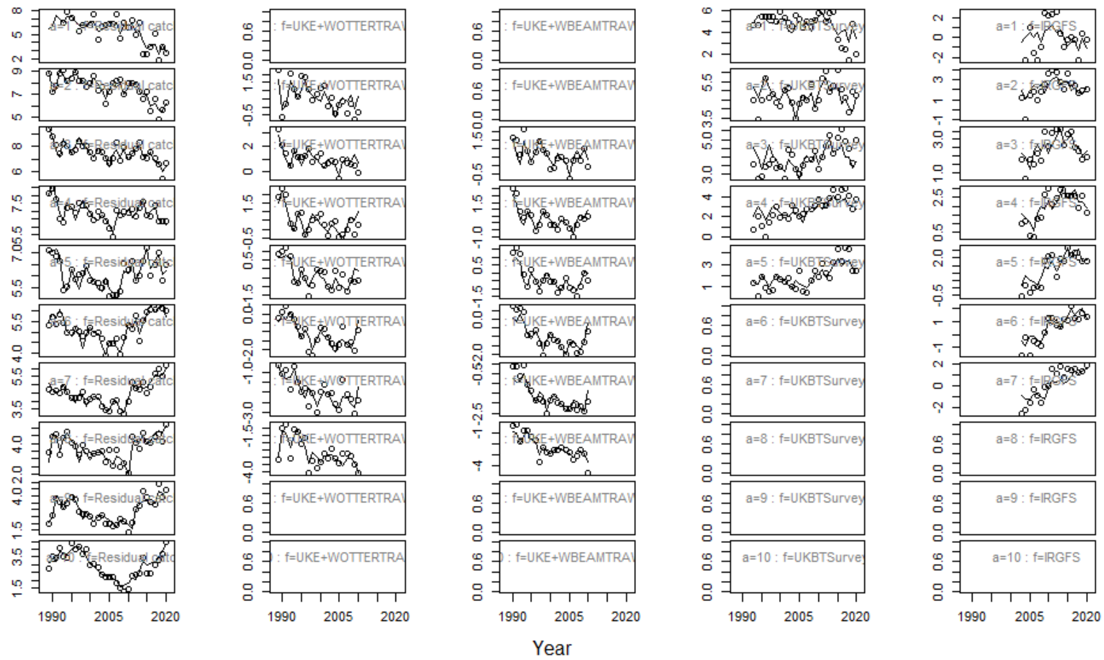


Figure 6.14. Fitplot of the model using M as in plaice of Irish Sea (low)

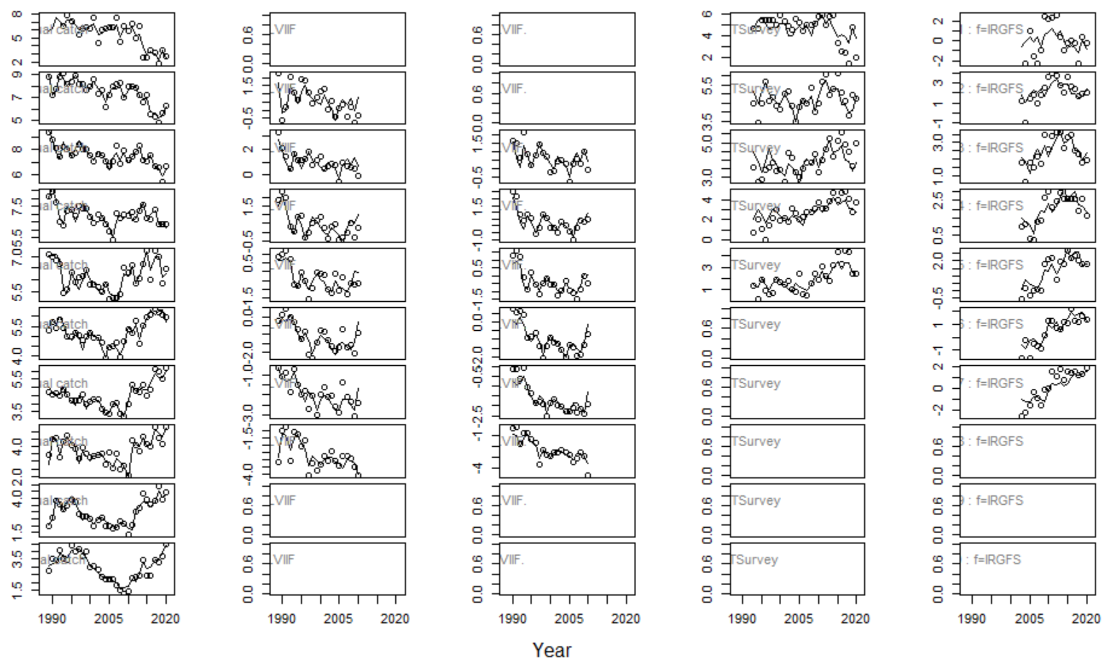


Figure 6.15. Fitplot of the model using M as estimated by Gislason equation for the Eastern Channel (high).

Fishery selectivity

Data on fishery selectivity are presented in Figures 6.A1 and 6.A2 (section 6.10). Runs using both, low and high, M lead to model to result in suggestion that during the fishing history the F was gradually increasing in elder age groups.

6.7 Short-term projections

Status Quo short-term projections of the model with two different mortalities are presented on figures 6.16 and 6.17 and primary numbers in Table A16. Short-term forecast for fishing at F_{MSY} are presented in tables A17 and A18.

Both trends are similar and predicted slow increase of SSB, stability of fishing mortality of fish of the commercial size, and slight increase in recruitment.

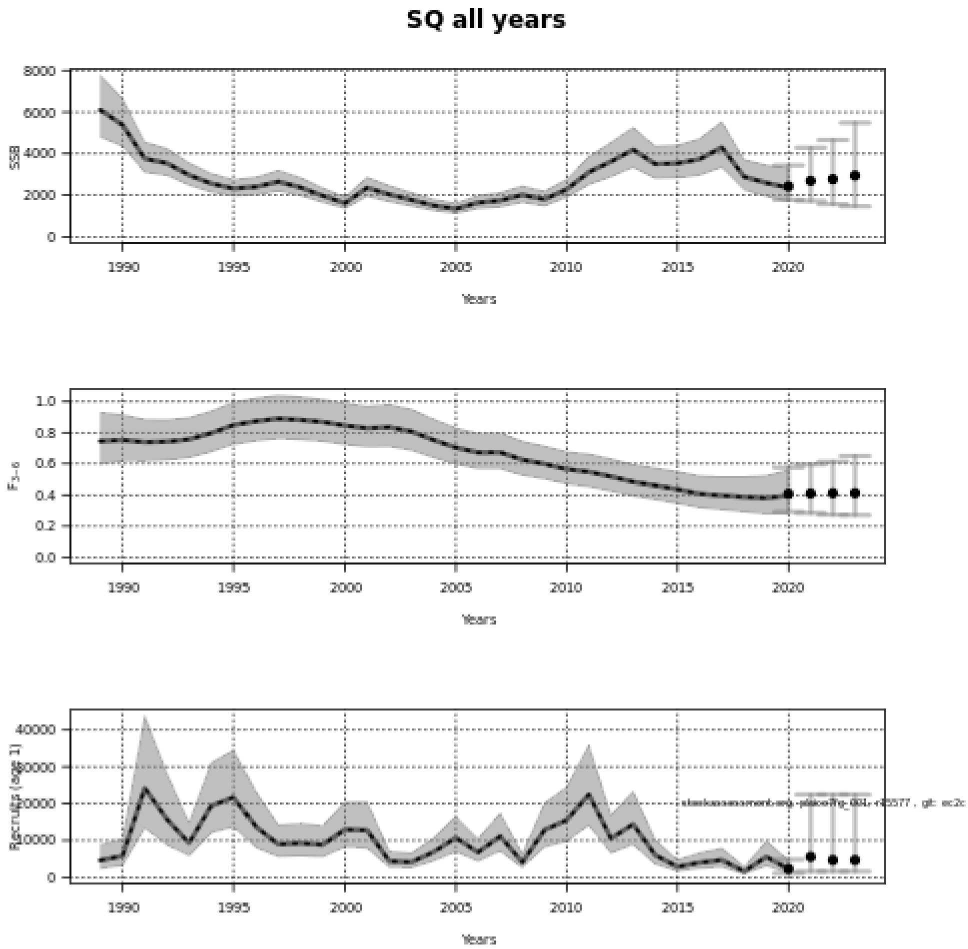


Figure 6.16. Short-term projections of the model using M as in plaice of Irish Sea (low)

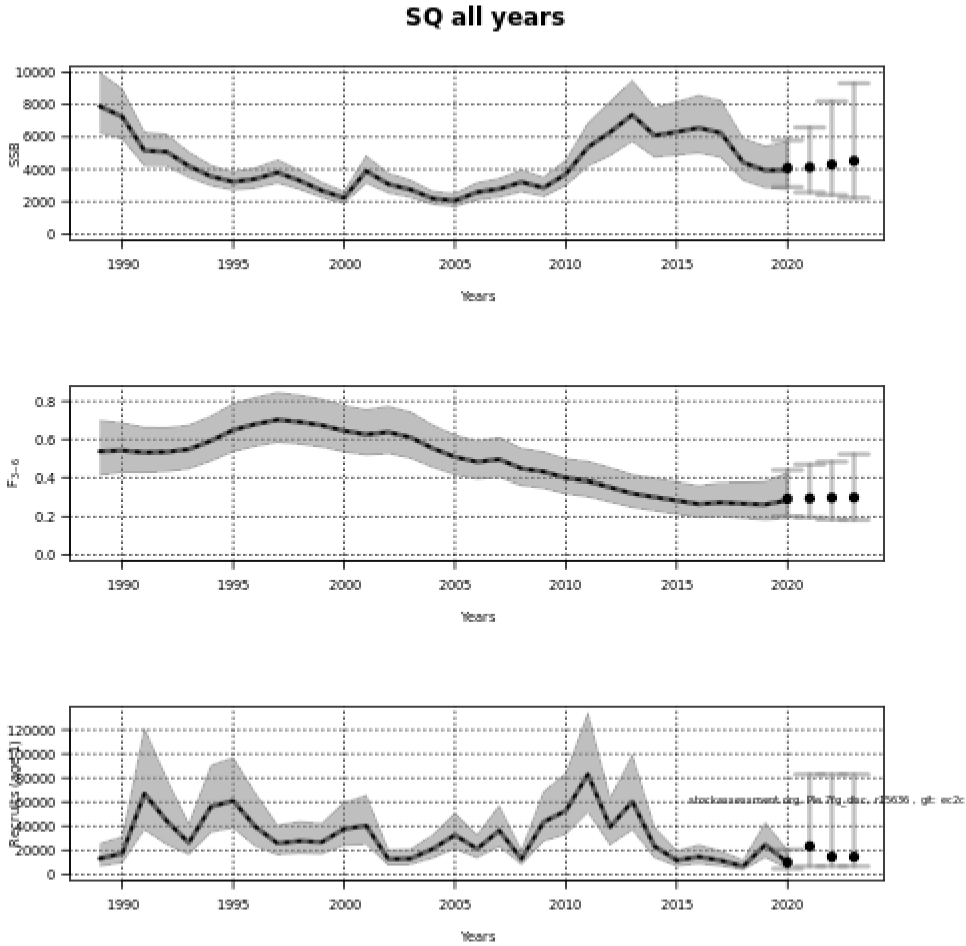


Figure 6.17 Short-term projections of the model using M as estimated by Gislason equation for the Eastern Channel (high)

6.8 Appropriate Reference Points (MSY)

The two runs produced different estimations of current (2019-2020) and historically high (1989-1990) SSB: some ~ 6000 t and 2500 t at low M and ~7500 t and ~4000 t at high M respectively. Consequently it impacted estimated reference (Table 6.8). Illustrative materials are presented in the Appendix.

Table 6.8. Estimated reference points

Reference Point	Value at low M	Value at high M	Rationale
MSY Btrigger	1,882 t	2,885t	Lower 5th percentile of BMSY; in tonnes
Fmsy	0.147	0.468	Stochastic simulations with segmented regression
FmsyLower	0.098	0.258	Median lower point estimates of Stochastic simulations
FmsyUpper	0.228	0.803	Median upper point estimates of Stochastic simulations
Blim	1,344t	2,061t	Lowest observed SSB
Bpa	1,882t	2885t	Blim combined with the assessment error
Flim	1.17	1.51	F with 50% probability of SSB less than Blim
Fpa	0.84	1.08	Flim combined with the assessment error

Resulting estimation of the stock status were similar and suggested that SSB is above Bpa so has full reproductive capacity (figures 6.18 and 6.19), which is in agreement with previous assessment by SPiCT.

However, assessment of fishing mortality was different. At low natural mortality Fbar was assessed always to be above F_{MSY} thus suggesting that stock dynamics nearly entirely is driven by the fishery. Meanwhile if high M was assumed, the Fbar was estimated to be below F_{MSY} for more than 10 years allows assuming that from ~ year 2007 the main forces shaping the stock abundance are of natural origin, not a human impact.

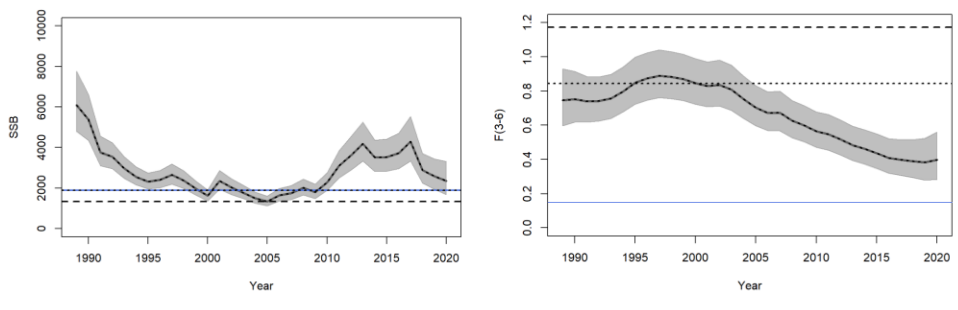


Figure 6.18. Stock and fishing mortality dynamics in respect to the reference points with low M assumed. SSB: solid line – MSY Btrigger, dotted line – Bpa, dashed line Blim. Fbar: solid line – F_{MSY}, dotted line – Fpa, dashed line – Flim.

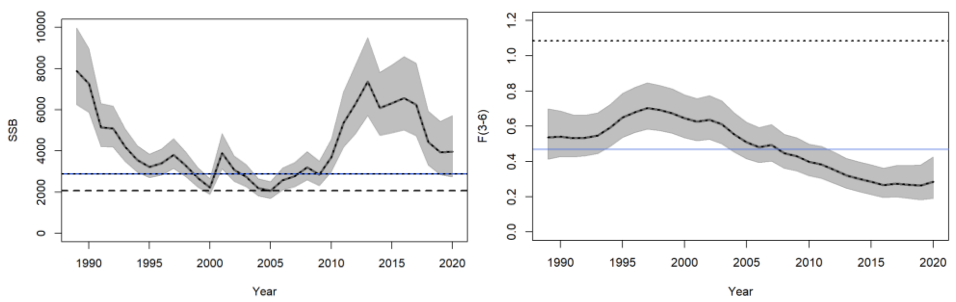


Figure 6.19. Stock and fishing mortality dynamics in respect to the reference points with high M assumed. SSB: dotted/solid line – MSY Btrigger and Bpa; dashed line – Blim. Fbar: dotted line – Fpa, solid line – F_{MSY}.

Therefore, the SAM performance in respect to estimation of reference points turned out to be highly sensitive to assumed natural mortality as the model splits "observed" total mortality between M and F. Relatively low natural mortality is "compensated" by increase of F creating output suggesting that fishing mortality is >F_{MSY}. As M is low, reduced fishing pressure should cause a large increase of the stock and high yield.

Vice-versa, at high values of M the fishing mortality was estimated to be relatively low and to be below F_{MSY} for more than 10 years that suggest that F is not limiting the stock.

This trade-off might be clarified only by reliable knowledge of M. Judging from AIC and retrospective (Mohn's Rho) the run based on high natural mortality (Gislason) is preferable for advice.

6.9 Future Research and data requirements

The plaice is a difficult fish to age, and the last otolith exchange workshop on its otoliths from the stock of Celtic Sea and Bristol Channel (2019) concluded that the threshold established by WKARP 2010 for plaice ageing (agreement = 85% and CV = 5%) was not achieved during the meeting and recommended that regular otolith exchanges, both internally and externally should be organised in order to learn and to improve the agreements between readers. Neither such agreement was achieved before by otolith exchange analysis for plaice in divisions 7.h-k (Celtic Sea South, Southwest of Ireland (2019) making plaice aging a larger issue.

As the model turned out to be highly sensitive to assumptions about M when estimating reference points (though not for estimation of stock trends), more work is required to get realistic values of this parameter. Tagging studies are recommended as our knowledge is based on tag-recapture data collected long time ago, in 1979-1980 and 1993-1996. Since then, the local ecosystem might change significantly and consequently interactions between species. Also, ontogenetic migratory pattern of plaice that plays an important role in connectivity between stocks of Irish Sea and Bristol Channel potentially might be subjected to some alterations due to climate changes. As important numbers of plaice are being discarded, such a tagging program should not be problematic.

As plaice in the Irish Sea, English Channel, North Sea and the Celtic Sea show similar interannual trends in abundance, a workshop on environmental factors impacting their stocks might be useful.

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6.11 Appendix A

Table 6.A1. Configuration suggested for assessment of plaice in the Bristol Channel and Celtic Sea and its description

```
$minAge
The minimium age class in the assessment
 1

$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 0 0

$keyLogFsta
Coupling of the fishing mortality states processes for each age (normally only
the first row (= fleet) is used).
  0  1  2  3  4  5  6  6  6  6
 -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 -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.3: Separable AR - Included for historic reasons.

```
 0

$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 -1
  0  1  2  3  4 -1 -1 -1 -1 -1
  5  6  7  8  9 10 10 -1 -1 -1
 -1 -1 11 12 13 14 15 15 -1 -1
 -1 16 17 18 19 20 21 21 -1 -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 -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

```
  0  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 -1 -1
 -1 -1 -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.

```
 0 1 1 1 1 1 1 1 1 1

$keyVarObs
```

Coupling of the variance parameters for the observations.

```
  0  0  0  0  0  0  0  0  0  0
  1  1  1  1  1 -1 -1 -1 -1 -1
  2  2  2  2  2  2  2 -1 -1 -1
 -1 -1  3  3  3  3  3  3 -1 -1
 -1  4  4  4  4  4  4  4 -1 -1

$obsCorStruct
```

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

"ID" "AR" "AR" "AR" "AR"

$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).

```
 NA  NA  NA  NA  NA  NA  NA  NA  NA
  0   0   0   0  -1  -1  -1  -1  -1
  1   1   1   1   1   1  -1  -1  -1
 -1  -1   2   2   2   2   2  -1  -1
 -1   3   3   3   3   3   3  -1  -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).
3

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

$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 and 5 TSB index).
-1 -1 -1 -1 -1

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

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

$fracMixF
The fraction of t(3) distribution used in logF increment distribution
0

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

```
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 0 0


$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 NA NA NA NA NA
 -1 -1 -1 -1 -1 -1 -1 NA NA NA
 NA NA -1 -1 -1 -1 -1 -1 NA NA
 NA -1 -1 -1 -1 -1 -1 -1 NA NA

$hockeyStickCurve
 20

$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)
 0

$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))
 0

$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)
 0

$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)
 0

$keyMortalityMean
 NA NA NA NA NA NA NA NA NA NA
```

Table 6.A2. Catch numbers

```
cn.dat auto written
1 2
1989  2020
```

1 10
1

NA	7107.2	11421.4	3479.3	1205.9	198.9	111.3
	30.1	7.0	16.0			
NA	1462.5	6685.6	4673.1	1066.0	300.8	97.6
	87.8	13.0	33.0			
NA	2488.0	3448.9	2297.1	940.6	222.5	106.7
	97.8	47.0	32.0			
NA	7134.0	1692.3	687.4	766.5	341.8	90.8
	26.3	35.0	61.0			
679.3	9084.2	3794.5	546.4	225.6	230.2	130.3
	77.1	25.6	33.4			
2755.9	3812.2	3009.8	1405.6	267.1	144.8	97.3
	115.4	32.1	32.4			
1171.7	4354.4	1840.6	1430.4	544.0	145.2	65.2
	59.8	51.9	79.9			
NA	7238.3	2362.1	990.7	356.4	170.2	66.7
	46.2	42.3	53.5			
228.3	3748.0	4240.4	1788.6	443.3	150.6	67.8
	25.3	17.3	65.0			
464.8	3798.8	2963.8	1634.9	467.1	119.7	92.7
	48.8	15.0	41.3			
610.6	2166.9	3158.1	1543.8	605.7	144.6	51.2
	34.4	14.9	53.9			
508.8	2854.5	1949.0	927.3	330.7	180.4	60.2
	27.2	12.2	19.8			
2049.0	5806.2	1192.7	621.0	323.2	134.2	69.8
	28.3	7.1	21.1			
82.5	1511.5	2125.3	1046.1	297.7	140.3	73.8
	30.4	11.1	16.5			
409.8	2132.2	1836.1	894.4	243.5	105.8	38.8
	32.7	13.5	10.7			
460.5	486.3	1219.4	599.0	329.3	48.7	30.7
	16.2	7.5	9.2			
595.5	1412.4	768.3	383.1	174.6	84.7	28.3
	35.7	7.1	9.3			
554.2	2915.3	1208.1	213.7	180.8	87.8	51.3
	13.3	6.3	8.9			
1837.1	3461.1	3921.4	1154.3	185.2	108.1	57.0
	35.2	6.6	6.2			
87.6	3864.5	973.0	836.0	214.0	51.0	29.7
	12.0	10.3	4.4			
673.4	1112.4	2667.0	1106.0	672.3	112.3	24.4
	15.3	8.6	3.6			
387.5	2853.6	1240.4	979.7	535.6	206.0	52.2
	7.8	3.9	4.0			
961.4	2790.6	1754.6	1226.5	749.1	174.6	168.2
	84.2	7.6	9.6			
143.8	2602.1	2438.0	792.2	343.6	326.5	122.8
	57.5	20.6	10.2			

617.2	1346.8	3906.7	1383.2	421.5	98.7	113.5
	40.4	28.2	11.3			
13.0	749.9	1229.1	2056.1	766.8	252.5	173.2
	105.9	75.9	32.0			
12.2	1333.6	1175.5	862.5	1357.2	394.0	90.2
	63.7	52.0	11.7			
31.4	243.8	1941.6	816.1	410.8	437.1	128.2
	56.7	35.7	11.5			
169.8	772.6	1135.5	1637.0	645.0	422.8	290.7
	87.0	30.6	19.3			
5.9	124.0	730.2	566.3	1060.7	506.0	399.1
	99.8	139.2	26.6			
33.0	288.1	241.7	576.1	336.3	446.8	253.0
	63.3	52.5	38.6			
14.2	546.0	827.7	577.5	650.4	398.0	485.1
	194.3	85.8	84.9			

Table A3. Catch weights
cw.dat auto written
1 2
1989 2020
1 10
1

0.095	0.131	0.185	0.255	0.334	0.465	0.577
	0.641	0.809	1.074			
0.095	0.141	0.201	0.266	0.329	0.440	0.534
	0.593	0.741	0.976			
0.095	0.140	0.207	0.288	0.369	0.507	0.623
	0.685	0.868	1.309			
0.095	0.140	0.218	0.321	0.420	0.581	0.702
	0.747	0.924	1.106			
0.094	0.140	0.203	0.291	0.381	0.532	0.607
	0.659	0.813	1.123			
0.096	0.144	0.201	0.286	0.353	0.532	0.746
	0.659	0.807	1.109			
0.096	0.139	0.200	0.269	0.372	0.536	0.670
	0.678	0.844	1.209			
0.095	0.139	0.197	0.262	0.388	0.496	0.502
	0.833	0.971	1.142			
0.097	0.144	0.200	0.266	0.360	0.585	0.697
	0.778	0.816	1.176			
0.095	0.140	0.204	0.278	0.358	0.537	0.623
	0.629	0.873	1.303			
0.095	0.141	0.192	0.253	0.344	0.484	0.585
	0.747	1.001	1.243			
0.097	0.140	0.199	0.272	0.368	0.485	0.633
	0.776	0.995	1.329			
0.097	0.145	0.211	0.287	0.360	0.499	0.636
	0.633	0.743	1.207			

0.097	0.143	0.193	0.258	0.340	0.441	0.518
	0.763	0.856	1.308			
0.095	0.144	0.205	0.264	0.343	0.455	0.614
	0.621	0.885	1.233			
0.124	0.180	0.229	0.291	0.347	0.503	0.594
	0.732	0.849	1.108			
0.101	0.146	0.214	0.304	0.373	0.499	0.599
	0.532	0.901	1.104			
0.068	0.123	0.206	0.283	0.337	0.476	0.546
	0.616	0.717	0.922			
0.089	0.131	0.174	0.204	0.308	0.395	0.504
	0.516	0.858	1.123			
0.120	0.121	0.204	0.255	0.330	0.421	0.506
	0.683	0.813	1.116			
0.089	0.143	0.162	0.190	0.238	0.361	0.450
	0.491	0.642	0.905			
0.086	0.133	0.177	0.228	0.239	0.387	0.575
	0.469	0.745	1.334			
0.118	0.153	0.193	0.196	0.276	0.424	0.446
	0.490	0.748	1.524			
0.106	0.129	0.190	0.234	0.290	0.332	0.375
	0.469	0.560	0.690			
0.097	0.136	0.188	0.256	0.319	0.463	0.464
	0.523	0.594	0.828			
0.075	0.122	0.160	0.204	0.254	0.347	0.363
	0.512	0.484	1.241			
0.137	0.134	0.159	0.208	0.264	0.367	0.361
	0.401	0.568	1.492			
0.153	0.161	0.194	0.233	0.307	0.355	0.465
	0.529	0.867	0.612			
0.141	0.044	0.136	0.224	0.599	0.479	0.519
	0.867	0.832	1.205			
0.150	0.152	0.172	0.213	0.235	0.272	0.358
	0.498	0.360	1.063			
0.099	0.129	0.207	0.243	0.268	0.328	0.343
	0.512	0.577	0.604			
0.102	0.144	0.162	0.198	0.227	0.260	0.306
	0.396	0.405	0.595			

Table 6.A3. Discard weights

dw.dat auto written
1 2
1989 2020
1 10
1

0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			

0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.091	0.125	0.153	0.167	0.191	0.262	0.344
	0.387	0	0			
0.123	0.152	0.177	0.194	0.212	0.337	0.230
	0.455	0.000	0.000			
0.095	0.127	0.154	0.188	0.202	0.344	0.403
	0.419	0.000	0.000			
0.064	0.107	0.154	0.176	0.201	0.242	0.395
	0.349	0.000	0.000			
0.088	0.126	0.159	0.163	0.204	0.249	0.368
	0.425	0.000	0.000			
0.092	0.110	0.154	0.172	0.211	0.282	0.365
	0.283	0.000	0.000			
0.088	0.127	0.127	0.127	0.143	0.194	0.200
	0.257	0.000	0.000			
0.085	0.125	0.143	0.149	0.163	0.189	0.445
	0.523	0.000	0.000			
0.118	0.148	0.173	0.168	0.225	0.304	0.339
	0.389	0.000	0.000			
0.105	0.124	0.168	0.192	0.239	0.247	0.238
	0.337	0.398	0.365			
0.096	0.129	0.179	0.232	0.277	0.459	0.380
	0.312	0.562	0.882			
0.075	0.118	0.146	0.177	0.211	0.276	0.301
	0.481	0.373	1.357			
0.136	0.129	0.147	0.177	0.225	0.319	0.213
	0.210	0.404	1.770			

0.148	0.153	0.177	0.205	0.261	0.288	0.341
	0.416	0.462	0.000			
0.140	0.147	0.186	0.225	0.258	0.324	0.271
	0.290	0.460	0.282			
0.105	0.126	0.150	0.190	0.182	0.209	0.325
	0.358	0.246	0.942			
0.084	0.118	0.169	0.196	0.180	0.183	0.159
	0.258	0.256	0.179			
0.095	0.127	0.143	0.161	0.172	0.180	0.187
	0.298	0.215	0.157			

Table 6.A4. Landings weights

lw.dat auto written
1 2
1989 2020
1 10
1

0.102	0.176	0.255	0.337	0.423	0.514	0.608
	0.706	0.809	1.074			
0.240	0.270	0.309	0.358	0.416	0.483	0.560
	0.646	0.741	0.976			
0.200	0.260	0.327	0.400	0.481	0.567	0.661
	0.761	0.868	1.309			
0.148	0.257	0.362	0.464	0.563	0.658	0.750
	0.839	0.924	1.106			
0.171	0.263	0.314	0.405	0.500	0.598	0.643
	0.728	0.813	1.123			
0.236	0.296	0.308	0.397	0.455	0.598	0.801
	0.728	0.807	1.109			
0.219	0.254	0.304	0.364	0.485	0.603	0.714
	0.752	0.844	1.209			
0.000	0.247	0.295	0.349	0.512	0.553	0.523
	0.947	0.971	1.142			
0.249	0.291	0.304	0.357	0.466	0.663	0.745
	0.877	0.816	1.176			
0.213	0.256	0.317	0.380	0.463	0.604	0.661
	0.690	0.873	1.303			
0.213	0.268	0.278	0.332	0.440	0.538	0.618
	0.839	1.001	1.243			
0.245	0.260	0.302	0.370	0.479	0.539	0.672
	0.875	0.995	1.329			
0.268	0.305	0.340	0.398	0.466	0.556	0.675
	0.695	0.743	1.207			
0.246	0.284	0.281	0.343	0.433	0.484	0.541
	0.859	0.856	1.308			
0.205	0.295	0.321	0.353	0.439	0.502	0.651
	0.681	0.885	1.233			
0.221	0.258	0.287	0.330	0.382	0.514	0.649
	0.750	0.849	1.108			

0.237 0.260 0.295 0.356 0.425 0.525 0.631
0.714 0.901 1.104
0.238 0.246 0.291 0.339 0.385 0.513 0.549
0.638 0.717 0.922
0.278 0.271 0.277 0.303 0.389 0.457 0.537
0.547 0.858 1.123
0.260 0.273 0.298 0.329 0.386 0.433 0.511
0.719 0.813 1.116
0.279 0.267 0.275 0.329 0.376 0.469 0.499
0.605 0.642 0.905
0.233 0.292 0.331 0.328 0.376 0.458 0.598
0.469 0.745 1.334
0.228 0.242 0.283 0.335 0.378 0.465 0.600
0.690 0.748 1.524
0.235 0.246 0.280 0.307 0.345 0.418 0.498
0.570 0.626 0.760
0.273 0.285 0.286 0.320 0.370 0.465 0.517
0.602 0.601 0.807
0.190 0.256 0.300 0.327 0.365 0.445 0.443
0.526 0.546 1.096
0.230 0.275 0.282 0.307 0.370 0.472 0.530
0.567 0.701 1.480
0.211 0.253 0.278 0.318 0.365 0.416 0.510
0.570 1.003 0.612
0.231 0.279 0.289 0.325 0.370 0.426 0.460
0.590 0.654 1.093
0.198 0.228 0.262 0.297 0.326 0.407 0.468
0.515 0.640 1.090
0.206 0.231 0.277 0.306 0.337 0.377 0.376
0.513 0.578 0.705
0.185 0.225 0.245 0.275 0.310 0.318 0.358
0.415 0.453 0.644

Table 6.A5. Stock weights

sw.dat auto written
1 2
1989 2020
1 10
1
0.095 0.131 0.185 0.255 0.334 0.465 0.577
0.641 0.809 1.074
0.095 0.141 0.201 0.266 0.329 0.440 0.534
0.593 0.741 0.976
0.095 0.140 0.207 0.288 0.369 0.507 0.623
0.685 0.868 1.309
0.095 0.140 0.218 0.321 0.420 0.581 0.702
0.747 0.924 1.106
0.094 0.140 0.203 0.291 0.381 0.532 0.607
0.659 0.813 1.123

0.096	0.144	0.201	0.286	0.353	0.532	0.746	0.659	0.807	1.109
0.096	0.139	0.200	0.269	0.372	0.536	0.670	0.678	0.844	1.209
0.095	0.139	0.197	0.262	0.388	0.496	0.502	0.833	0.971	1.142
0.097	0.144	0.200	0.266	0.360	0.585	0.697	0.778	0.816	1.176
0.095	0.140	0.204	0.278	0.358	0.537	0.623	0.629	0.873	1.303
0.095	0.141	0.192	0.253	0.344	0.484	0.585	0.747	1.001	1.243
0.097	0.140	0.199	0.272	0.368	0.485	0.633	0.776	0.995	1.329
0.097	0.145	0.211	0.287	0.360	0.499	0.636	0.633	0.743	1.207
0.097	0.143	0.193	0.258	0.340	0.441	0.518	0.763	0.856	1.308
0.095	0.144	0.205	0.264	0.343	0.455	0.614	0.621	0.885	1.233
0.124	0.180	0.229	0.291	0.347	0.503	0.594	0.732	0.849	1.108
0.101	0.146	0.214	0.304	0.373	0.499	0.599	0.532	0.901	1.104
0.068	0.123	0.206	0.283	0.337	0.476	0.546	0.616	0.717	0.922
0.089	0.131	0.174	0.204	0.308	0.395	0.504	0.516	0.858	1.123
0.120	0.121	0.204	0.255	0.330	0.421	0.506	0.683	0.813	1.116
0.089	0.143	0.162	0.190	0.238	0.361	0.450	0.491	0.642	0.905
0.086	0.133	0.177	0.228	0.239	0.387	0.575	0.469	0.745	1.334
0.118	0.153	0.193	0.196	0.276	0.424	0.446	0.490	0.748	1.524
0.106	0.129	0.190	0.234	0.290	0.332	0.375	0.469	0.560	0.690
0.097	0.136	0.188	0.256	0.319	0.463	0.464	0.523	0.594	0.828
0.075	0.122	0.160	0.204	0.254	0.347	0.363	0.512	0.484	1.241
0.137	0.134	0.159	0.208	0.264	0.367	0.361	0.401	0.568	1.492
0.153	0.161	0.194	0.233	0.307	0.355	0.465	0.529	0.867	0.612
0.141	0.044	0.136	0.224	0.599	0.479	0.519	0.867	0.832	1.205
0.150	0.152	0.172	0.213	0.235	0.272	0.358	0.498	0.360	1.063

0.099	0.129	0.207	0.243	0.268	0.328	0.343
	0.512	0.577	0.604			
0.102	0.144	0.162	0.198	0.227	0.260	0.306
	0.396	0.405	0.595			

Table A6 Landing fraction
lf.dat auto written
1 2
1989 2020
1 10
1

0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.036	0.112	0.311	0.519	0.614	0.805	0.881
	0.797	1	1			
0.012	0.26	0.474	0.715	0.794	0.938	0.87
	0.938	1	1			
0.039	0.143	0.426	0.692	0.765	0.858	0.859
	0.384	1	1			
0.022	0.114	0.379	0.654	0.74	0.863	0.981
	0.925	1	1			
0.004	0.038	0.131	0.295	0.563	0.704	0.807
	0.744	1	1			
0.167	0.07	0.35	0.53	0.678	0.922	0.966
	0.917	1	1			

0.004	0.115	0.235	0.312	0.407	0.608	0.836
	0.673	1	1			
0.006	0.047	0.18	0.439	0.356	0.738	0.847
	1	1	1			
0.001	0.048	0.186	0.169	0.331	0.742	0.411
	0.335	1	1			
0.013	0.041	0.199	0.365	0.478	0.5	0.528
	0.565	0.709	0.808			
0.005	0.047	0.078	0.274	0.452	0.678	0.614
	0.728	0.824	0.732			
0.003	0.031	0.09	0.177	0.28	0.422	0.434
	0.698	0.644	0.455			
0.015	0.037	0.086	0.236	0.271	0.317	0.468
	0.532	0.555	0.99			
0.077	0.081	0.171	0.246	0.443	0.522	0.735
	0.736	0.748	1			
0.018	0.165	0.072	0.261	0.117	0.19	0.318
	0.277	0.355	0.567			
0.489	0.258	0.196	0.216	0.37	0.316	0.231
	0.89	0.289	0.838			
0.121	0.098	0.35	0.431	0.557	0.752	0.85
	0.995	0.994	0.808			
0.086	0.179	0.187	0.328	0.394	0.575	0.695
	0.837	0.799	0.9			

Table A7. Maturity ogive
mo.dat auto written
1 2
1989 2020
1 10
1

0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			

0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.26	0.52	0.86	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			
0	0.62	0.81	0.94	1	1	1
	1	1	1			

Table 6.A8. Natural mortality as in plaice of Celtic Sea

nm.dat auto written
1 2
1989 2020
1 10

1

0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			

0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			
0.139	0.128	0.124	0.122	0.119	0.115	0.11
	0.107	0.107	0.107			

Table 6.A.9 Natural mortality as estimated by Gislason equation for the plaice of East English Channel

1989	2020					
1	10					
1						
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			

0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			
0.685	0.483	0.407	0.353	0.309	0.277	0.244
	0.244	0.244	0.244			

Table 6.A10. Proportion of fishing mortality

pf.dat auto written
1 2
1989 2020
1 10
1

0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			

```
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
0	0	0	0	0	0	0
	0	0	0
```

Table 6.A11. Proportion of natural mortality.

```
pm.dat auto written
1 2
1989  2020
1  10
1
0	0	0	0	0	0	0
	0	0	0
```

0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			
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0	0	0	0	0	0	0
	0	0	0			
0	0	0	0	0	0	0
	0	0	0			

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Table A12. Survey indices
survey.dat auto written
104
UKBTSurvey
1993 2020
1 1 0.8 0.8
1 5
1 101.81 90.32 36.56 1.97 3.94
1 107.22 31.6 15.79 7.9 1.19
1 239.59 90.48 17.23 2.96 6.84
1 223.69 288.11 30.78 0.99 2.62
1 225.37 102.14 34.54 4.25 1.77
1 237.2 126.22 46.99 8.92 2
1 152.59 79.62 29.03 19.67 7
1 339.63 63.17 31.25 6.56 5.5
1 211.44 156.14 15.81 8.74 4.23
1 136.74 175.12 80.45 5.93 6.13
1 98.37 80.48 60.95 21.83 2.72
1 258.51 33.41 27.08 13.42 2.19
1 192.5 75.22 20.87 8.06 10.93
1 85.78 101.97 34.16 9.57 1.79
1 150.4 92.25 47.26 15.11 1.67
1 140.69 217.04 6.79 15.7 4.82
1 161.81 55.96 78.58 21.45 10.89
1 331.76 88.54 26.41 39.94 6.68
1 362.26 300.14 55.04 21.86 21.37
1 142.13 430.79 100.57 22.36 9.02
1 329.79 139.06 185.39 46.85 5.77
1 371.76 202.3 64.65 105.7 23.8
1 28.36 454.08 162.34 52.37 76.66
1 12.52 163.1 268.26 102.3 27.5
1 11.49 104.1 137.39 121.11 91.87
1 4.15 45.26 90.2 58.1 75.08
1 114.94 138.97 38.18 15.37 11.19
1 7.17 113.19 139.61 42.71 11.95
IRGFS
2003 2020
1 1 0.855 0.855

1 7

1 NA 3.23 6.04 2.69 0.56 0.2
0.07

1 0.1 0.4 1.9 3.1 1.2 0.8
0.1

1 2.8 4.4 5.9 1.3 0.7 0.2
0.2

1 0.2 6 4.6 1.2 1 0.6
0.7

1 0.1 2.6 8.5 3.5 1.1 0.5
0.4

1 0.4 6 5.6 3.8 1 0.4
0.2

1 12.5 11.7 32.3 14.6 5.9 1.2
0.9

1 10.1 37.9 13.2 20.8 8.6 3.7
1

1 10.8 49.5 30.2 8.4 9.1 3.6
4.6

1 14.6 40.5 36.8 11.3 2.1 2
2.9

1 1.5 16.1 37.3 19.7 7.2 1.9
6.2

1 0.4 7.9 14.3 13.6 6.1 3.4
2.2

1 0.8 37.8 28.2 13 15.2 3
5

1 1.1 13.8 33.6 13.9 9.2 9
4.2

1 0.8 11.5 12.8 13 10.8 3.7
4.6

1 0.1 5.5 9.8 6.6 7.9 3.2
3.2

1 1.6 7.2 5.8 13.1 5.8 5.1
4

1 0.8 8.1 7 5.1 5.9 3.8
6.6

UKE+WBEAMTRAWLVIIF.

1990 2010

1 1 0.5 0.5

3 8

1	5.392	12.6	3.656	2.103	0.868	0.725
1	4.402	8.372	5.158	1.715	0.894	0.834
1	1.923	2.254	3.289	1.93	0.528	0.162
1	8.514	1.528	0.947	1.498	0.923	0.443
1	2.393	2.245	0.424	0.415	0.347	0.446
1	1.298	1.715	1.289	0.43	0.252	0.278
1	2.251	0.569	0.569	0.535	0.159	0.184
1	4.291	0.909	0.319	0.256	0.169	0.026
1	2.6	2.221	0.618	0.127	0.151	0.095
1	2.102	1.72	0.844	0.252	0.078	0.062

1 0.833 0.858 0.568 0.405 0.156 0.057
1 0.876 0.867 0.558 0.318 0.186 0.076
1 1.557 0.637 0.294 0.279 0.143 0.079
1 1.727 1.349 0.393 0.199 0.135 0.094
1 1.402 1.051 0.711 0.136 0.104 0.08
1 0.483 0.671 0.396 0.269 0.102 0.061
1 1.368 0.353 0.338 0.233 0.12 0.03
1 1.755 0.853 0.227 0.142 0.099 0.043
1 1.34 1.506 0.433 0.158 0.117 0.075
1 2.733 1.375 0.968 0.271 0.09 0.054
1 0.947 1.601 0.62 0.508 0.146 0.009
UKE+WOTTERTRAWLVIIF
1989 2010
1 1 0.5 0.5
2 8
1 9.357 26.291 6.366 2.37 0.766 0.518
0.041
1 0.521 7.857 10.452 2.774 1.074 0.333
0.35
1 1.257 4.334 7.29 3.415 1.529 0.413
0.46
1 7.613 1.625 1.391 2.059 0.946 0.156
0.045
1 3.051 5.074 1.065 0.479 0.754 0.491
0.335
1 1.878 3.274 2.407 0.433 0.498 0.225
0.273
1 6.533 3.137 2.5 0.948 0.276 0.138
0.121
1 6.056 3.492 0.725 0.574 0.422 0.169
0.186
1 2.893 5.925 0.953 0.208 0.121 0.069
0.017
1 1.509 2.128 1.664 0.387 0.097 0.135
0.039
1 2.124 3.085 1.997 0.961 0.228 0.051
0.025
1 3.279 4.055 2.327 0.882 0.458 0.141
0.035
1 3.655 1.617 1.326 0.809 0.42 0.194
0.065
1 1.081 2.017 0.696 0.36 0.264 0.12
0.048
1 1.723 2.326 1.335 0.302 0.187 0.129
0.086
1 0.671 2.231 1.622 0.905 0.14 0.078
0.047
1 1.153 0.616 0.628 0.331 0.171 0.057
0.034
1 1.396 2.542 0.736 0.703 0.487 0.26
0.065

1	0.676 0.063	1.892	0.939	0.276	0.175	0.125
1	1.251 0.056	1.758	1.645	0.52	0.197	0.098
1	0.472 0.03	1.584	0.731	0.472	0.122	0.046
1	0.744 0.018	0.903	1.311	0.496	0.407	0.089

Table A13. Estimated recruitment, spawning stock biomass (SSB), and average fishing mortality using low M (plaice of Irish Sea).

Year	R Low	Low High	High TSB	SSB Low	Low High	High	Fbar
1989	4610 0.597	2392 0.930	8884 11391	6099 8846	4790 14669	7767	0.745
1990	5838 0.618	3242 0.916	10513 7808	5375 6383	4355 9551	6634	0.753
1991	24203 0.617	13364 0.885	43836 7159	3757 5644	3099 9082	4555	0.739
1992	15739 0.624	8789 0.883	28183 7693	3541 6162	2952 9606	4249	0.742
1993	9309 0.639	5862 0.898	14784 6244	2968 5125	2478 7608	3554	0.757
1994	19411 0.677	12111 0.940	31111 5869	2558 4758	2149 7238	3044	0.798
1995	21730 0.723	13688 0.997	34497 6167	2323 4945	1962 7692	2749	0.849
1996	13643 0.747	8040 1.024	23150 6423	2404 5149	2014 8012	2871	0.874
1997	8943 0.761	5633 1.040	14199 5862	2651 4807	2198 7148	3198	0.890
1998	9267 0.755	5870 1.031	14631 4877	2372 4041	1976 5885	2847	0.882
1999	8843 0.743	5586 1.016	13998 4081	1973 3381	1655 4927	2352	0.869
2000	12969 0.723	8221 0.990	20460 3892	1616 3167	1365 4783	1914	0.846
2001	12754 0.708	7923 0.970	20530 4344	2356 3484	1937 5417	2865	0.829

2002	4382 0.711	2726 0.981	7045 3013	2034 2486	1685 3652	2457	0.835
2003	4123 0.686	2592 0.951	6561 2592	1772 2151	1473 3124	2132	0.807
2004	6895 0.638	4469 0.888	10638 2649	1504 2164	1255 3243	1802	0.753
2005	10725 0.596	6958 0.831	16532 2781	1344 2225	1120 3475	1613	0.704
2006	6777 0.568	4389 0.794	10464 2595	1640 2128	1354 3164	1987	0.672
2007	11117 0.567	7122 0.799	17354 3205	1742 2578	1429 3986	2124	0.673
2008	4112 0.526	2641 0.744	6404 3048	2012 2500	1657 3716	2443	0.626
2009	12835 0.502	8189 0.714	20117 3341	1802 2687	1485 4155	2187	0.599
2010	15499 0.471	9815 0.677	24475 4139	2283 3332	1888 5141	2760	0.565
2011	22473 0.454	14067 0.662	35903 6666	3103 5140	2504 8646	3846	0.548
2012	10530 0.425	6580 0.631	16851 5804	3619 4594	2883 7332	4544	0.518
2013	14399 0.394	8889 0.595	23325 6452	4190 5138	3338 8102	5259	0.484
2014	6015 0.371	3574 0.573	10123 4567	3503 3671	2815 5681	4360	0.461
2015	2858 0.347	1706 0.550	4785 4566	3535 3647	2833 5716	4410	0.437
2016	3995 0.320	2412 0.522	6616 4872	3732 3871	2958 6132	4710	0.408
2017	4687 0.307	2789 0.516	7876 5194	4300 4092	3340 6592	5536	0.398
2018	1604 0.293	905 0.516	2841 3435	2885 2690	2245 4387	3709	0.389
2019	5565 0.279	3151 0.523	9829 3371	2590 2552	1945 4452	3448	0.382
2020	2234 0.282	1078 0.561	4627 2954	2361 2105	1679 4146	3320	0.398

Table A14. Estimated recruitment, spawning stock biomass (SSB), and average fishing mortality using high M (Gislason for plaice of the Eastern Channel).

Year	R Low	Low High	High TSB	SSB Low	Low High	High	Fbar
1989	13169 0.413	6783 0.700	25567 14814	7893 11598	6245 18921	9974	0.538
1990	17333 0.427	9601 0.687	31293 12192	7258 9888	5870 15032	8975	0.542
1991	66983 0.426	36967 0.664	121371 13703	5154 9964	4217 18847	6300	0.532
1992	44520 0.431	24870 0.662	79694 12889	5088 10101	4193 16446	6174	0.534
1993	26164 0.445	16385 0.675	41779 10370	4208 8413	3488 12783	5076	0.548
1994	56203 0.486	34920 0.723	90457 12683	3563 9568	2985 16812	4254	0.592
1995	61060 0.536	38441 0.788	96991 12816	3232 9696	2716 16941	3846	0.649
1996	39613 0.564	23287 0.821	67386 7754	3407 6131	2832 9808	4099	0.680
1997	25747 0.584	16208 0.847	40900 10955	3806 8817	3154 13611	4593	0.703
1998	27644 0.575	17461 0.832	43767 8862	3302 7135	2757 11007	3955	0.692
1999	26739 0.560	16830 0.812	42484 7594	2684 6038	2254 9551	3196	0.674
2000	37702 0.534	23873 0.779	59542 8587	2233 6506	1882 11333	2649	0.645
2001	40336 0.518	24800 0.757	65605 10804	3899 8071	3143 14463	4837	0.626
2002	12607 0.526	7800 0.774	20378 5617	3085 4506	2528 7002	3764	0.638
2003	13028 0.501	8129 0.744	20881 4867	2745 3923	2260 6037	3335	0.611
2004	21099 0.452	13600 0.676	32731 5289	2199 4096	1826 6829	2648	0.553
2005	32653 0.414	21091 0.623	50553 5973	2061 4525	1693 7886	2508	0.508

2006	21146	13632	32803	2587	2107	3176	0.482	0.392	0.592	4880	3904	6101
2007	36360	23167	57064	2787	2262	3433	0.495	0.401	0.610	6853	5252	8940
2008	12812	8138	20170	3215	2607	3965	0.447	0.361	0.554	5722	4564	7175
2009	43470	27553	68582	2856	2321	3514	0.431	0.347	0.535	7418	5611	9807
2010	52739	33135	83942	3704	2999	4575	0.399	0.319	0.499	9224	6978	12192
2011	83010	51455	133917	5367	4194	6866	0.384	0.303	0.485	16973	12221	23574
2012	39324	24406	63360	6303	4850	8190	0.353	0.275	0.453	12249	9305	16124
2013	60483	36892	99162	7375	5722	9505	0.321	0.247	0.416	15398	11574	20486
2014	23318	13777	39465	6097	4753	7821	0.302	0.229	0.397	9180	7091	11884
2015	11636	6929	19541	6318	4885	8172	0.284	0.212	0.380	9379	7181	12250
2016	14582	8721	24383	6566	5020	8587	0.265	0.195	0.361	9889	7548	12955
2017	11466	6800	19333	6254	4737	8257	0.274	0.199	0.376	8680	6622	11378
2018	6670	3753	11856	4430	3310	5929	0.267	0.190	0.377	5983	4506	7945
2019	24543	13975	43104	3933	2850	5428	0.263	0.182	0.382	6846	4918	9529
2020	9730	4785	19787	3969	2752	5722	0.285	0.191	0.426	5828	4015	8460

Table 6.A15. Status Quo forecast using low natural mortality (m=median, l-low, h-high)

Year	Fbar:m	Fbar:l	Fbar:h	Rec:m	Rec:l	Rec:h	SSB:m	SSB:l	SSB:h	Catch:m	Catch:l	Catch:h
2020	0.409	0.293	0.575	2272	1079	4824	2428	1779	3433	728	597	909
2021	0.411	0.285	0.595	5565	1604	22473	2693	1719	4281	869	620	1250

2022	0.413	0.274	0.613	4687	1604	22473	2773	1564	4653	848	543	1308
2023	0.413	0.272	0.649	4687	1604	22473	2947	1466	5481	888	507	1656

Table A16. Forecast using low natural mortality (m=median, l-low, h-high) and fishing at F_{MSY} (m=median, l-low, h-high)

Year	Fbar:m	Fbar:l	Fbar:h	Rec:m	Rec:l	Rec:h	SSB:m	SSB:l	SSB:h	Catch:m	Catch:l	Catch:h
2020	0.406	0.293	0.559	2264	1097	4833	2450	1754	3356	732	602	897
2021	0.147	0.105	0.22	4687	1604	22473	2715	1690	4034	360	261	496
2022	0.147	0.1	0.223	4687	1604	22473	3319	2026	5628	429	283	662
2023	0.147	0.096	0.233	5565	1604	22473	4089	2263	7800	528	319	961

Table A17. Status Quo forecast using high natural mortality (m=median, l-low, h-high)

Year	Fbar:m	Fbar:l	Fbar:h	Rec:m	Rec:l	Rec:h	SSB:m	SSB:l	SSB:h	Catch:m	Catch:l	Catch:h
2020	0.293	0.201	0.439	9891	4787	20605	4084	2906	5793	738	610	912
2021	0.295	0.195	0.468	23318	6670	83010	4133	2575	6593	831	589	1217
2022	0.299	0.184	0.482	14582	6670	83010	4306	2419	8212	808	506	1297
2023	0.300	0.182	0.522	14582	6670	83010	4525	2237	9325	811	447	1636

Table A18. Forecast using high natural mortality and fishing at F_{MSY} (m=median, l-low, h-high)

Year	Fbar:m	Fbar:l	Fbar:h	Rec:m	Rec:l	Rec:h	SSB:m	SSB:l	SSB:h	Catch:m	Catch:l	Catch:h
2020	0.292	0.199	0.443	9743	4557	19106	4111	2769	5934	745	601	900
2021	0.468	0.314	0.757	23318	6670	83010	4128	2539	6486	1226	866	1727
2022	0.468	0.285	0.808	14582	6670	83010	3852	2028	8316	1026	624	1705

2023	0.468 9325	0.279 955	0.828 521	23318 2066	6670	83010	3950	1876

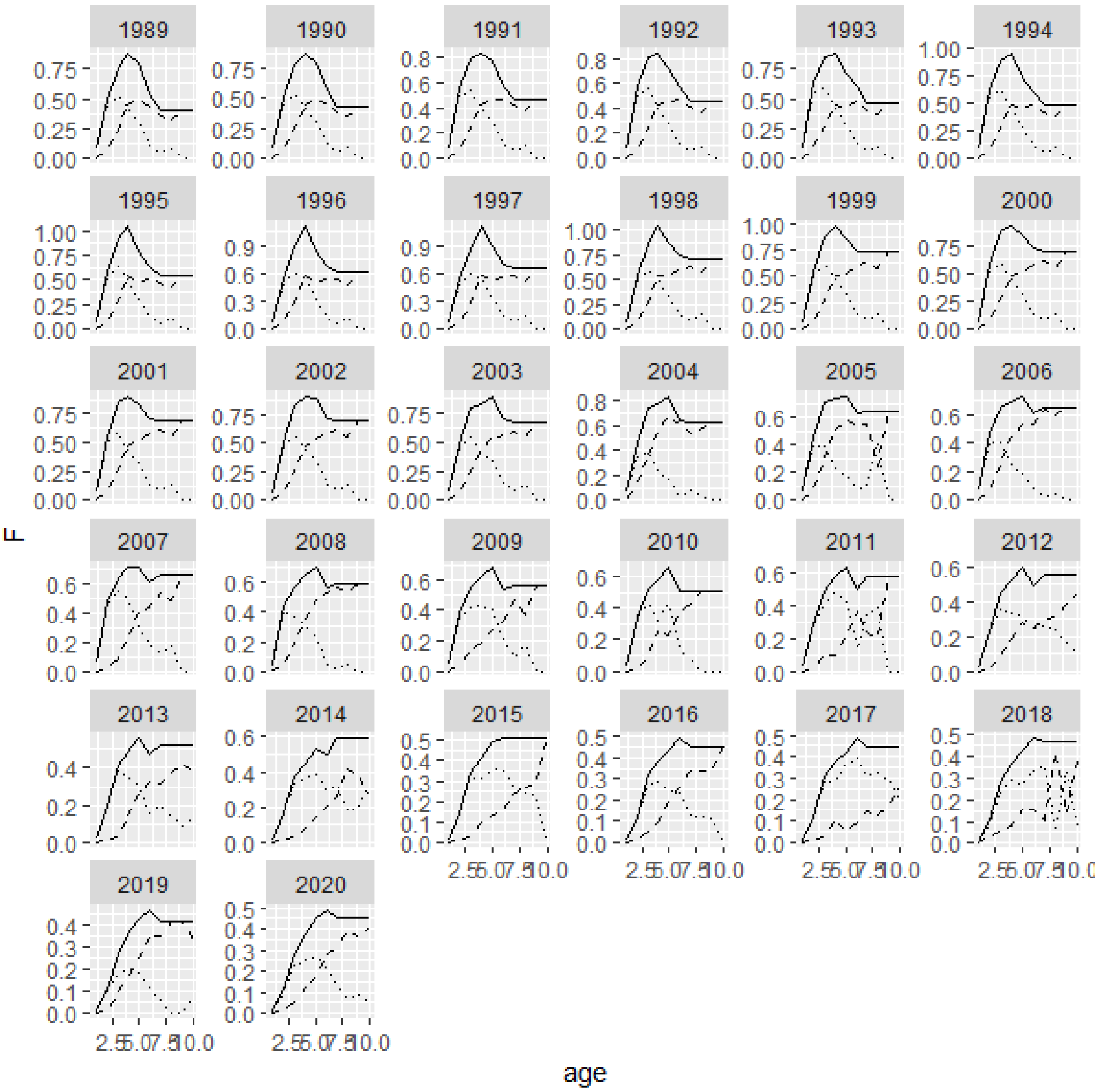


Figure 6.A1 Historical changes in selectivity-at-age between landings (dashed line) and discards (dotted line) with low natural mortality assumed.

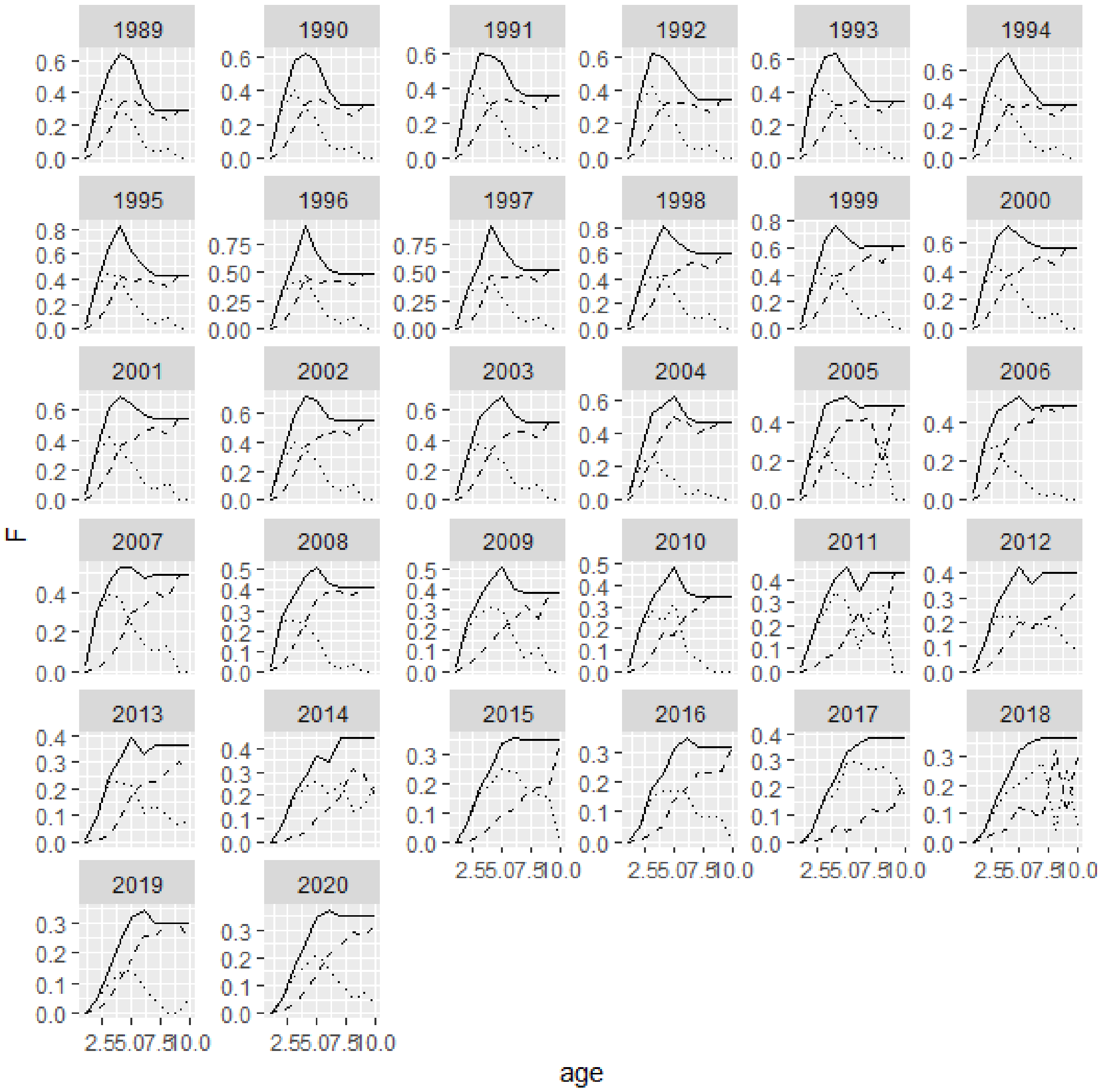
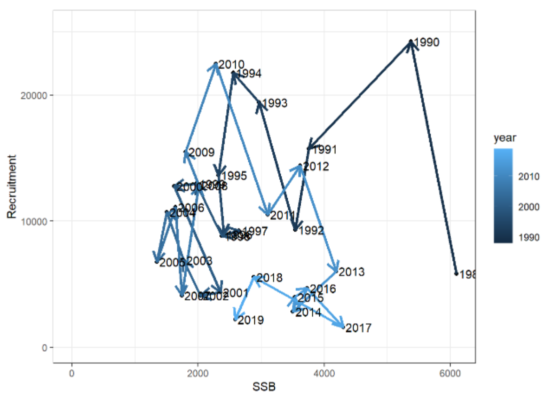


Figure 6.A2. Historical changes in selectivity-at-age between landings (dashed line) and discards (dotted line) with high natural mortality assumed.



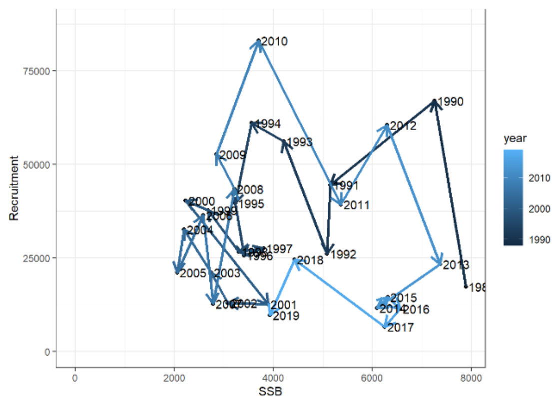


Figure 6.A3. Stock-recruitment fits with low (left) and high (right) natural mortality assumed.

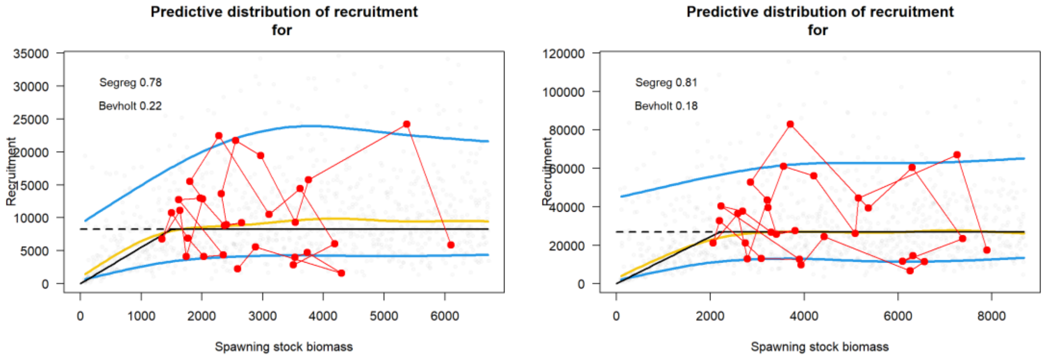


Figure 6.A4. Predictive recruitment distribution with low (left) and high (right) natural mortality assumed.

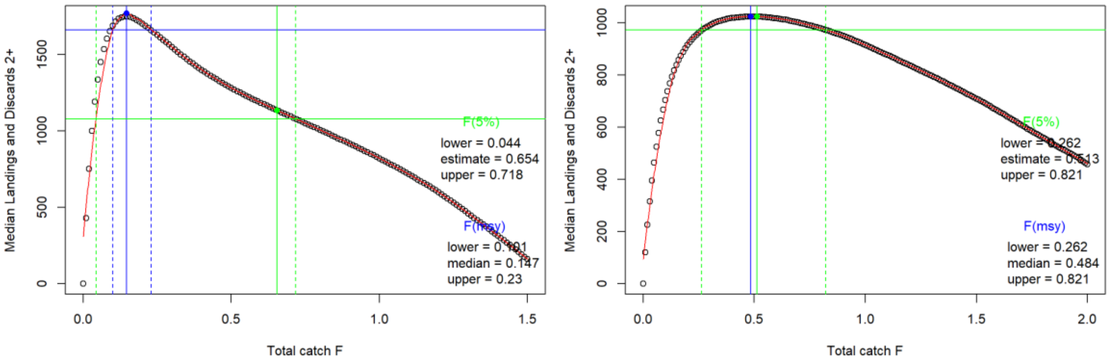


Figure 6.A5. Catch-at-F curves with low (left) and high (right) natural mortality assumed.

7 Haddock (*Melanogrammus aeglefinus*) in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, West of Scotland, Skagerrak) - had.27.46a20

7.1 Stock ID and sub-stock structure

The Northern Shelf haddock stock was formed at the ICES Benchmark Meeting on Northern Haddock Stocks (WKHAD; ICES, 2014) from two previous stocks covering the North Sea and Skagerrak (SubArea 4 and Subdivision 20) and the West Coast of Scotland (Division 6.a). An extensive investigation of the stock ID and sub-stock structure was undertaken at WKHAD. While there was apparent evidence of biological variation at the sub-stock level the connectivity between these populations during early life-history stages was considered high enough for haddock within these areas to be considered a single stock.

7.2 Issue list

The issue list in the table below outlines the issues relating to the Northern Shelf haddock stock and indicates those issues which were addressed at WKNSCS 2022. The primary issue needing to be addressed at WKNSCS 2022 is a change in the assessment model. Support for the existing assessment model (TSA) will become unavailable over the next few years and so a new assessment model needs to be explored.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed at WKNSCS 2022
(New) data to be Considered and/or quantified	SSB is used to indicate both reproductive potential and harvestable biomass, and it may be a poor proxy for both.	Investigate indices of reproductive potential and methods to use them in management advice.	Weight-at-age and fecundity/egg condition data.	Fecundity modelling	No
Stock ID	The stock is considered to be homogenous throughout subareas 4 and 6a, but there may be relevant substock structure.	Explore stock ID and structure, using otolith micro-chemistry, tagging data, and the spatial range of genetic data.	Otolith micro-chemistry, tagging, genetic data.	Stock ID	No
Tuning series	The survey data used in the assessment cover only the North Sea component.	Combining survey indices from the North Sea and West of Scotland.	Survey data covering the North Sea and West Coast of Scotland.	Survey modelling: Andrzej Jaworski (MSS)	Yes
	Indices calculated using other methods may provide indices with better consistency than the currently used DATRAS derived	Explore new survey methods.	Survey data covering the North Sea and West Coast of	Survey modelling: Andrzej Jaworski	Yes

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed at WKNSCS 2022
	survey indices.		Scotland.	(MSS)	
Biological parameters	Maturity is currently fixed through time and knife-edged at age 3.	Derive time-varying maturity estimates following guidelines in WKMOG 2008.	Maturity data from surveys covering the North Sea and West Coast of Scotland.	Maturity modelling: Aaron Brazier (MSS)	Yes
	Mean weight-at-age in the stock is assumed to be equal to the mean weight-at-age in the catch. Mean weights-at-age in the catch are generally found to be an overestimate of mean weight-at-age in the stock and this assumption may be overestimating SSB.	Compare mean weights-at-age in survey data and commercial catch data to derive correction factors to be applied to the catch data to get an estimate of mean weight-at-age in the stock.	Survey data covering the North Sea and West Coast of Scotland. Commercial catch data available in InterCatch.	Weight modelling: Aaron Brazier (MSS)	Yes
Assessment method	TSA support likely unavailable after 2021/22.	Consider alternative models which are compatible with high performance computing (for MSE).	Alternatives likely to use same data as TSA.	SAM: Anders Nielsen (DTU-Aqua).	Yes
	Plus group does not seem to be well fitted in TSA.	Investigate poor fit in plus group in view of increasing relative importance of this age class. This issue may resolve with the move to a new assessment model.	No extra data requirements.	SAM: Anders Nielsen (DTU-Aqua).	Yes
	Exploratory model SURBAR requires further development.	Develop likelihood profiling for ad hoc parameters, and catchability estimation model based on catch curves.	No extra data requirements.	SURBAR: Coby Needle (MSS).	No
	Haddock is characterised by occasional large year-classes, which do not conform to the usual distributional assumptions for modelling recruitment.	Exploration of modelling techniques for sporadic recruitment is needed (mixed distributions etc.). This will be incorporated into the selection of a new assessment model.	No extra data requirements.	SAM: Anders Nielsen (DTU-Aqua)	Yes
Biological Reference Points	Reference points will need to be updated following data, assessment and forecast revisions.	Follow the standard processes where appropriate to generate new reference points.	No extra data requirements.	No external expertise required. Proposed person: Alan Baudron	Yes

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed at WKNSCS 2022
				(MSS)	
Forecast	Growth model used in forecast needs to evaluated.	Ensure consistency between catch components for weight at age cohort modelling. Develop non-spreadsheet approach to forecasting weights.	No extra data requirements.	No external expertise required.	Yes
	Approach for recruitment estimation in the intermediate year needs to be evaluated.	Investigate intermediate year recruitment assumption. Forecast value for recruitment would benefit from including information on the probability of large year classes occurring.	No extra data requirements.	Statistical modelling:	Yes
Other	There appear to be SOP issues in InterCatch data.	Ensure consistency in catch data used in assessment and advice sheet.	InterCatch database.	InterCatch experts: Henrik Kjems-Nielsen (ICES)	Yes
	Ecosystem drivers for long term forecasts/MSE need investigating.	Explore density dependence effects. Explore environmental drivers with consideration to climate change.	Environmental and biological time-series.	Ecosystem modelling:	No

7.3 Multispecies and mixed fisheries issues

ICES mixed fisheries considerations are given each year for Northern Shelf haddock. The benchmark did not concentrate on multispecies considerations.

7.4 Ecosystem drivers

An extensive discussion on ecosystem drivers was provided at WKHAD (ICES, 2014). Aspects of the biology and ecology of Northern Shelf haddock which are relevant to the data and assessment are discussed in the corresponding sections of this report.

7.5 Stock Assessment

7.5.1 Catch – quality, misreporting, discards

Prior to the data compilation meeting for WKNSCS 2022 in November 2021, a data call was issued requesting national data on landings, discards, sample information (age and length compositions) and effort (disaggregated by quarter and métier) for 2002 to 2020. However, Scotland were unable to submit data from before 2008 at this time and since Scotland provides the majority of the data for this stock, the update to InterCatch data only included data from 2008 onwards.

7.5.1.1 Data in InterCatch

The total catches by country imported into InterCatch are shown in Figure 7.1. The vast majority of the catch is taken by Scotland with significant contributions from Denmark and Norway. There are 4 components to the total catch – landings, discards, industrial bycatch and Below Minimum Size (BMS) landings. Industrial bycatch used to be a larger component of the catch but has been a relatively minor component since 2002. Reporting of BMS landings started with the introduction of the EU Landing Obligation for haddock in 2016. The quantities of BMS landings reported so far have been small.

The split of landings and discards by metier are shown in Figure 7.2 and tables 7.1 and 7.2. The landings predominately come from the OTB_DEF_>=120_0_0_all metier whereas the discards are split more or less equally between the OTB_DEF_>=120_0_0_all and the OTB_CRU_70-99_0_0_all metiers. Before 2017, a minor part of the catch was taken by the OTB_DEF_>=120_0_0_all_FDF metier when the Fully Documented Fisheries (FDF) scheme was in operation. When the share of the catch by metier is broken down by country it can be seen that the catch is dominated by the Scottish OTB_DEF_>=120_0_0_all metier.

The proportion of the catch that is sampled is high for this stock (Figure 7.3). The majority of sampled catch is provided by Scotland though contributions from Norway and Denmark are also significant. On average, discard estimates are provided for ~92% of the landings over the time-series. The average proportion of the landings and discards for which age distributions are provided is similarly high; 91% and 98% respectively. Scotland is the only country to provide sampling information for BMS landings although reliable estimates were unavailable in 2017. The proportion of the BMS landings for which age distributions are provided was inconsistent at first but has been high in the most recent years (2019-2020, average of 92%). The majority of the total abundance in all age classes comes from sampled data.

Table 7.1. Northern Shelf haddock. Percentage of landings by metier over time from data imported into InterCatch. Industrial bycatch landings are recorded under the MIS_MIS_0_0_0_IBC metier. Metiers that individually account for less than 0.35% of the total landings across 2008-2020 are aggregated under "Minor metiers".

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2008-2020
OTB_DEF_>=120_0_0_all	80.84	83.98	71.13	76.62	77.70	74.76	75.73	71.98	78.06	88.40	90.07	88.42	84.57	79.88
OTB_DEF_>=120_0_0_all_FDF			10.04	1.49	1.66	12.64	12.41	17.56	11.69	0.21	0.18	0.21	0.05	5.66
OTB_CRU_70-99_0_0_all	8.16	9.59	8.04	7.07	6.24	2.76	1.98	1.10	0.54	1.17	0.83	0.85	0.59	3.73
OTB_CRU_90-119_0_0_all	2.20	2.14	1.48	2.33	2.67	1.73	2.19	1.84	1.10	1.26	1.20	0.95	0.64	1.70
SSC_DEF_>=120_0_0_all	0.28	0.24	0.69	0.77	0.99	1.56	1.49	1.64	1.50	3.04	1.42	1.37	2.32	1.33
MIS_MIS_0_0_0_HC	1.60	0.09	0.25	4.84	4.24	0.29	0.21	0.12	0.33	0.23	0.46	1.04	4.52	1.32
SDN_DEF_>=120_0_0_all	0.66	1.23	1.48	1.44	1.33	0.61	1.10	1.25	0.93	0.95	1.16	1.95	0.37	1.10
OTB_DEF_100-119_0_0_all	3.17	0.75	0.90	0.71	1.04	0.70	0.43	0.45	1.18	1.32	1.13	0.99	0.29	1.00
LLS_FIF_0_0_0_all	0.04	0.04	0.15	0.19	0.08	0.79	0.85	1.03	0.63	0.75	0.87	0.86	0.27	0.52
GNS_DEF_all_0_0_all	0.02	0.01	0.03	0.04	0.02	0.82	0.60	0.66	0.75	0.63	0.74	0.73	0.49	0.44
OTB_DEF_100-119_0_0	1.05	0.62	0.29	0.54	0.39	0.39	0.51	0.26	0.22	0.15	0.11	0.28	0.11	0.38
SSC_DEF_100-119_0_0_all	0.04			0.00	0.19	0.59	0.17	0.75	1.23	0.53	0.53	0.29	0.18	0.36
MIS_MIS_0_0_0_IBC	0.00	0.00	0.00	0.00	0.05	0.38	0.16	0.06	0.10	0.02	0.09	0.60	3.57	0.35
Minor metiers	1.95	1.31	5.53	3.95	3.40	1.98	2.15	1.31	1.75	1.33	1.19	1.47	2.03	2.24

Table 7.2. Northern Shelf haddock. Percentage of discards by metier over time from data imported into InterCatch. Metiers that individually account for less than 0.35% of the total landings across 2008-2020 are aggregated under "Minor metiers".

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2008-

														2020
OTB_CRU_70-99_0_0_all	55.80	62.95	41.80	52.66	51.89	30.21	37.89	53.68	33.16	39.25	30.04	46.67	40.83	47.59
OTB_DEF_>=120_0_0_all	40.83	34.62	50.50	35.45	32.86	52.99	46.04	36.66	60.69	59.42	64.71	47.01	36.66	44.21
OTB_CRU_90-119_0_0_all	1.08	2.19	4.44	7.72	12.97	3.66	1.45	1.11	0.43	0.81	1.01	1.12	2.02	2.98
OTB_DEF_>=120_0_0_all_FDF			2.93	1.36	0.37	10.09	13.99	6.28	4.46					2.12
OTB_CRU_100-119_0_0_all	0.00			0.03					0.13		0.15	0.45	15.06	1.03
OTB_DEF_100-119_0_0_all	0.53		0.00	0.03	0.16	0.08	0.09	0.41	0.49	0.30	3.80	0.32	0.03	0.40
Minor métiers	1.76	0.24	0.32	2.75	1.75	2.97	0.53	1.86	0.63	0.23	0.29	4.43	5.39	1.67

7.5.1.2 Catch estimation in InterCatch

The current raising procedure in InterCatch uses the "all to all" approach in that there is no stratification by gear type, area or season (e.g. quarter). This is true for raising discard estimates as well as allocating age distributions and mean weights-at-age. The rationale for this is that the overwhelming majority of the catch comes from the Scottish TR1 fleet and so stratifying by gear type/area/season would make little difference. However, the sensitivity to stratification by gear type and season was investigated at WKNSCS 2022. The details of this examination can be found in WD-5. Overall, very little difference was seen in the raised discards, estimated age distributions and mean weights-at-age and so the current "all to all" raising procedure was followed.

A couple of issues with the current raising procedure needed to be addressed at WKNSCS 2022. Firstly, the industrial bycatch landings were being included when raising the discards. These erroneous discards are very small and did not add very much to the total catch (<0.03%). However, including industrial bycatch in the discard raising is not appropriate since this fleet does not have any associated discards (i.e. a known 0) and so the industrial bycatch landings are now excluded from the discard raising procedure. Secondly, the internal consistency of the data exported from InterCatch has been a concern in recent years with the total numbers-at-age summed over all the catch components (landings, discards, industrial bycatch and BMS landings) not equaling the total numbers-at-age from the total catch. Part of this issue comes from the inclusion of industrial bycatch when raising discards however, correcting this issue was not enough to correct the problem. Further investigation revealed a bug in InterCatch in the way data are filtered for exporting. It would seem that the filters being used to isolate just the human consumption landings (i.e. no industrial bycatch) did not filter the data as expected and so the total exported human consumption landings did not match the the total imported human consumption landings. The InterCatch team has been notified of the issue. In the meantime, no issue was found in exporting total landings (human consumption landings and industrial bycatch) or in exporting just the industrial bycatch landings and so the numbers-at-age for the human consumption landings component can be calculated manually outside of InterCatch.

A further update to the age allocation procedure from the last benchmark was needed due to the presence of BMS landings and Logbook Registered Discards. In the case of BMS landings there is adequate sampling information available to allocate age distributions. Submissions of Logbook Registered Discards are all reported as zero (i.e. no catch). If in future non-zero catches are reported and no corresponding samping information is available then the most appropriate age distrubtion to use would be that of discards.

7.5.1.3 Final catch data

The updated time-series of numbers-at-age and mean weight-at-age in the total catch are presented in tables 7.3 and 7.4 respectively and figures 7.4 and 7.5. The yield per catch component is shown in Figure 7.6. The new submissions have resulted in mostly minor revisions to the catch time-series. However, a major revision to the catch from Denmark in 2011 was submitted to correct some double counting of catch in the older time-series. Revisions have also been made to the industrial bycatch catch by Denmark between 2008-2012. However, these changes were queried with the data submitter and a coding error was found. Therefore, a further revision to the industrial bycatch between 2008-2012 will be made although not until after WKNSCS 2022 has concluded. The original industrial bycatch tonnage in these years represent <1% of the total catch and so these revisions are not expected to greatly affect the outcome of the stock assessment.

Table 7.3. Northern Shelf haddock. Numbers-at-age for total catch (thousands).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1972	255110	696714	671965	43309	23547	211817	4067	241	53	27	475	11	0	0	0	0
1973	79461	412305	587335	260080	6450	5689	72652	1406	140	34	234	49	5	0	0	0
1974	665110	1283252	187149	342628	60523	1956	1795	22380	345	57	63	4	7	4	0	0
1975	51796	2276937	673960	62175	112242	17691	1078	718	6168	339	70	11	0	8	0	0
1976	171400	192030	1127520	225532	11538	32677	5864	228	84	1863	64	3	5	0	0	0
1977	119506	263702	109480	426291	45756	4984	6757	1608	163	40	460	8	0	1	0	0
1978	281785	223294	130963	31141	144703	11791	1582	2322	740	122	33	275	16	2	0	0
1979	844410	261156	220200	45487	7978	38097	3069	377	629	181	57	13	52	3	0	0
1980	374573	439674	374310	80225	11364	2040	11143	827	143	168	96	34	9	7	1	0
1981	645352	116229	430149	180553	17044	2225	497	3320	164	78	26	32	5	1	4	0
1982	275508	217834	89989	390347	49835	4275	820	551	1072	60	28	8	2	2	0	0
1983	513034	148158	222772	83199	166812	20055	2365	338	255	385	93	21	4	4	0	0
1984	95862	483045	139887	143821	29321	56077	6238	967	127	84	185	19	5	1	1	0
1985	127003	161400	441785	80605	41508	7082	18393	1929	296	56	29	144	9	0	0	1
1986	45703	137091	144075	328016	29497	10595	1686	4421	581	156	56	47	37	16	4	1
1987	10249	253236	259369	56407	92705	6214	3993	1187	2596	462	56	65	35	32	17	8
1988	16679	33092	424014	96795	17161	27728	2030	874	368	1076	95	21	12	13	17	1
1989	19587	51743	43162	216359	21015	4189	7671	763	285	170	469	69	8	3	2	1
1990	19286	82571	78881	17811	60888	4373	1104	1839	254	100	54	13	12	1	4	2
1991	128703	188087	101425	24822	4706	17618	1388	684	1024	171	65	11	11	1	2	2
1992	277933	166550	255051	43257	7162	1486	6376	611	337	401	149	22	6	2	0	0
1993	136841	302610	269220	123469	11822	1986	669	2050	215	210	188	84	4	4	0	0
1994	89104	91674	339428	106673	35056	3381	601	366	746	132	48	36	26	5	0	0
1995	200151	336460	119210	182969	33802	9237	898	161	155	151	21	8	6	2	1	0
1996	167032	46797	505401	73987	66245	11159	4058	1080	75	72	37	9	8	3	1	0
1997	36954	162449	107657	251339	18037	18288	2762	937	121	16	18	5	4	4	2	0
1998	21919	88387	224037	60861	128348	7110	4590	850	263	60	7	8	3	2	1	1
1999	90634	69455	119094	110046	28510	45221	2700	2047	438	53	8	3	3	2	0	0
2000	12630	397390	110381	61263	33137	7254	9935	765	367	53	13	2	1	1	0	0

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
2001	3518	95086	633162	34548	12078	5573	2094	1611	257	89	28	3	4	0	0	0
2002	50927	36063	99685	372036	7812	2801	1615	729	603	283	25	8	5	0	0	0
2003	7082	13136	15234	48729	127241	2166	786	339	144	100	48	5	1	0	0	0
2004	3758	25698	24627	8958	38784	97827	1010	248	82	42	37	12	1	0	0	0
2005	8779	17695	24596	15085	5446	27745	61457	371	132	38	11	8	4	1	0	0
2006	3229	122537	30995	20657	11284	6078	16415	32978	156	56	20	7	4	1	0	0
2007	2046	20565	171600	16796	8187	4782	2237	6876	7254	75	8	14	3	1	0	0
2008	2550	25087	35038	80164	4156	2093	1354	552	1577	2473	6	4	1	1	0	0
2009	27313	11967	13754	18495	77722	1904	759	563	133	242	545	8	2	0	0	0
2010	2508	49728	14174	17429	11677	37295	833	379	142	78	81	162	10	0	0	3
2011	5024	4342	64649	12999	7402	5791	20830	450	119	70	25	12	70	0	0	0
2012	1377	3879	5072	66385	5431	3697	2414	8051	137	176	50	28	32	22	2	0
2013	1303	12258	4251	4651	68803	2216	1532	840	3919	36	7	7	2	2	2	0
2014	3504	7593	20031	4690	7647	46684	1080	962	371	1694	13	6	1	1	0	2
2015	3776	27610	15630	17723	1719	5013	21935	1062	434	437	785	108	0	0	0	0
2016	1701	9374	61656	8846	5556	655	451	10138	253	151	9	149	9	0	0	1
2017	2615	12732	23207	54472	3228	1498	144	367	1442	502	6	20	3	1	0	1
2018	3632	5556	24263	17121	35201	925	522	210	100	970	20	0	3	3	1	1
2019	3555	17935	11790	25744	7145	21202	432	369	23	46	143	5	1	4	1	10
2020	1540	45286	27157	11930	14636	3281	7953	178	164	62	61	20	0	0	0	0

Table 7.4. Northern Shelf haddock. Mean weights-at-age for total catch (kg).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1972	0.025	0.117	0.242	0.383	0.503	0.585	0.987	1.380	1.967	1.979	1.618	2.861	0.000	0.000	0.000	0.000
1973	0.043	0.118	0.239	0.369	0.578	0.611	0.648	1.044	1.378	2.658	1.603	1.988	2.123	0.000	0.000	0.000
1974	0.025	0.129	0.226	0.339	0.536	0.867	0.828	0.863	1.377	1.704	1.854	4.057	1.927	0.890	0.000	0.000
1975	0.023	0.105	0.240	0.353	0.442	0.678	1.190	1.077	1.031	1.564	2.188	2.764	0.000	3.318	0.000	0.000
1976	0.014	0.129	0.225	0.394	0.505	0.578	0.916	1.829	1.656	1.247	2.296	2.425	1.679	0.000	0.000	0.000
1977	0.020	0.111	0.238	0.339	0.586	0.612	0.787	1.160	1.715	1.971	1.490	2.067	0.000	3.898	0.000	0.000
1978	0.011	0.104	0.254	0.396	0.424	0.707	0.784	0.921	1.350	1.995	1.990	1.329	2.182	4.475	0.000	0.000
1979	0.009	0.093	0.287	0.417	0.611	0.669	0.931	1.241	1.320	1.453	2.505	1.575	1.233	1.580	0.000	0.000
1980	0.012	0.081	0.276	0.464	0.693	0.985	0.908	1.264	1.511	1.501	1.676	3.104	1.050	2.134	2.921	0.000
1981	0.009	0.060	0.264	0.445	0.726	1.055	1.222	1.195	1.545	1.672	1.531	1.515	2.982	4.273	1.896	0.000
1982	0.010	0.074	0.286	0.423	0.759	1.109	1.415	1.578	1.466	2.136	2.122	1.877	1.886	3.179	0.000	0.000
1983	0.011	0.132	0.303	0.431	0.612	0.904	1.211	1.191	1.630	1.460	1.449	1.972	2.853	4.689	0.000	0.000
1984	0.010	0.142	0.303	0.461	0.645	0.736	1.077	1.205	1.821	2.030	1.732	1.950	2.422	2.822	4.995	0.000
1985	0.010	0.148	0.296	0.466	0.649	0.835	0.934	1.344	1.638	2.097	2.109	2.061	2.555	2.471	2.721	4.139
1986	0.023	0.123	0.261	0.406	0.600	0.848	1.195	1.098	1.524	1.356	2.178	2.366	2.498	2.993	2.778	2.894
1987	0.010	0.125	0.264	0.405	0.594	0.974	1.215	1.322	1.260	1.358	1.870	2.132	2.609	2.450	2.768	2.638
1988	0.042	0.163	0.232	0.411	0.581	0.731	1.203	1.363	1.281	0.974	1.633	2.163	2.547	3.139	3.435	2.863
1989	0.036	0.200	0.282	0.367	0.590	0.770	0.935	1.259	1.586	1.507	1.034	1.534	2.431	2.559	2.307	0.980
1990	0.040	0.187	0.313	0.422	0.506	0.795	0.995	1.179	1.495	1.898	2.519	2.259	2.188	0.562	1.852	4.731
1991	0.030	0.175	0.308	0.454	0.574	0.644	0.959	1.136	1.313	1.701	2.163	2.012	1.622	1.070	1.208	2.888
1992	0.019	0.102	0.306	0.466	0.717	0.923	0.903	1.382	1.514	1.813	2.014	2.064	2.441	1.781	0.000	0.000
1993	0.010	0.110	0.282	0.454	0.660	0.877	1.053	1.062	1.545	1.460	1.830	1.894	2.155	2.460	0.000	0.000
1994	0.018	0.121	0.247	0.435	0.599	0.846	1.240	1.274	1.289	1.573	2.060	2.070	2.834	2.403	2.523	0.000
1995	0.012	0.107	0.290	0.369	0.581	0.774	1.058	1.418	1.261	1.320	1.889	2.491	1.713	1.699	2.243	0.000
1996	0.022	0.126	0.241	0.382	0.484	0.746	0.847	0.825	1.616	1.538	1.433	1.830	2.358	2.636	3.433	0.000
1997	0.029	0.138	0.280	0.360	0.585	0.634	0.923	0.997	1.293	2.196	1.961	2.058	2.757	2.270	2.867	2.782
1998	0.027	0.153	0.255	0.396	0.444	0.665	0.777	1.041	1.109	1.251	2.373	2.334	1.656	2.433	2.085	2.509
1999	0.025	0.166	0.250	0.356	0.477	0.510	0.735	0.798	0.826	1.305	1.533	2.478	2.086	2.698	2.904	2.220
2000	0.052	0.121	0.256	0.355	0.480	0.605	0.656	1.033	0.973	1.529	1.911	2.323	2.365	2.310	3.595	1.843

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
2001	0.029	0.111	0.219	0.321	0.466	0.658	0.735	0.945	1.690	1.148	1.725	2.923	1.286	2.534	1.239	3.425
2002	0.017	0.109	0.255	0.311	0.527	0.703	0.829	0.818	1.279	1.945	1.798	1.839	2.352	2.762	0.000	0.000
2003	0.024	0.082	0.221	0.327	0.400	0.681	0.758	1.110	1.281	1.612	2.022	2.219	2.506	2.606	1.981	3.092
2004	0.039	0.139	0.238	0.378	0.395	0.440	0.686	0.926	1.184	1.602	1.753	2.605	2.170	0.000	0.000	0.000
2005	0.054	0.160	0.271	0.364	0.495	0.479	0.522	0.925	1.054	1.373	1.847	2.750	2.545	2.309	3.431	0.000
2006	0.042	0.126	0.283	0.352	0.442	0.507	0.538	0.550	1.048	1.395	2.031	2.525	1.834	3.532	5.274	2.580
2007	0.042	0.159	0.227	0.407	0.478	0.538	0.657	0.700	0.745	0.902	2.272	0.971	1.712	2.348	4.244	0.000
2008	0.034	0.141	0.252	0.359	0.570	0.642	0.758	0.836	0.878	0.834	2.058	1.248	3.538	2.685	3.792	2.923
2009	0.050	0.158	0.305	0.329	0.384	0.631	0.754	0.726	1.016	1.077	0.957	1.055	0.944	3.019	2.097	0.000
2010	0.031	0.104	0.305	0.417	0.456	0.470	0.718	0.897	1.308	1.414	1.381	1.423	2.725	2.245	2.654	2.567
2011	0.040	0.157	0.265	0.449	0.533	0.531	0.543	0.722	1.002	0.912	1.693	1.892	1.621	0.000	0.000	0.000
2012	0.034	0.160	0.442	0.407	0.568	0.687	0.680	0.642	1.146	0.848	1.426	2.158	2.121	2.095	2.368	0.000
2013	0.034	0.171	0.426	0.596	0.485	0.717	0.843	0.790	0.757	1.098	1.643	2.216	2.607	1.810	2.512	0.000
2014	0.042	0.140	0.432	0.590	0.653	0.534	0.772	0.825	0.928	0.793	1.692	2.800	1.323	2.682	0.000	1.602
2015	0.031	0.145	0.421	0.564	0.765	0.702	0.631	0.683	0.970	0.723	0.714	0.719	1.425	2.954	0.000	0.000
2016	0.048	0.161	0.363	0.638	0.765	0.874	1.022	0.737	0.798	1.083	2.622	1.122	1.286	1.978	3.312	2.835
2017	0.040	0.149	0.343	0.450	0.781	0.961	1.338	1.045	1.020	0.654	2.834	0.930	2.682	2.237	4.673	5.554
2018	0.043	0.139	0.355	0.503	0.533	1.021	1.030	1.147	1.421	0.890	1.235	1.883	2.383	3.356	2.198	4.662
2019	0.046	0.151	0.310	0.462	0.628	0.580	1.009	0.983	2.065	2.677	1.324	3.551	3.491	2.628	4.051	5.040
2020	0.041	0.125	0.371	0.501	0.580	0.838	0.613	1.640	2.340	2.318	3.309	1.625	1.257	0.000	0.000	0.000

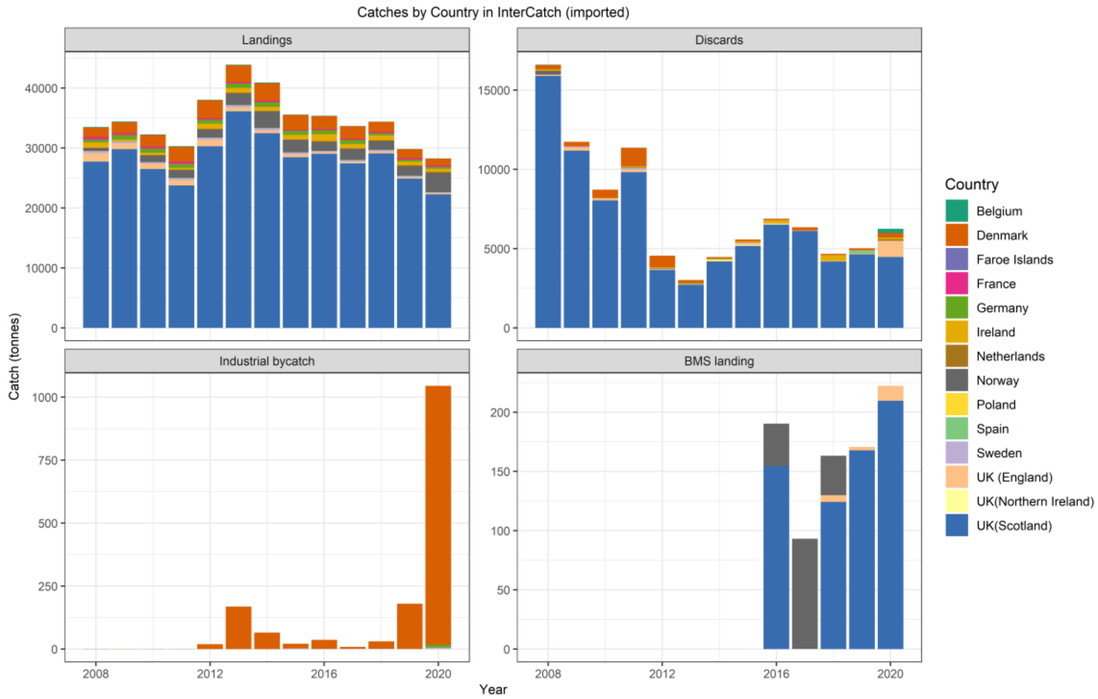


Figure 7.1. Northern Shelf haddock. Total landings, discards, industrial bycatch landings and below minimum size (BMS) landings by country, imported into InterCatch.

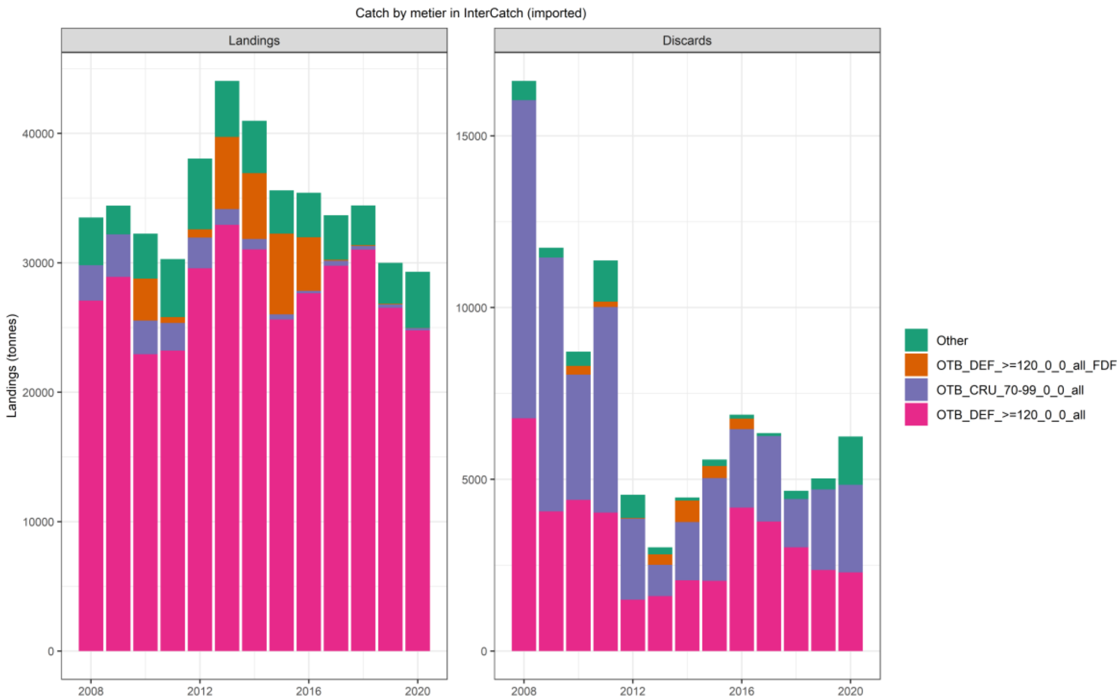


Figure 7.2. Northern Shelf haddock. Total landings and discards by metier from catch data imported into InterCatch. Metiers accounting for less than 10% of the total catch are grouped together under “Other”.

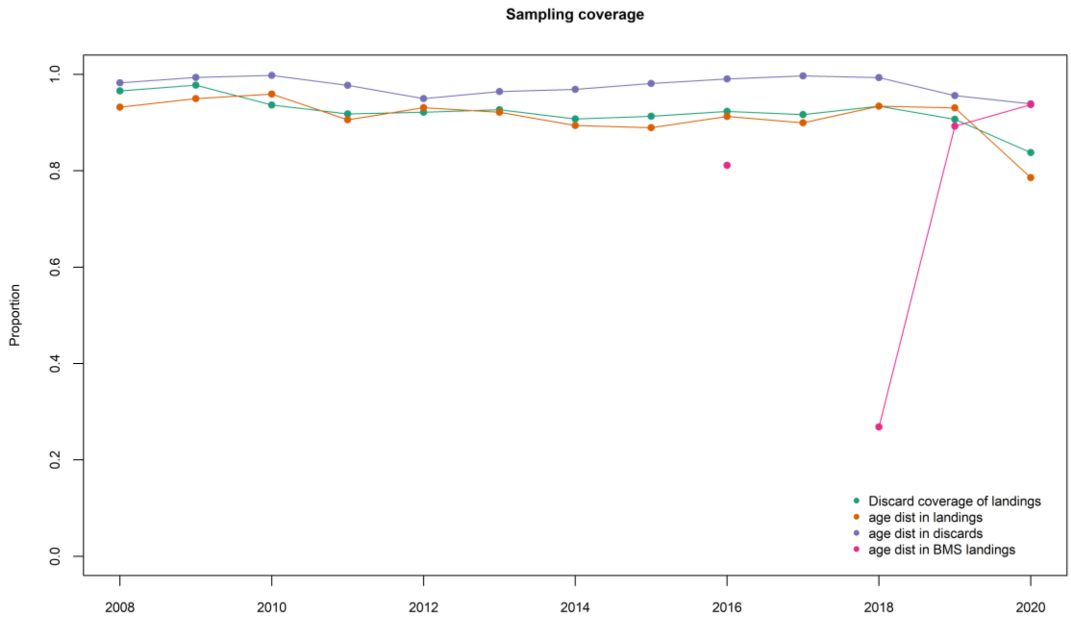


Figure 7.3. Northern Shelf haddock. Proportion of the catch that is sampled over time – the proportion of landings where discards estimates are available (green), the proportion of landings (orange), discards (purple) and BMS landings (pink) for which age distributions are available.

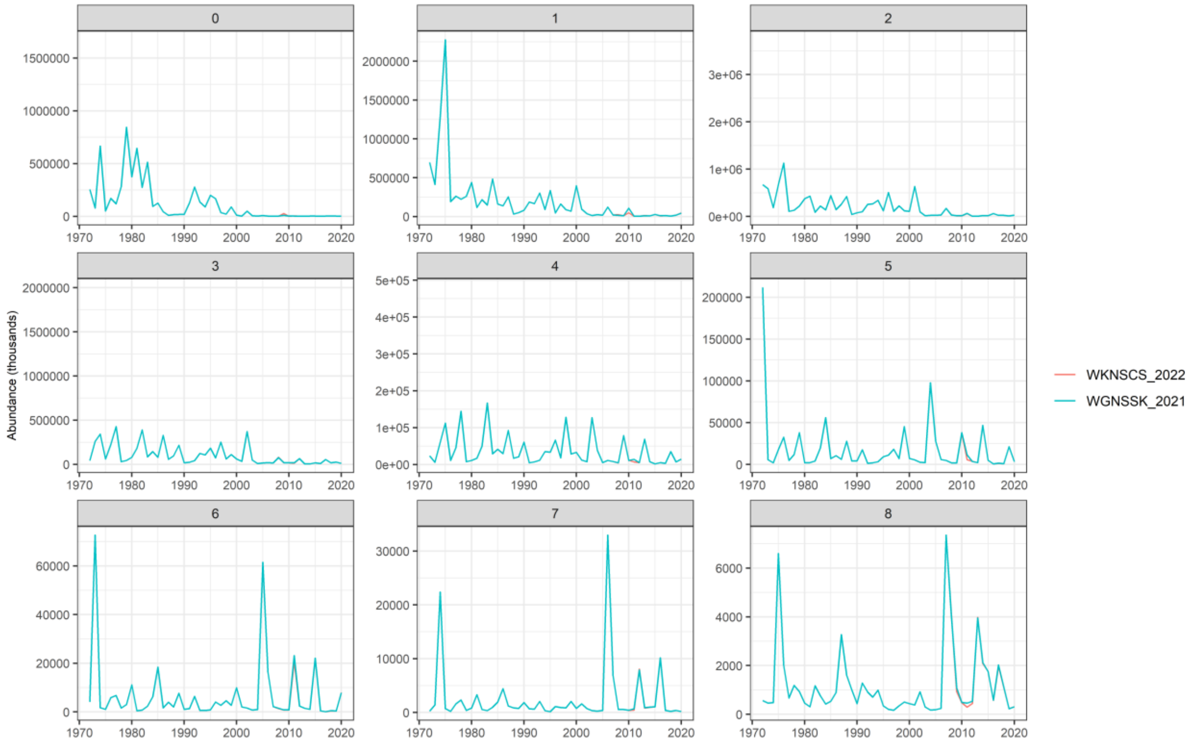


Figure 7.4. Northern Shelf haddock. Numbers-at-age (thousands) for total catch used as input for WKNSCS 2022 compared to the old data used at WGNSSK 2021 (ICESc, 2021).

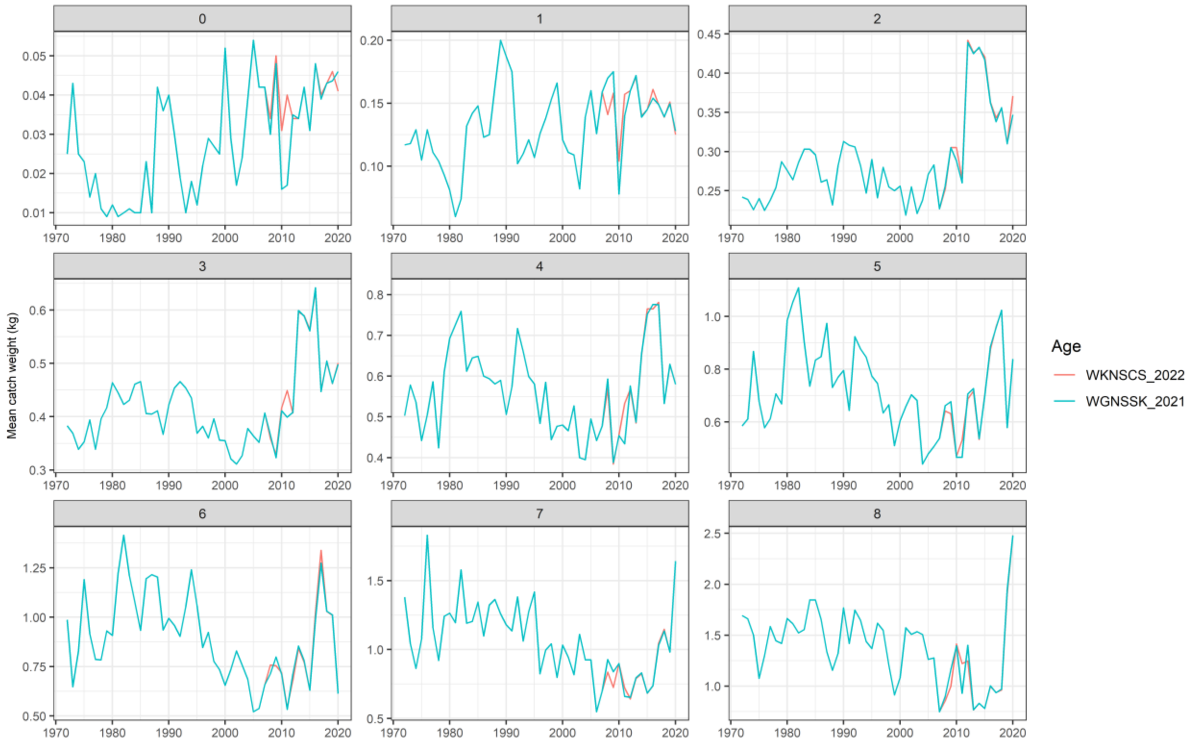


Figure 7.5. Northern Shelf haddock. Mean weight-at-age (kg) for total catch used as input for WKNSCS 2022 compared to the old data used at WGNSSK 2021 (ICESc, 2021).

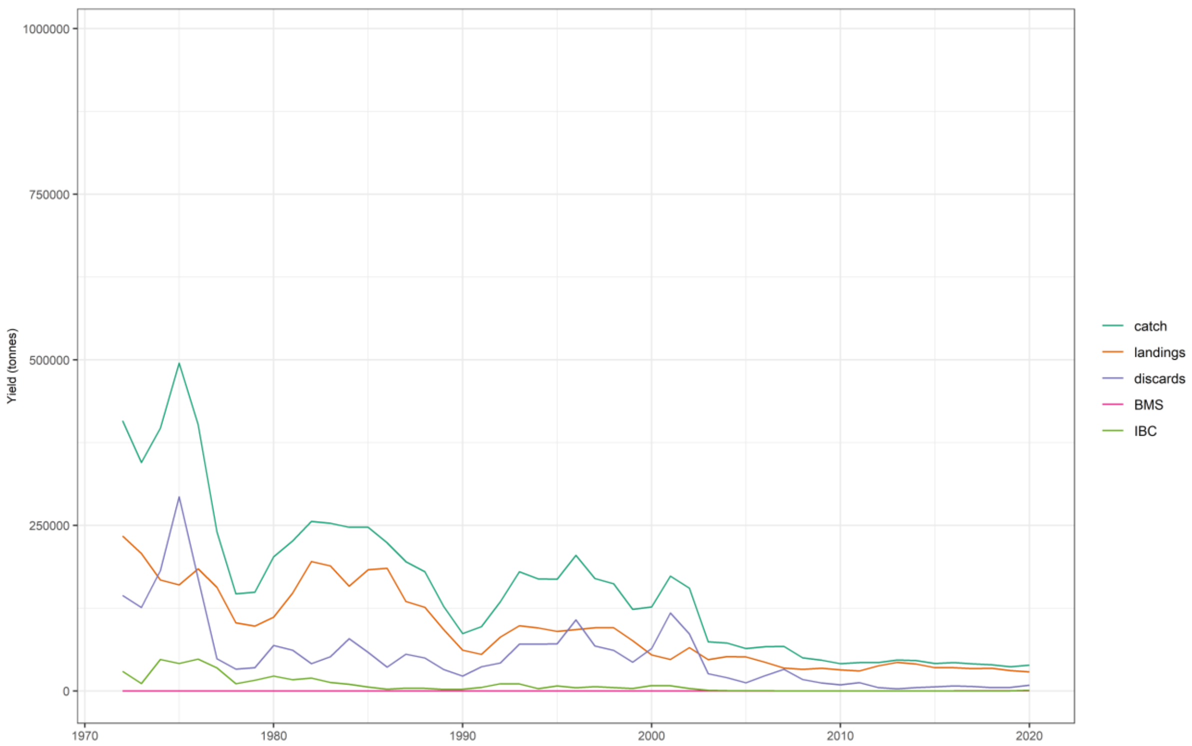


Figure 7.6. Northern Shelf haddock. Yield from total catch, landings, discards, below minimum size (BMS) landings and industrial bycatch (IBC).

7.5.2 Surveys

Following the recommendations made at WKHAD (ICES, 2014), the tuning indices used in the TSA assessment are those available in DATRAS from the North Sea International Bottom Trawl Surveys (NS-IBTS) in quarter 1 (Q1) and quarter 3 (Q3). However, the NS-IBTS surveys do not cover the entire Northern Shelf and so do not wholly represent the dynamics of the stock across its entire extent. As a result, further work was recommended to investigate methods for producing combined North Sea-West Coast of Scotland (NS-WC) survey indices.

Data available for use in constructing survey indices covering the Northern Shelf region are listed in Table 7.5. The analysis used to combine these indices was conducted using a GAM-based delta-lognormal model. The model accounts for a number of explanatory variables and is described in Berg *et al*. (2014). The model has previously been found to give a better fit to survey data compared to other GAM-based approaches (Berg *et al*., 2014). The GAM-based delta-lognormal model method follows the same statistical modelling approach used to develop indices for use in the assessment of herring in the North Sea and West of Scotland (ICES, 2019), cod in the North Sea (Berg *et al*., 2014; ICES, 2021a) and whiting in West of Scotland (ICES, 2021a). The full methodological details can be found in WD-3 for modelled NS-WC Q1 survey indices, WD-4 for separately modelled NS Q3 and WC Q4 survey indices and WD-7 for combined, modelled NS-WC Q3+Q4 survey indices. The DATRAS survey indices and the modelled survey indices for Q1, Q3 and Q4 are shown in Figure 7.7.

Table 7.5. Northern Shelf haddock. Data sources available for use in constructing survey indices covering the Northern Shelf.

Survey	Quarter	Area	Years	Ages
ScoGFS-WIBTS-Q1: Scottish first-quarter west coast groundfish survey	Q1	West Coast of Scotland (27.6.a)	1985-2010	Age 1+
UK-SCOWCGFS-Q1: Scottish first-quarter west coast groundfish survey	Q1	West Coast of Scotland (27.6.a)	2011-2021	Age 1+
NS-IBTS-Q1: First quarter North Sea International Bottom Trawl Survey	Q1	North Sea (27.4) and Skagerrak (27.3.a)	1983-2021	Age 1+
NS-IBTS-Q3: Third quarter North Sea International Bottom Trawl Survey	Q3	North Sea (27.4) and Skagerrak (27.3.a)	1991-2021	Age 0+
ScoGFS-WIBTS-Q4: Scottish fourth-quarter West Coast groundfish survey	Q4	West Coast of Scotland (27.6.a)	1996-2009	Age 0+
IGFS-WIBTS-Q4: Irish fourth-quarter West Coast groundfish survey	Q4	West Coast of Scotland (27.6.a)	2003-2020	Age 0+
UK-SCOWCGFS-Q4: Scottish fourth-quarter West Coast groundfish survey	Q4	West Coast of Scotland (27.6.a)	2011-2020	Age 0+

Initially, modelled Q1 indices combining all available surveys from the NS and WC, modelled Q3 indices for the NS and modelled Q4 indices (combining all available surveys) for the WC were produced Table 7.6). However, the modelled Q4 indices were not recommended for use in the Northern Shelf haddock stock assessment as the survey data used only covered the West Coast of Scotland. This would mean that using this survey would tune the assessment on data that only covered a small geographical region of the stock extent and as such cannot be considered to fully capture the dynamics of the whole stock. This can be seen in the variations in the relative sizes of the peaks in abundance between the NS and WC surveys as seen in Figure 7.7. A recommendation was made at the data evaluation workshop to explore developing a GAM-based delta-lognormal model that combined survey data from different quarters so that the WC Q4 surveys could be combined with the NS Q3 survey. This would ensure that data from the different stock region were weighted appropriately in the final modelled indices. Combining survey data from different quarters is not a suitable method when a stock is likely to engage in large-scale, seasonal migrations. Haddock are not known to migrate seasonally over large distances and data from tag-recapture studies documented at the last benchmark (ICES, 2014) suggest that Northern Shelf haddock have a high fidelity to a home range that is less extensive than the stock area. This would indicate that combining surveys from different quarters will not result in an under- or overestimation of the stock abundance. The benefit of combining surveys from different quarters is that the resulting indices provide greater coverage of the stock extent.

Following this recommendation, combined NS-WC Q3+Q4 indices were modelled. The GAM-based delta-lognormal model used for this included an extra interaction term between time of day and quarter compared to the model used for the modelled NS-WC Q1 indices. This additional interaction term allows for a different pattern along the time-of-day gradient for Q4 compared to Q3 (Zuur *et al.*, 2009).

An analysis of the diagnostics for all the modelled indices indicated that the indices were of good quality (figures 7.8 and 7.9). Internal consistency within all the models was high, and all the indices had relatively narrow confidence intervals. An analysis of the residuals found few issues and there was a high level of consistency both within and between the indices. A retrospective analysis of the modelled indices showed a high level of robustness and provided consistent results with removal of data up to a number of years. This indicates that there should be little issue with recalculating the modelled indices each year at the Working Group on the Assessments of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) as new survey data are added each year. Overall, the diagnostics for the modelled WC Q4 indices were not as robust as the other modelled indices although all the modelled indices offered an improvement in diagnostics compared to the individual DATRAS survey indices.

The final decision on which survey indices to use in the assessment was to use the modelled NS-WC Q1 and NS-WC Q3+Q4 indices (tables 7.7 and 7.8). These indices include data from across the entire Northern Shelf which means these indices are able to fully capture the stock dynamics. The use of the NS-WC Q3+Q4 indices, which offers a greater geographical extent compared to the modelled NS Q3 indices, was considered to be appropriate for use since haddock are not known to migrate large distances on a seasonal basis. For both surveys the data availability was considered adequate for use in the assessment up to and including the plus group. Although the NS-WC Q3+Q4 indices are the preferred input, an assessment run was done using the modelled NS Q3 survey indices as the second survey input instead, to ensure that the assessment results were not vastly different.

These new survey indices are compared to the old, DATRAS survey indices (NS-IBTS-Q1 and NS-IBTS-Q3) in Figure 7.10. In general, the relative height of peaks in abundance in the new survey indices are lower than those seen in the old indices especially in later years (post-2000). The stratified mean method used to calculate the old, DATRAS indices assumes that abundance is homogenous across the area-defined strata and this may result in too much influence being given to occasional large hauls compared to the GAM-based modelling approach which assumes a log-normal distribution. Furthermore, up until recently, age-length key fill-ins used in the calculation of the DATRAS indices have been made manually, in a subjective manner. This methodology was updated in 2020 to better adhere to the protocol for calculating the DATRAS indices by changing to an automated allocation of age-length key fill-ins for the entire time-series. A comparison of the TSA assessment using the revised DATRAS indices was done at WGNSSK 2020 which resulted in 20-30% reduction in SSB, seen almost exclusively in the latter part of the time-series (2000 onwards) (ICES, 2020). The revised DATRAS indices were not adopted at WGNSSK 2020 as this finding suggested further investigation was needed. The GAM-based modelling approach used to derive the new indices does not used age-length key fill-ins. Instead the age-length keys are estimated by modelling the probability of age given the length and spatial coordinates. These methodological differences go some way to explain the differences in the old and new survey indices in addition to the inclusion of West Coast of Scotland data in the new indices. Since the new modelled indices and the revised DATRAS indices both given lower abundance estimates in later years (2000 onwards), it suggests that the old DATRAS indices previously used may have overestimated abundance in the latter part of the time-series.

Table 7.6. Northern Shelf haddock. Modelled survey indices available for use in stock assessment. The indices in bold were the indices chosen for use in the stock assessment.

Survey	Quarter	Area	Years	Ages
Modelled NS-WC Q1 survey indices	Q1	North Sea (27.4), Skagerrak (27.3.a) and West Coast of Scotland (27.6.a)	1983-2021	1-8+
Modelled NS Q3 survey indices	Q3	North Sea (27.4) and Skagerrak (27.3.a)	1991-2021	0-8+
Modelled WC Q4 survey indices	Q4	West Coast of Scotland (27.6.a)	1996-2020	0-8+
Modelled NS-WC Q3+Q4 survey indices	Q3+Q4	North Sea (27.4), Skagerrak (27.3.a) and West Coast of Scotland (27.6.a)	1991-2021	0-8+

Table 7.7. Northern Shelf haddock. Modelled NS-WC Q1 survey abundance indices.

	1	2	3	4	5	6	7	8
1983	311.378	405.329	67.136	64.408	11.272	2.361	0.208	0.392
1984	1654.176	223.318	113.974	17.435	15.798	2.821	0.488	0.175
1985	341.606	768.925	108.561	31.882	4.791	4.247	0.659	0.298
1986	685.850	186.500	264.871	19.435	7.230	1.310	1.065	0.194
1987	1061.653	237.640	53.661	45.939	3.481	1.432	0.192	0.555
1988	166.461	423.011	75.872	12.255	8.195	0.893	0.196	0.496
1989	174.113	74.343	168.489	13.773	2.068	3.201	0.290	0.165
1990	252.222	83.199	33.645	32.122	2.813	0.579	0.828	0.101
1991	706.471	145.608	30.073	7.692	6.822	1.410	0.113	0.272
1992	986.848	306.121	35.050	2.987	2.085	1.309	0.165	0.193
1993	1619.004	515.135	132.665	14.111	0.902	0.357	0.719	0.396
1994	294.352	485.952	106.824	19.577	2.657	0.618	0.048	0.449

	1	2	3	4	5	6	7	8
1995	1926.157	197.306	152.714	23.546	5.593	0.809	0.196	0.245
1996	663.527	642.535	77.161	37.783	5.661	1.409	0.217	0.088
1997	1105.847	333.653	237.724	22.054	9.992	2.032	0.546	0.101
1998	394.437	332.787	90.321	63.340	7.201	2.893	0.914	0.313
1999	197.093	154.558	95.809	24.897	16.760	1.967	0.954	0.461
2000	4953.967	120.410	44.904	18.047	5.391	3.533	0.591	0.342
2001	894.798	1465.482	74.244	11.874	4.913	1.984	0.969	0.480
2002	85.988	440.661	560.817	14.087	5.241	1.724	1.032	0.469
2003	81.628	69.286	215.212	205.826	4.058	1.354	0.792	0.694
2004	61.332	78.383	37.267	87.727	72.879	1.152	0.572	0.399
2005	64.619	46.977	32.133	10.952	26.240	27.773	1.259	0.539
2006	341.323	45.992	24.170	8.796	3.982	7.891	10.046	1.086
2007	81.632	283.385	24.099	8.129	3.260	1.626	3.772	5.335
2008	64.082	64.657	131.757	8.764	2.500	1.100	0.728	3.163
2009	49.785	46.980	38.483	44.407	2.667	0.917	0.599	1.451
2010	346.120	42.472	29.657	14.024	20.437	1.645	0.532	0.891
2011	33.050	228.800	34.558	11.221	8.122	12.666	0.370	0.537
2012	21.215	33.046	156.319	12.385	7.634	4.073	4.687	0.421
2013	51.614	17.710	19.058	50.560	5.504	2.960	1.376	2.650
2014	48.394	25.161	9.986	8.855	21.587	1.561	0.988	1.695
2015	391.022	32.958	16.751	3.556	5.040	11.248	0.600	1.159
2016	97.567	176.215	16.790	4.539	1.642	1.044	5.142	0.349
2017	142.123	74.824	95.244	6.484	2.071	0.486	0.510	2.120
2018	65.909	78.123	38.192	28.979	1.893	0.673	0.116	0.939
2019	243.155	34.658	35.008	7.708	11.335	0.607	0.211	0.263
2020	368.817	111.277	19.210	12.106	3.753	5.923	0.144	0.185
2021	861.830	415.462	56.075	6.615	7.000	1.585	3.352	0.130

Table 7.8. Northern Shelf haddock. Modelled NS-WC Q3+Q4 survey abundance indices.

	0	1	2	3	4	5	6	7	8
1991	1644.554	421.236	42.004	3.877	1.4221	4.1509	0.186	0.0608	0.2212
1992	3189.185	1136.417	162.176	9.268	1.2904	0.4981	1.3297	0.0357	0.1085
1993	504.295	1062.151	197.338	31.202	1.8972	0.8863	0.0425	0.1802	0.08
1994	1639.722	404.488	230.130	30.809	10.0757	0.766	0.0619	0.0069	0.1516
1995	1409.221	1642.304	122.595	67.965	8.8296	3.9538	0.8381	0	0.2574
1996	615.749	507.096	330.371	33.827	19.4793	3.1244	0.7608	0.0617	0.0448
1997	315.648	630.522	140.674	116.275	7.9843	5.3271	0.9823	0.3742	0.0559
1998	282.224	235.403	150.532	37.166	24.509	2.4909	1.7429	0.2009	0.1664
1999	4559.828	176.372	70.629	36.492	9.3665	7.5419	0.6941	0.4691	0.2522
2000	983.913	3193.843	40.924	14.259	6.62	2.2411	1.8847	0.1306	0.1146
2001	59.153	566.213	949.327	25.525	6.2054	2.9981	1.166	0.5871	0.0735
2002	120.495	96.201	233.033	395.865	8.9078	3.2198	1.7634	0.3857	0.3293
2003	73.007	139.463	55.987	122.302	105.841	2.4302	1.1972	0.3107	0.1779
2004	89.569	84.565	66.436	21.893	42.1649	54.6206	1.2775	0.3859	0.2808
2005	238.685	68.885	38.599	18.402	8.6372	14.8066	11.1482	0.1933	0.1295
2006	131.098	175.191	28.312	10.040	6.5268	3.7062	5.5411	5.4027	0.1434
2007	118.691	77.329	186.388	13.549	6.7182	2.0743	1.1298	1.4633	1.618
2008	63.029	47.443	39.627	74.918	4.9598	3.0857	1.8058	0.5258	1.4951
2009	215.585	30.713	30.159	17.650	26.7506	1.5866	1.1535	0.5194	0.4144
2010	32.703	262.475	35.431	21.540	11.2165	18.0982	0.9995	0.3197	0.3326
2011	28.091	31.288	225.300	22.945	11.3814	5.2099	9.9925	0.3695	0.2775
2012	68.657	21.610	21.090	106.887	6.233	3.8807	2.7437	3.286	0.1743
2013	77.513	28.686	16.400	10.322	47.9356	2.4967	2.1588	0.7107	1.8322
2014	1004.983	42.551	20.952	6.329	5.2959	24.8798	1.2431	0.6336	1.0138
2015	153.944	390.979	38.166	11.108	2.4644	3.1188	12.1251	0.5675	0.5043
2016	232.601	91.738	184.425	14.428	3.6539	0.8816	1.4533	3.6631	0.2684
2017	90.193	131.430	80.315	88.835	5.0899	1.278	0.3087	0.5315	1.3657
2018	278.060	44.451	50.448	25.472	32.6318	1.2144	0.6819	0.0537	0.3138
2019	660.706	199.209	22.636	24.642	10.1477	14.2919	0.5282	0.0386	0.0943

	0	1	2	3	4	5	6	7	8
2020	731.145	779.345	90.167	15.033	14.2216	4.125	8.1389	0.1611	0.0487
2021	209.364	733.356	274.939	13.909	4.2106	3.3506	0.6142	0.432	0.0348

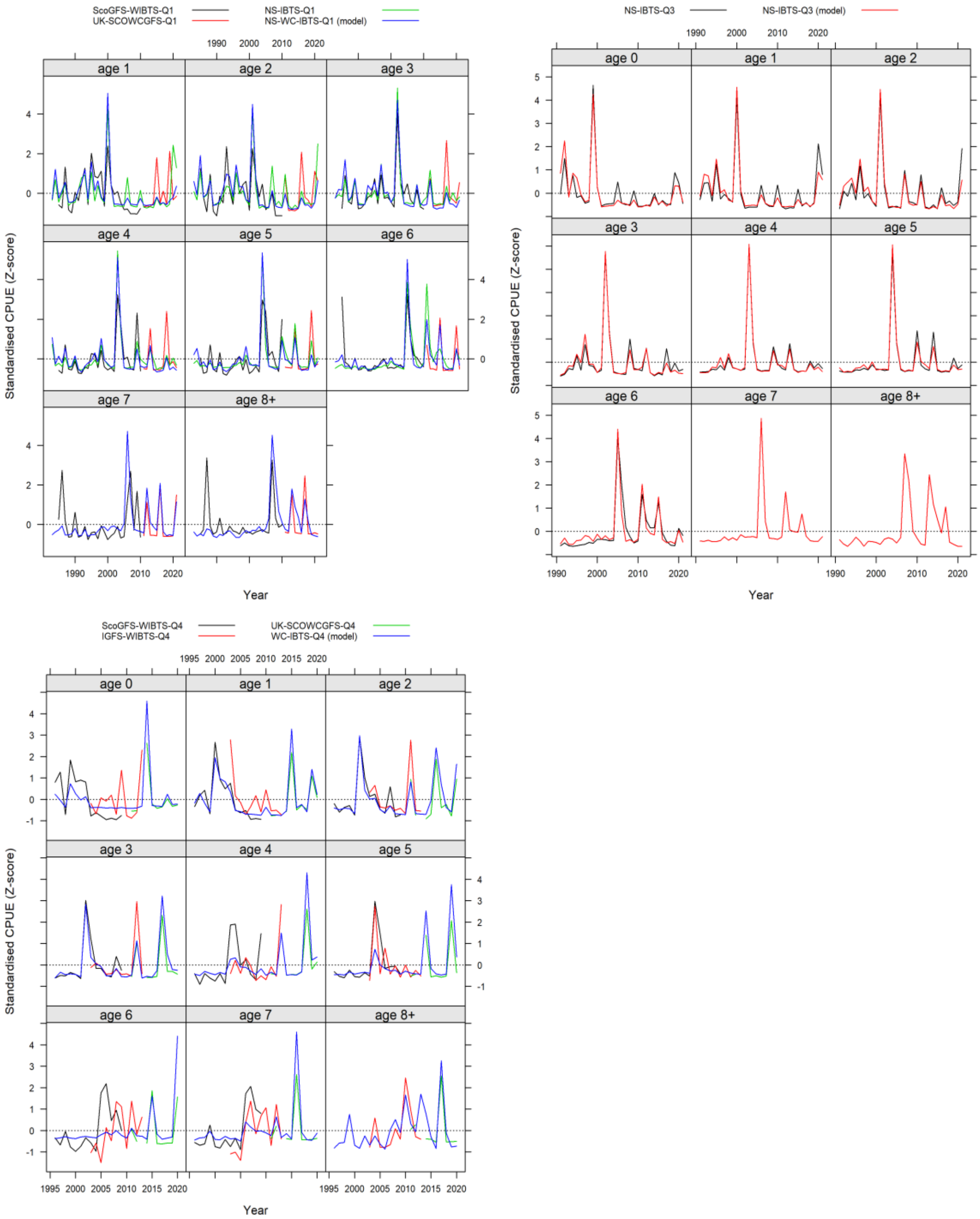


Figure 7.7. Northern Shelf haddock. Scaled survey indices (Z-scores) from the four-survey series in Q1 (top left), the two-survey series in Q3 (top right) and the four survey series in Q4 (bottom left). Modelled survey indices are indicated with "(model)". The abundance indices for NS-IBTS-Q1 and NS-IBTS-Q3 are shown for ages 1–6. The abundance indices for ScoGFS-WIBTS-Q1 and UK-SCOWCGFS-Q1 are shown for ages 1–8. The abundance index for ScoGFS-WIBTS-Q4 is shown for ages 0–7. The abundance indices for IGFS-WIBTS-Q4 and UK-SCOWCGFS-Q4 are shown for ages 0–8.

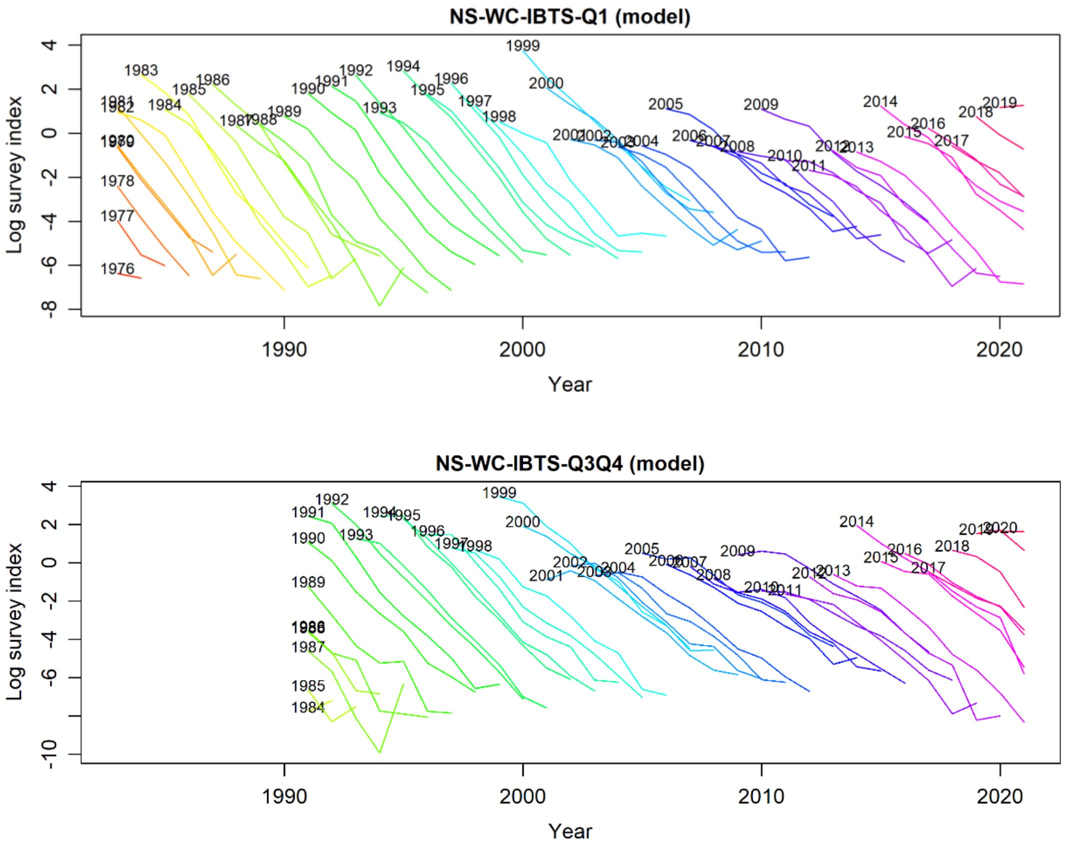


Figure 7.8. Northern Shelf haddock. Log abundance indices by year with a line for each cohort, for the two modelled survey series in Q1 and Q3+Q4. year-class is indicated at the start of each line.

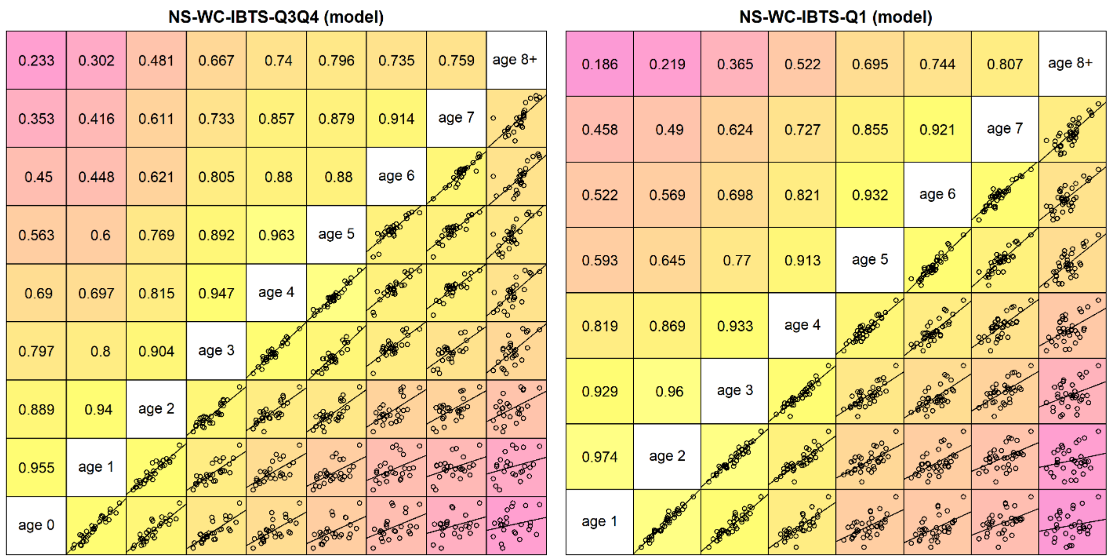


Figure 7.9. Northern Shelf haddock. Within-survey correlations comparing index values at different ages for the same year classes for the two modelled survey series in Q1 and Q3+Q4. The straight line is a linear regression.

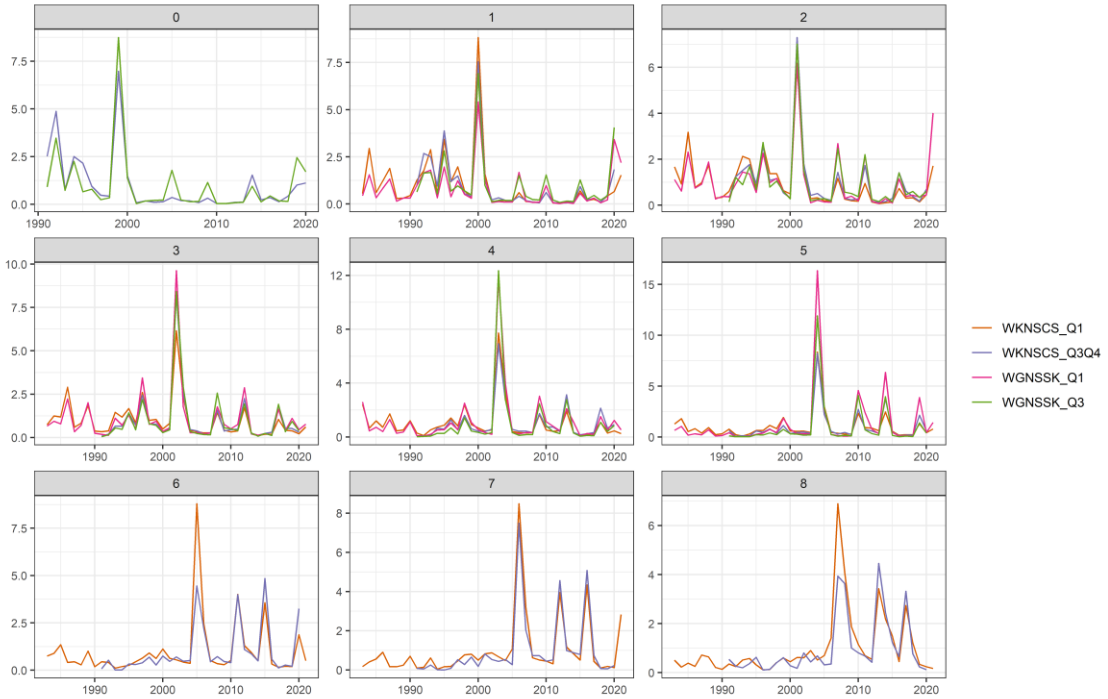


Figure 7.10. Northern Shelf haddock. Modelled survey indices for quarter 1 (Q1) and quarter 3 and quarter 4 combined (Q3Q4) used as input for WKNSCS 2022 compared to the DATRAS survey indices in quarter 1 and quarter 3 used at WGNSSK 2021 (ICESc, 2021). The DATRAS survey indices are shown up to age 5 to correspond with the age classes from the indices that were used in the TSA assessment.

7.5.3 Weights, maturities, growth

7.5.3.1 Stock weights

At the last benchmark the stock mean weights-at-age were assumed to be equal to individual catch weights-at-age over an entire year (ICES, 2014). However, using annual commercial catch weights-at-age data leads to an overestimation of SSB, particularly in younger fish which are expected to grow throughout the year. Furthermore, selectivity of the fishery may lead to size distributions of catches not being representative of the stock. As maturation can occur as early as age-1, this emphasises the need to correct the calculation of SSB by using mean weights-at-age which are representative of the stock at the beginning of the year. To do this, correction factors were derived by comparing mean weights-at-age in survey and commercial catch data which were then applied to the catch data time-series to obtain a better estimate of mean weights in the stock. More details of this method can be found in WD-2, though a summary is given below.

Reliable individual weights-at-age data for haddock in Q1 were only available from 2000–2021 for both the North Sea IBTS (NS-IBTS) and West of Scotland surveys (SWC-IBTS and SCOWCGFS). Commercial catch weights-at-age, aggregated each year, were available for ages 1–8+ from 1972–2020. Both datasets show similar trends in mean weights over time. The survey data were raised to account for the length-stratified sampling scheme. Furthermore, an area-specific weighting was applied to account for biological differences seen between two apparent subpopulations within the stock (east and west of the meridian). Various studies have presented evidence in genetics and biological factors in support of the existence of these two haddock subpopulations (Wright and Tobin, 2013; Wright *et al.*, 2010; González-Irusta and Wright, 2016; Jones, 1959; Jamieson and Birley, 1989). The raw time-series of both survey and commercial catch mean weights was smoothed using a generalised additive model for each age class. The correction factors were then calculated by minimising the mean squared error between the two smoothed times-series. The resulting correction factors are shown in Table 7.9. The mean stock weights-at-age were then obtained by applying these correction factors to the unsmoothed, commercial catch time-series (Figure 7.11, Table 7.10).

The correction factors were calculated up to the plus group (8+) whereas catch data are available up to age 15. To calculate the mean stock weight for ages 8 to 15 the mean catch weight for the plus group was first calculated, the correction factor applied and then the resulting mean stock weight for the plus group was used for ages 8 to 15. This kept the age range of this dataset consistent with other datasets. The final mean stock weights-at-age are shown in Figure 7.12. These correction factors will be retained until the next benchmark where they should be recalculated to include the new data that will become available in the intervening period.

Table 7.9. Northern Shelf haddock. Correction factors by age to derive stock mean weights-at-age from total catch mean weights-at-age.

0	1	2	3	4	5	6	7	8+
0.4	0.4	0.648	0.79	0.845	0.86	0.86	0.823	0.625

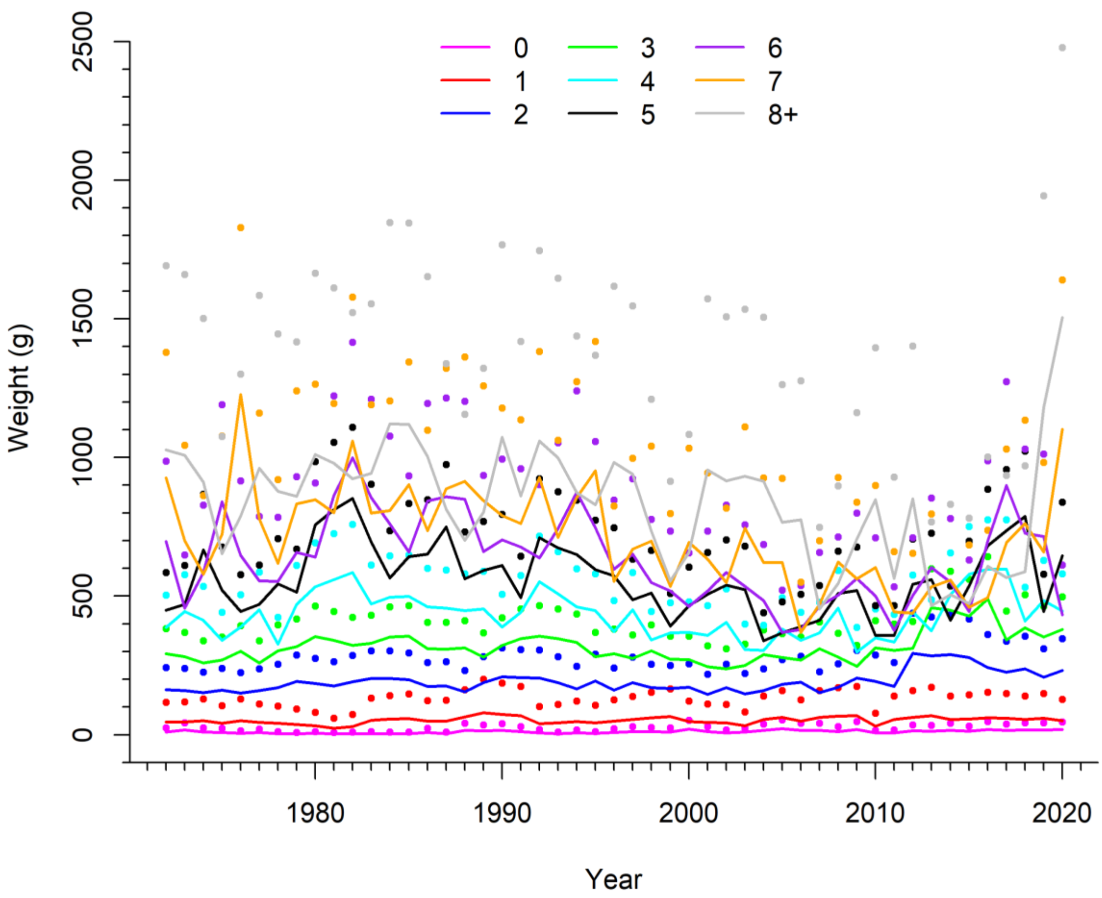


Figure 7.11. Northern Shelf haddock. Stock weights-at-age. Dots represent the original, catch weights-at-age whilst lines represent the derived stock weights-at-age (i.e. correction factor applied to catch weight-at-age). Age 8+ denotes a plus group.

Figure 7.12. Northern Shelf haddock. Mean weight-at-age in the stock (kg) used as input for WKNSCS 2022 compared to the old data used at WGNSSK 2021 (ICESc, 2021). Age 8 is a plus group.

Table 7.10. Northern Shelf haddock. Mean stock weights-at-age (kg).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1972	0.010	0.047	0.157	0.303	0.425	0.503	0.849	1.136	1.229	1.237	1.011	1.788	0.000	0.000	0.000	0.000
1973	0.017	0.047	0.155	0.292	0.488	0.525	0.557	0.859	0.861	1.661	1.002	1.243	1.327	0.000	0.000	0.000
1974	0.010	0.052	0.146	0.268	0.453	0.746	0.712	0.710	0.861	1.065	1.159	2.536	1.204	0.556	0.000	0.000
1975	0.009	0.042	0.156	0.279	0.373	0.583	1.023	0.886	0.644	0.978	1.368	1.728	0.000	2.074	0.000	0.000
1976	0.006	0.052	0.146	0.311	0.427	0.497	0.788	1.505	1.035	0.779	1.435	1.516	1.049	0.000	0.000	0.000
1977	0.008	0.044	0.154	0.268	0.495	0.526	0.677	0.955	1.072	1.232	0.931	1.292	0.000	2.436	0.000	0.000
1978	0.004	0.042	0.165	0.313	0.358	0.608	0.674	0.758	0.844	1.247	1.244	0.831	1.364	2.797	0.000	0.000
1979	0.004	0.037	0.186	0.329	0.516	0.575	0.801	1.021	0.825	0.908	1.566	0.984	0.771	0.988	0.000	0.000
1980	0.005	0.032	0.179	0.367	0.586	0.847	0.781	1.040	0.944	0.938	1.048	1.940	0.656	1.334	1.826	0.000
1981	0.004	0.024	0.171	0.352	0.613	0.907	1.051	0.983	0.966	1.045	0.957	0.947	1.864	2.671	1.185	0.000
1982	0.004	0.030	0.185	0.334	0.641	0.954	1.217	1.299	0.916	1.335	1.326	1.173	1.179	1.987	0.000	0.000
1983	0.004	0.053	0.196	0.340	0.517	0.777	1.041	0.980	1.019	0.913	0.906	1.233	1.783	2.931	0.000	0.000
1984	0.004	0.057	0.196	0.364	0.545	0.633	0.926	0.992	1.138	1.269	1.083	1.219	1.514	1.764	3.122	0.000
1985	0.004	0.059	0.192	0.368	0.548	0.718	0.803	1.106	1.024	1.311	1.318	1.288	1.597	1.544	1.701	2.587

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1986	0.009	0.049	0.169	0.321	0.507	0.729	1.028	0.904	0.953	0.848	1.361	1.479	1.561	1.871	1.736	1.809
1987	0.004	0.050	0.171	0.320	0.502	0.838	1.045	1.088	0.788	0.849	1.169	1.333	1.631	1.531	1.730	1.649
1988	0.017	0.065	0.150	0.325	0.491	0.629	1.035	1.122	0.801	0.609	1.021	1.352	1.592	1.962	2.147	1.789
1989	0.014	0.080	0.183	0.290	0.499	0.662	0.804	1.036	0.991	0.942	0.646	0.959	1.519	1.599	1.442	0.613
1990	0.016	0.075	0.203	0.333	0.428	0.684	0.856	0.970	0.934	1.186	1.574	1.412	1.368	0.351	1.158	2.957
1991	0.012	0.070	0.200	0.359	0.485	0.554	0.825	0.935	0.821	1.063	1.352	1.258	1.014	0.669	0.755	1.805
1992	0.008	0.041	0.198	0.368	0.606	0.794	0.777	1.137	0.946	1.133	1.259	1.290	1.526	1.113	0.000	0.000
1993	0.004	0.044	0.183	0.359	0.558	0.754	0.906	0.874	0.966	0.913	1.144	1.184	1.347	1.538	0.000	0.000
1994	0.007	0.048	0.160	0.344	0.506	0.728	1.066	1.049	0.806	0.983	1.288	1.294	1.771	1.502	1.577	0.000
1995	0.005	0.043	0.188	0.292	0.491	0.666	0.910	1.167	0.788	0.825	1.181	1.557	1.071	1.062	1.402	0.000
1996	0.009	0.050	0.156	0.302	0.409	0.642	0.728	0.679	1.010	0.961	0.896	1.144	1.474	1.648	2.146	0.000
1997	0.012	0.055	0.181	0.284	0.494	0.545	0.794	0.821	0.808	1.373	1.226	1.286	1.723	1.419	1.792	1.739
1998	0.011	0.061	0.165	0.313	0.375	0.572	0.668	0.857	0.693	0.782	1.483	1.459	1.035	1.521	1.303	1.568
1999	0.010	0.066	0.162	0.281	0.403	0.439	0.632	0.657	0.516	0.816	0.958	1.549	1.304	1.686	1.815	1.388
2000	0.021	0.048	0.166	0.280	0.406	0.520	0.564	0.850	0.608	0.956	1.194	1.452	1.478	1.444	2.247	1.152
2001	0.012	0.044	0.142	0.254	0.394	0.566	0.632	0.778	1.056	0.718	1.078	1.827	0.804	1.584	0.774	2.141
2002	0.007	0.044	0.165	0.246	0.445	0.605	0.713	0.673	0.799	1.216	1.124	1.149	1.470	1.726	0.000	0.000
2003	0.010	0.033	0.143	0.258	0.338	0.586	0.652	0.914	0.801	1.008	1.264	1.387	1.566	1.629	1.238	1.933
2004	0.016	0.056	0.154	0.299	0.334	0.378	0.590	0.762	0.740	1.001	1.096	1.628	1.356	0.000	0.000	0.000
2005	0.022	0.064	0.176	0.288	0.418	0.412	0.449	0.761	0.659	0.858	1.154	1.719	1.591	1.443	2.144	0.000
2006	0.017	0.050	0.183	0.278	0.373	0.436	0.463	0.453	0.655	0.872	1.269	1.578	1.146	2.208	3.296	1.613
2007	0.017	0.064	0.147	0.322	0.404	0.463	0.565	0.576	0.466	0.564	1.420	0.607	1.070	1.468	2.653	0.000
2008	0.014	0.056	0.163	0.284	0.482	0.552	0.652	0.688	0.549	0.521	1.286	0.780	2.211	1.678	2.370	1.827
2009	0.020	0.063	0.198	0.260	0.324	0.543	0.648	0.597	0.635	0.673	0.598	0.659	0.590	1.887	1.311	0.000
2010	0.012	0.042	0.198	0.329	0.385	0.404	0.617	0.738	0.818	0.884	0.863	0.889	1.703	1.403	1.659	1.604
2011	0.016	0.063	0.172	0.355	0.451	0.459	0.469	0.597	0.654	0.633	1.143	1.294	1.023	0.000	0.000	0.000
2012	0.014	0.064	0.286	0.322	0.480	0.591	0.585	0.528	0.716	0.530	0.891	1.349	1.326	1.309	1.480	0.000
2013	0.014	0.068	0.276	0.471	0.410	0.617	0.725	0.650	0.473	0.686	1.027	1.385	1.629	1.131	1.570	0.000
2014	0.017	0.056	0.280	0.466	0.552	0.459	0.664	0.679	0.580	0.496	1.058	1.750	0.827	1.676	0.000	1.001

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
2015	0.012	0.058	0.273	0.446	0.646	0.604	0.543	0.562	0.606	0.452	0.446	0.449	0.891	1.846	0.000	0.000
2016	0.019	0.064	0.235	0.504	0.646	0.752	0.879	0.607	0.499	0.677	1.639	0.701	0.804	1.236	2.070	1.772
2017	0.016	0.060	0.222	0.356	0.660	0.826	1.151	0.860	0.638	0.409	1.771	0.581	1.676	1.398	2.921	3.471
2018	0.017	0.056	0.230	0.397	0.450	0.878	0.886	0.944	0.888	0.556	0.772	1.177	1.489	2.098	1.374	2.914
2019	0.018	0.060	0.201	0.365	0.531	0.499	0.868	0.809	1.291	1.673	0.828	2.219	2.182	1.643	2.532	3.150
2020	0.016	0.050	0.240	0.396	0.490	0.721	0.527	1.350	1.463	1.449	2.068	1.016	0.786	0.000	0.000	0.000

7.5.3.2 **Maturity**

Following recommendations from WKHAD, a knife-edged maturity-at-age key was assumed for the Northern Shelf haddock stock assessment (ICES, 2014). However, a recommendation was made to derive time-varying maturity ogives from survey data with a method that properly accounted for the length-stratified sampling scheme. The analysis conducted at WKNSCS 2022 followed the guidelines as set out by the ICES Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG; ICES, 2008). More details of this analysis can be found in WD-1.

Differences in maturity between regions and sexes were explored in the analysis. Various studies have described sub-stock structure in various biological parameters which broadly fall into two sub-stock regions, east and west of the meridian (Wright and Tobin, 2013; Wright *et al*., 2010; González-Irusta and Wright, 2016; Jones, 1959; Jamieson and Birley, 1989). Due to this evidence, an area-specific weighting was applied to the survey data. Differences were seen in the speed of maturation between the sexes with males maturing faster as previously documented by Wright *et al*. (2011). In such cases weighting the data by sex ratio can address these differences (ICES, 2007). However, maturity data for males was highly variable across the whole time-series and was therefore considered to be unreliable. Furthermore, the inclusion of males would have lowered the average age of maturity leading to an impression of spawning potential at younger ages that would be higher than could actually be realised by females within the stock. Therefore, the maturity ogives are generated from female only maturity data.

Data from the Q1 North Sea International Bottom Trawl Survey (NS-IBTS), Q1 Scottish West Coast International Survey (SWC-IBTS) and Q1 Scottish West Coast Groundfish Survey (SCOWCGFS) were used. Reliable maturity data were only available from 1991 onwards. Data were raised in accordance with the WKMOG (ICES, 2008) guidelines and properly accounted for the length-stratified sampling scheme. The maturity ogives were modelled using a binomial GLM with logit link and the resulting time-series was smoothed using a generalised additive model for each age class.

The resulting maturity ogives are shown in Figure 7.13 and Table 7.11. The new maturity ogives represent a significant change from the previous ogives with approximately 5% of age-1 fish and 60% of age-2 fish now considered to be mature. Previously, maturity was assumed to be knife-edged at age 3 with all fish under age 3 being considered immature (ICES, 2014). This decision was based on the view that first time spawners, who are mostly age 2, tend to spawn later in the season and that this late timing means their offspring do not seem to contribute very much to that year's recruitment. This in comparison to older, more experience spawners who produce multiple batches of eggs throughout the season (Wright and Gibb, 2005). However, this study only considered 3 cohorts and did not consider the importance of the timing of prey availability on reproductive success (trophic mismatch – Cushing, 1990). The degree of trophic mismatch on recruitment has been seen to be an important influence on the year class strength of haddock (Platt *et al.*, 2003) as well as sandeels (Regnier *et al.*, 2017, 2019). Although older fish are seen to spawn earlier and, in more batches (Wright and Gibb, 2005, Morgan *et al.*, 2013) this is likely a bet-hedging strategy to account for variability in the timing of peak prey availability and produce more steady reproductive success. In contrast, variability in reproductive success will likely be higher amongst younger, late-spawning fish where the probability of overlap with the peak in prey availability is reduced. Despite this, mature younger fish should not be totally disregarded when considering the contribution to recruitment. This is because in some years, when peak prey availability occurs later in the season, the contribution from the younger fish could be quite important whereas early egg batches from older fish may not contribute very much.

The final maturity ogives are shown in Figure 7.14 in comparison to the old ogives. Since reliable survey data was only available from 1991 onwards, maturity in the years 1972 to 1990 are set equal to the earliest year of data (1991) for input to the assessment. The calculation of the maturity ogives will need to be repeated each year at WGNSSK as new survey data are added each year. A retrospective analysis should be conducted to ensure the robustness of the resulting ogives to the addition of data.

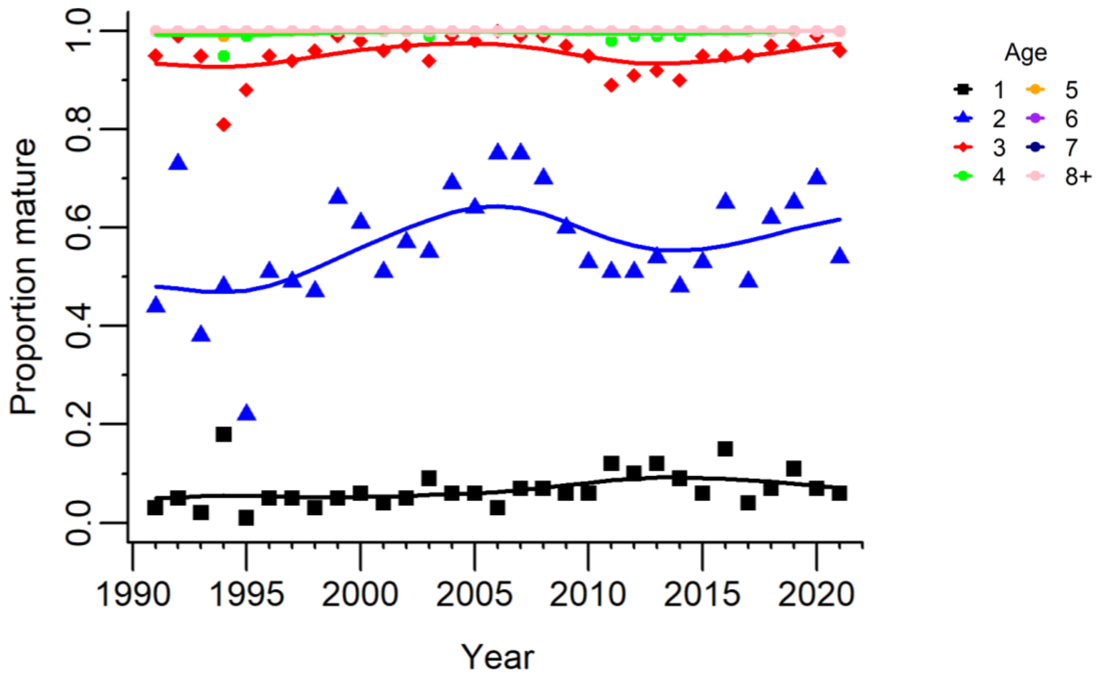


Figure 7.13. Northern Shelf haddock. Proportion mature-at-age. Symbols represent the modelled proportion mature-at-age whilst lines represent the GAM-smoothed values. Age 8+ denotes a plus group.

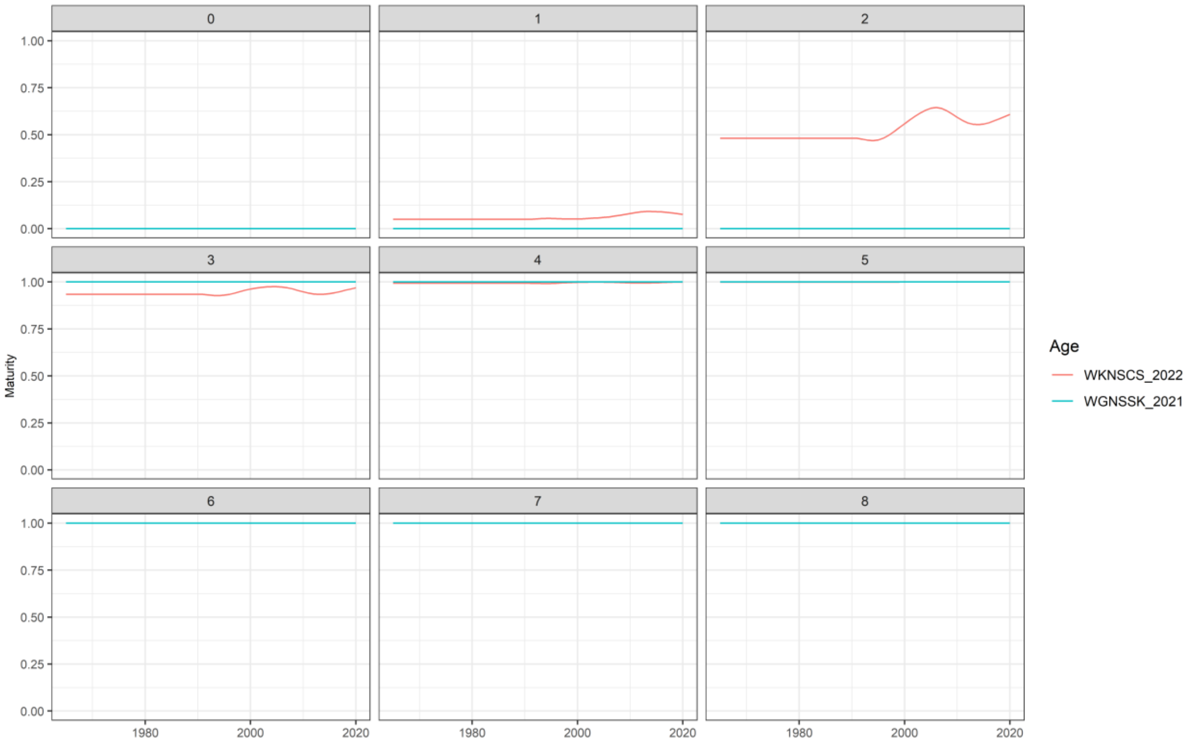


Figure 7.14. Northern Shelf haddock. Proportion mature-at-age used as input for WKNSCS 2022 compared to the old data used at WGNSSK 2021 (ICESc, 2021).

Table 7.11. Northern Shelf haddock. Proportion mature-at-age.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1972	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1973	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1974	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1975	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1977	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1978	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1979	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1980	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1981	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1982	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1983	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1984	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1985	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1986	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1987	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1988	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1989	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1990	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.000	0.050	0.481	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1992	0.000	0.052	0.476	0.931	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1993	0.000	0.054	0.471	0.928	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1994	0.000	0.055	0.469	0.927	0.991	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1995	0.000	0.055	0.472	0.930	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	0.000	0.054	0.482	0.934	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1997	0.000	0.053	0.498	0.941	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1998	0.000	0.052	0.517	0.949	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1999	0.000	0.052	0.538	0.956	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	0.000	0.052	0.559	0.962	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2001	0.000	0.053	0.579	0.967	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2002	0.000	0.055	0.599	0.971	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.000	0.057	0.616	0.974	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2004	0.000	0.058	0.631	0.975	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2005	0.000	0.061	0.641	0.975	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2006	0.000	0.063	0.645	0.973	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2007	0.000	0.067	0.640	0.969	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2008	0.000	0.071	0.628	0.963	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2009	0.000	0.076	0.611	0.955	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2010	0.000	0.081	0.593	0.948	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2011	0.000	0.086	0.576	0.941	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2012	0.000	0.090	0.563	0.936	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2013	0.000	0.092	0.556	0.934	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2014	0.000	0.092	0.554	0.935	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
2015	0.000	0.091	0.557	0.938	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2016	0.000	0.090	0.564	0.943	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2017	0.000	0.087	0.574	0.949	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2018	0.000	0.084	0.585	0.956	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2019	0.000	0.080	0.597	0.962	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2020	0.000	0.076	0.608	0.969	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

1.1.1.1 Natural mortality

Time varying natural mortality estimates for haddock are provided by the Working Group on Multispecies Assessment Methods (WGSAM) as output from the SMS key run (ICES, 2014). Natural mortality estimates are updated regularly and the latest estimates were produced in 2020 (ICES, 2021). The raw natural mortality estimates are aggregated to an annual value and then smoothed for each age class using a GAM to remain consistent with the method set at WKHAD (ICES, 2014) (Figure 7.15). The time-series for the estimates starts in 1974 and so the years in the assessment time-series before that (1972-1973) are set equal to the estimates in the earliest available year (1974). When a gap occurs between the present and the most recent estimates from WGSAM, the estimate in the most recent year is to be used for the intervening years.

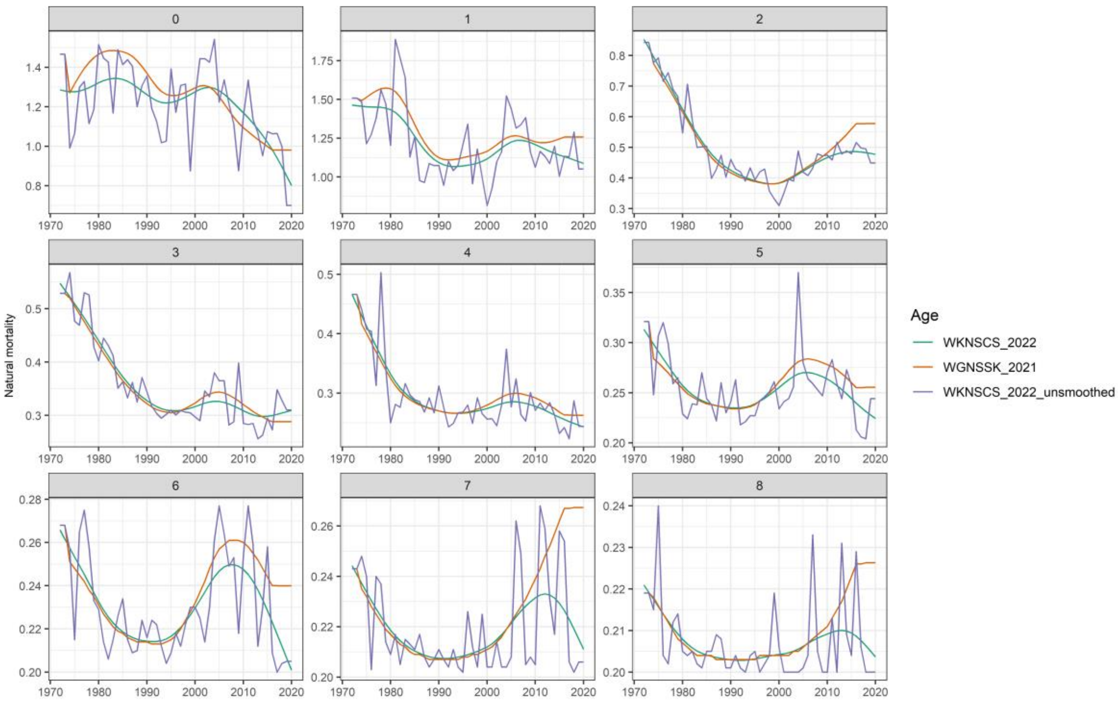


Figure 7.15. Northern Shelf haddock. Natural mortality-at-age estimates used as input for WKNSCS 2022 compared to the old data used at WGNSSK 2021 (ICESc, 2021). The raw (unsmoothed) estimates provided by WGSAM 2021 are also shown for comparison (WKNSCS_2022_unsmoothed).

7.5.4 Assessment model

The current stock assessment model used for Northern Shelf haddock is TSA (Fryer, 2002). However, the primary motivation for this benchmark is that support for this model will soon be unavailable. Therefore, a new assessment model needs to be chosen.

It is proposed here that the state-space assessment model (SAM; Nielsen and Berg, 2014) should be considered. Both TSA and SAM are state-space assessment models which build on the state-space modelling approach to age based assessment first described by Gudmundsson (1994). Therefore, SAM is very similar to TSA; the state vector and the survival and catch equations are the same though there are subtle differences, for example, in the state equations for the fishing mortality and various model options. However, both models are based on similar assumptions and treat catches as observations with noise and allow for time-varying selectivity and so similar results should be expected if similar model settings are used. SAM has been run alongside TSA as an exploratory assessment every year at the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). The full description of the process by which the final SAM assessment was decided can be found in WD-8.

7.5.4.1 Updating SAM configuration

The SAM model has been updated several times since it was first configured for Northern Shelf haddock at the last benchmark (ICES, 2014). A further update was also included to add an option for mixed distribution modelling for recruitment which may be of use to sporadic spawners such as haddock which produce occasionally very high year classes.

The results of the exploratory SAM assessment at WGNSSK 2021 (ICESd, 2021) showed significant retrospective bias (Mohn's rho) in spawning stock biomass (SSB) and fishing mortality (F) (0.51 and -0.18, respectively). To address this, various setting within SAM were changed using the TSA settings as a guide. Of the resulting model runs, the NShaddock2021explore05 run was considered to be acceptable based on its diagnostics. The updated SAM configuration settings are shown in Table 7.12.

Table 7.12. Northern Shelf haddock. Settings used for run NShaddock2021explore05 specific to Northern Shelf haddock. Default values were used for settings not listed.

Configuration setting	Details
Assessment age range	0-8+
Is maximum considered a plus group	1 0 0
Coupling of the fishing mortality states	0 1 2 3 4 5 6 7 7
Correlation of fishing mortality across ages	Independent (0)
Coupling of the survey catchability parameters	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 1 2 3 3 -1 -1 -1 4 5 6 7 8 8 -1 -1 -1
Coupling of process variance parameters for F	0 0 0 0 0 0 0 0 0
Coupling of process variance parameters for N	0 1 1 1 1 1 1 1 1
Coupling of the variance parameters for observations	0 1 2 2 2 2 2 2 2 -1 3 4 4 4 4 -1 -1 -1 5 6 7 7 7 7 -1 -1 -1
Covariance structure for each fleet	Independent (ID) for all
Stock recruitment code	Random walk (0)
F range	2-4

7.5.4.2 Incorporating new data

The new data presented at WKNSCS 2022 include natural mortality, mean stock weights-at-age, catch data, maturity ogives and survey indices. The new data were added in a stepwise fashion to the NShaddock2021explore05 run. A comparison of SSB, F and recruitment as each dataset is added is shown in figures 7.16, 7.17 and 7.18 respectively.

The new natural mortality data was the first dataset to be added. These new natural mortality values tend to be lower than those used at WGNSSK 2021, especially towards the end of the time-series which translates to higher SSB and lower F estimates which become more noticeable in later years. Recruitment values are similar across most of the times series though lower recruitment values are seen at the beginning and very end of the time-series with the new natural mortality values. Next, the stock mean weights-at-age were added. The new stock mean weight-at-age age data do not affect the model fit, or the resulting F and recruitment as they are only used to calculate SSB. The new SSB estimate is seen to lower as the new stock weights are lower than the old stock weights (which were set equal to the mean weights-at-age in the catch). The next dataset to be added was the catch data. The new catch data time-series has only been revised from 2008 onwards and overall gives slightly lower catches each year. The biggest revisions were seen in 2010 and 2011. Overall, changes to SSB, F and recruitment were small. The resulting new SSB estimate is slightly higher from 2008 onwards. The effect of the new catch data on F is mostly small reductions with the largest changes seen in 2010 and 2011. The next dataset to be added was the new maturity ogive. The old ogive was fixed through time and knifed-edged at age 3 (i.e. all fish aged 3 or older are all mature; fish aged 0-2 are all immature). Since the stock-recruitment model is random walk, the new maturity ogive does not impact the model fit or resulting F and recruitment. The only effect is on the calculation of SSB. The new maturity ogive means that a significant proportion of fish are now mature at age 2, the majority by age 3 and a small amount not until age 4. The resulting SSB time-series is smoother as cohorts are now added to SSB over a number of years rather than in a single year. This results in some compensatory action in years where larger cohorts are being fished out and new cohorts are maturing. Next, one set of new modelled survey indices were added. These were the combined North Sea (NS) and West Coast of Scotland (WC) Q1 indices and the North Sea Q3 indices. This run was conducted to ensure the results were not vastly different from using the modelled NS-WC Q3+Q4 indices which is the preferred option for the second survey input. Replacing the modelled NS Q3 indices with the preferred NS-WC Q3+Q4 indices gave similar results to the previous run. Overall, the trends in the new SSB estimate are similar to the previous run although are generally lower, especially towards the end of the time-series. Consistent with this, F is seen to be higher towards the end of the time-series. Peaks in recruitment are seen to be similar up until 1999 but is lower from 1999 onwards.

7.5.4.3 Sensitivity analysis

Various model settings were explored to see if these changes resulted in a substantial improvement in model fit. These changes included settings associated with the modelling of fishing mortality, survey catchabilities, observation variances, process error and including external estimates of variances for the survey indices and catch data. The model diagnostics considered when assessing if a change in the settings resulted in a substantial improvement included visual comparisons of the residuals (one-observation-ahead, process error), leave-one-out analysis, retrospective patterns as well as consideration of the Akaike Information Criterion (AIC) value and the number of parameters. Some settings were not explored due to lack of time but could be explored in future (e.g. covariance structure for each fleet, using the GMRF model within SAM for biological data). Details of key model runs are summarised in Table 7.13.

Only two setting changes resulted in an improvement to the model fit compared to the base model (NShaddock2021_ex05_newQ1_Q3Q4). Both were considered substantial enough with little loss of stability in the assessment (i.e. similar Mohn's rho values for SSB, F and recruitment) for inclusion in the final model settings. The first setting was the correlation of fishing mortality across ages which was changed from independent (i.e. no correlation) to first-order autoregressive (AR(1)). The AR(1) option is the default setting within SAM and is the most realistic assumption given that changes in F are expected to be correlated across ages. This change resulted in a more variable trend in the estimate of fishing mortality and some minor reductions in the size of the residuals as well as an improvement in the patterning within the residuals. The second setting change that improved the model fit was decoupling the survival process variance parameters for the oldest age. This resulted in an improvement in the process error residuals and other model fit diagnostics. The size of the residuals, especially in the plus group, were mostly reduced for both fishing mortality and the survival process.

An issue from the issue list for this benchmark was to investigate mixed distribution modelling methods for recruitment due to the occurrence of sporadic large year classes in this stock. This functionality was added to SAM for this benchmark to allow for longer tails on the distribution used for modelling the recruitment (i.e. a mix of normal and t-3 distributions). An exploratory run (NShaddock_WKNSCS_2022_Run1) was conducted where this setting was used (fracMixN

= [0.1 0 0 0 0 0 0 0 0]). However, only small differences were seen between the recruitment estimates for this run compared to the base model and there was no substantial improvement in the model fit diagnostics. As a result, this setting was not chosen for inclusion in the final model settings.

Table 7.13. Northern Shelf haddock. Model diagnostics from key model runs. Run name refers to the stockassessment.org reference.

Run name	Data	Settings	n par	log lik	AIC	Mohns rho SSB	Mohns rho F	Mohns rho rec
NShaddock2021explore01	WGNSSK 2021	Settings used at WGNSSK 2021.	16	-958.86	1949.71	0.51	-0.18	-0.10
NShaddock2021explore05	WGNSSK 2021	start in 1972; independent F; decouple variance parameters for observations at younger ages	20	-681.19	1402.37	0.07	0.08	0.15
NShaddock2021_ex05_newQ1_Q3Q4	WKNSCS 2022	Same as NShaddock2021explore05	26	-637.19	1314.37	0.02	-0.03	-0.01
NShaddock_WKNSCS_2022_Run1	WKNSCS 2022	Same as NShaddock2021explore05 with change: fracMixN = [0.1 0 0 0 0 0 0 0 0]	26	-647.34	1346.69	0.02	-0.03	-0.01
NShaddock_WKNSCS_2022_Run11	WKNSCS 2022	Same as NShaddock2021explore05 with change: corFlag: 2 (AR(1)) + keyVarN: [0 1 1 1 1 1 1 1 2]	28	-589.57	1235.15	0.00	-0.05	0.01

7.5.4.4 Final model

The stockassessment.org reference for the final model run is NShaddock_WKNSCS_2022_Run11.

The assessment start date was set as 1972 at the last benchmark. The start year of 1972 was chosen as a compromise between the longer landings time-series, the lack of reliable estimates of industrial bycatch before 1972 and only reconstructed discards being available before 1978 (ICES, 2014). All input datasets used in the final model start in 1972. Some biological datasets do not have reliable data available as far back as 1972. In these cases, data in earlier years are set equal to data from the earliest year available. Data are mostly available up to age 15 although the plus group is set as age 8+.

The input data to the final model is summarised in Table 7.14. As the input to SAM needs to be total catches, the four catch components (landings, discards, industrial bycatch and below minimum size (BMS) landings) were combined together. However, some extra inputs are needed for the calculation of plus group data. For this the industrial bycatch and BMS landings were combined with the discards data for the required inputs (mean weights-at-age for landing, mean weights-at-age for discards+bycatch+BMS and numbers-at-age for discards+bycatch+BMS). Landings numbers-at-age were also provided to enable the resulting catches from forecast projections to be split into the landings and discards+bycatch+BMS components. The setting used within SAM are listed in Table 7.15. Settings not listed are set to the default values.

Table 7.14. Northern Shelf haddock. Summary of data inputs to SAM.

Dataset	Year	Ages	Details
Catch numbers	1972-2020	0-8+	Catch-at-age in numbers. Combination of landings, discards, BMS landings and industrial bycatch
Survey: delta-GAM NS-WC Q1	1983-2021	1-8+	Delta-GAM modelled survey indices covering the North Sea and West Coast of Scotland in quarter 1.
Survey: delta-GAM NS-WC Q3+Q4	1991-2020	0-8+	Delta-GAM modelled survey indices covering the North Sea in quarter 3 and West Coast of Scotland in quarter 4.
Stock weights	1972-2020	0-8+	Mean weights-at-age. Produced from applying survey-derived correction factors to mean weights-at-age in the catch.
Catch weights	1972-2020	0-8+	Mean weights-at-age in the total catch.
Landing weights	1972-2020	0-8+	Mean weight-at-age in the landings.
Discard weights	1972-2020	0-8+	Mean weight-at-age in the discards.
Discard numbers	1972-2020	0-8+	Numbers-at-age for discards. Used for plus group calculations.
Landings fraction (numbers)	1972-2020	0-8+	Numbers-at-age for landings. Used to separate out the landings portion of the total catch for use in the forecast. This is converted to a landings fraction within the model code.
Natural mortality	1972-2020	0-8+	Natural mortality estimates from the SMS key run produced by WGSAM. Smoothed.
Maturity	1972-2020	0-8+	Proportion mature. Survey-derived maturity ogives. Smoothed. Time varying.
Proportion of natural mortality before spawning	1972-2020	0-8+	Set to zero for all ages and years.
Proportion of fishing mortality before spawning	1972-2020	0-8+	Set to zero for all ages and years.

Table 7.15. Northern Shelf haddock. Settings used for final SAM assessment model (NShaddock_WKNSCS_2022_Run11) specific to Northern Shelf haddock. Default values were used for settings not listed.

Configuration setting	Details								
Assessment age range	0-8+								
Is maximum considered a plus group	1 1 1								
Coupling of the fishing mortality states	0 1 2 3 4 5 6 7 7								
Correlation of fishing mortality across ages	2 (i.e. AR(1))								
Coupling of the survey catchability parameters	-	-	-	-1	-1	-1	-1	-1	-1

	1	1	1						
	-1	0	1	2	3	4	5	6	6
	7	8	9	10	11	12	13	14	14
Coupling of process variance parameters for F	0 0 0 0 0 0 0 0 0								
Coupling of process variance parameters for N	0 1 1 1 1 1 1 1 2								
Coupling of the variance parameters for observations	0	1	2	2	2	2	2	2	2
	-1	3	4	4	4	4	4	4	4
	5	6	7	7	7	7	7	7	7
Covariance structure for each fleet	Independent (ID) for all								
Stock recruitment code	Random walk (0)								
F range	2-4								

The trends in the final model for the SSB, recruitment and catch estimates are similar to the base model. SSB is seen to be slightly higher in the final model compared to the base model (Figure 7.19). The trend in the fishing mortality estimate is seen to be more variable in the final model compared to the base model though still with a general decline over the time-series. Though the size and patterns in the residuals are seen to have reduced in the final model there are still some persistent patterns in the residuals associated with the plus group (Figure 7.20). A residual pattern in the plus group is often associated with the accumulation of fish in this age class suggesting that natural mortality estimates may be too low. Some additional runs were conducted to try and address this residual pattern. These runs aimed to artificially inflate the residual natural mortality estimate for the plus group (residual mortality is separate from mortality from predation and WGSAM assume a value of 0.2 for the plus group). Several approaches were tried (e.g. a scaling up; adding an increasing linear trend) however, these extra runs did not have an effect on the pattern in the residuals. A recommendation for the next benchmark was made to assess the age range used in the assessment and potentially increase the age at which the plus group is formed (e.g. age 10+).

The leave-one-out analysis (Figure 7.21) shows good agreement in trends between the surveys with both leave-one-out runs falling mostly within the confidence intervals of the full assessment run. The retrospective analysis shows that the final model assessment run is still very robust to the removal of data up to the last 5 years (Figure 7.22) (Mohn's rho values: SSB = 0.00, F = -0.05, recruitment = 0.01).

A comparison of the final model results to the TSA assessment estimates from WGNSSK 2021 (ICESc, 2021) is given in Figure 7.23. The overall trends between the two assessement results are very similar, however some key differences can be seen. SSB is substantially lower in the latter part of the time-series (post 2000) and fishing mortality is correspondingly higher in the new assessment results. The new estimated recruitment also shows lower values, especially for the larger peaks in abundance in the years after 2000. SSB is also seen to be smoother in the new assessment results with less distinction between the peaks and valleys. These changes can also be seen in figures 7.16-7.18 which document the addition of the new datasets. From this, it is apparent that these changes can be mostly attributed to the new maturity ogives and survey indices. The new maturity ogives now indicate that 50-60% of age-2 fish are mature whereas age-2 fish were all considered to be immature in the old maturity ogives. The effect of this is to smooth out the trends in SSB as individual cohorts now become mature over several years as opposed to in a single year when they turn 3 as indicated by the old maturity ogives. The reduction in SSB and recruitment after 2000 corresponds to the lower relative size of peaks in abundance in the new, modelled survey indices compared to the old, DATRAS survey indices. The reasons for these differences are described in detail in section 7.6.2 and relate to methodological differences in the estimation of the indices. A correction was made to the calculation of the DATRAS indices in 2020 (see section 7.6.2 for more details) which, when used in the previous assessment model, also resulted in lower SSB and recruitment estimates. This suggests that the old, DATRAS survey indices may have been over estimating abundances and the new, modelled indices give a better reflection of the true state of the stock.

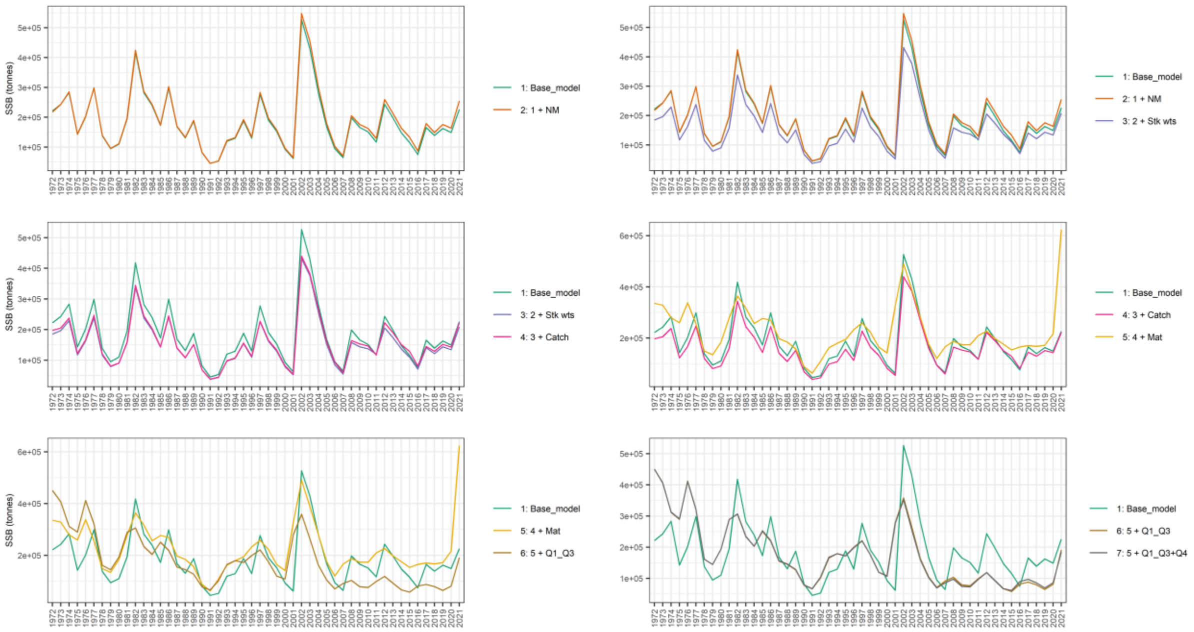


Figure 7.16. Northern Shelf haddock. Estimated SSB (tonnes) when each new dataset is added successively to the NShaddock2021explore05 run ("Base_model"). The labelled coloured lines indicate which new data set has been added (NM = natural mortality, Stk wts = stock weights, Catch = catch data, Mat = maturity, Q1_Q3 = delta GAM survey indices for Q1 (North Sea and West Coast) and Q3 (North Sea)., Q1_Q3+Q4 = delta GAM survey indices for Q1 (North Sea and West Coast) and combined Q3 (North Sea) and Q4 (West Coast)).

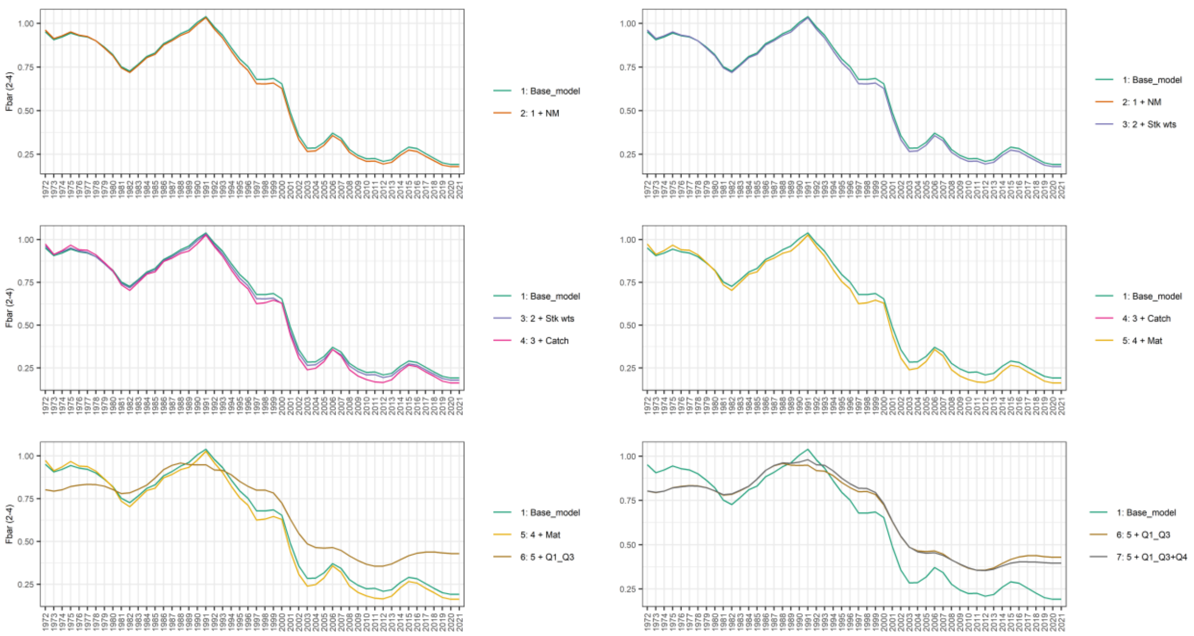


Figure 7.17. Northern Shelf haddock. Estimated fishing mortality when each new dataset is added successively to the NShaddock2021explore05 run. The labelled coloured lines indicate which new data set has been added (NM = natural mortality, Stk wts = stock weights, Catch = catch data, Mat = maturity, Q1_Q3 = delta GAM survey indices for Q1 (North Sea and West Coast) and Q3 (North Sea)., Q1_Q3+Q4 = delta GAM survey indices for Q1 (North Sea and West Coast) and combined Q3 (North Sea) and Q4 (West Coast)).

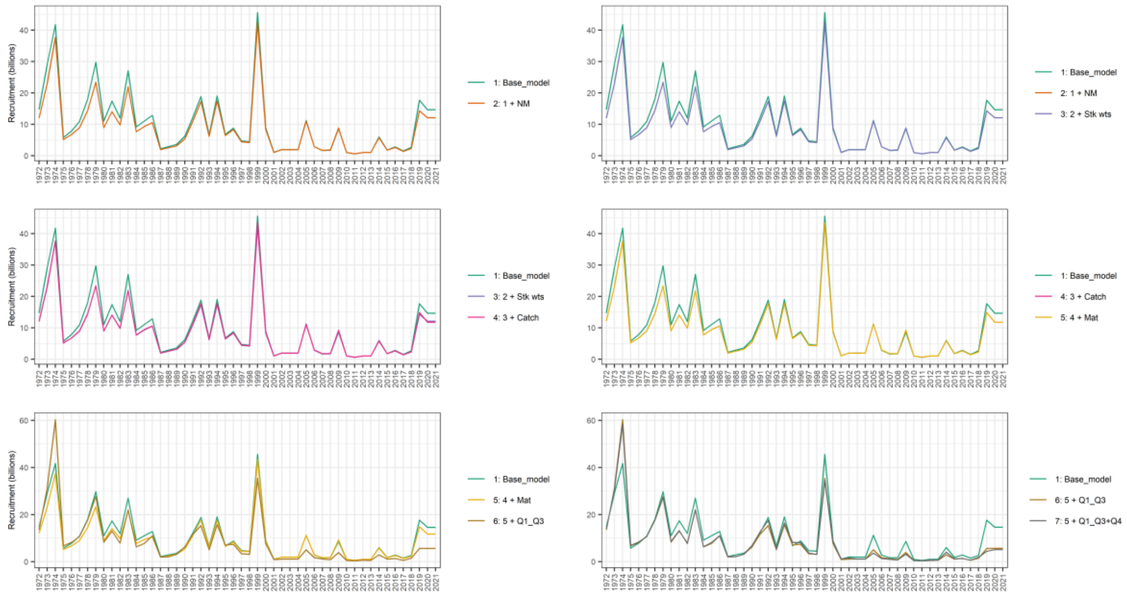


Figure 7.18. Northern Shelf haddock. Estimated recruitment (age 0, billions) when each new dataset is added successively to the NShaddock2021explore05 run. The labelled coloured lines indicate which new data set has been added (NM = natural mortality, Stk wts = stock weights, Catch = catch data, Mat = maturity, Q1_Q3 = delta GAM survey indices for Q1 (North Sea and West Coast) and Q3 (North Sea)., Q1_Q3+Q4 = delta GAM survey indices for Q1 (North Sea and West Coast) and combined Q3 (North Sea) and Q4 (West Coast)).

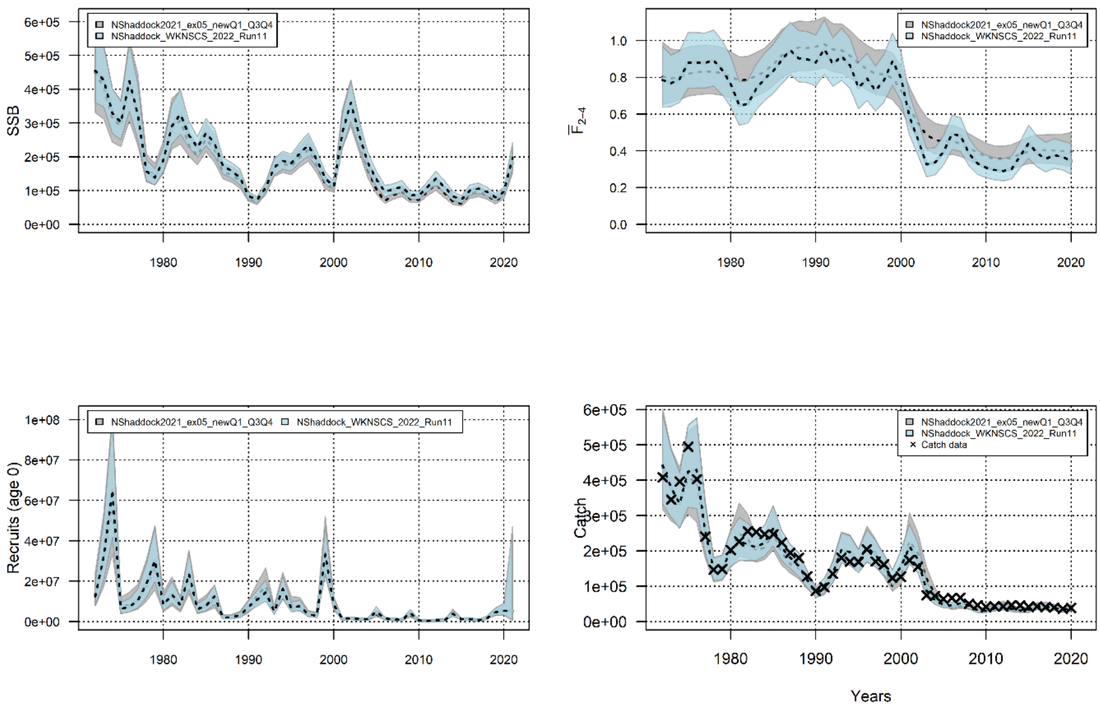


Figure 7.19. Northern Shelf haddock. Estimated spawning stock biomass (SSB, tonnes), fishing mortality (F), recruitment (recruits, age 0, thousands) and total catch for the base model run (NShaddock_ex05_newQ1_Q3Q4) and the final model run (NShaddock_WKNSCS_2022_Run11). The pointwise 95% confidence intervals are indicated by the blue (NShaddock_WKNSCS_2022_Run11) and grey (NShaddock_ex05_newQ1_Q3Q4) shaded area.

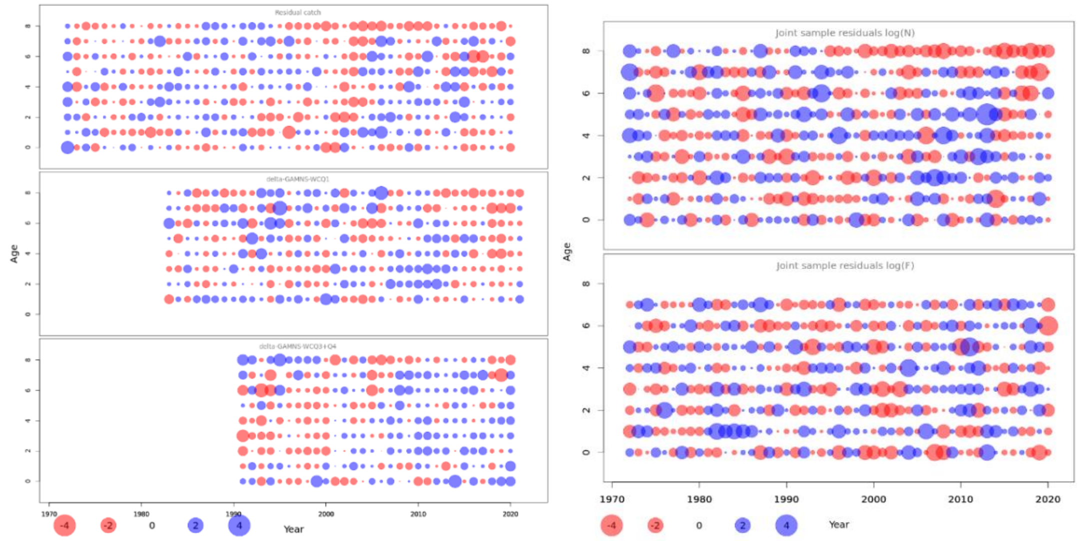


Figure 7.20. Northern Shelf haddock. Results for the final model (NShaddock_WKNSCS_2022_Run11). One-observation-ahead fleet residuals (catch, delta GAM NS-WC Q1, delta GAM NS-WC Q3+Q4) and process error residuals (N and F).

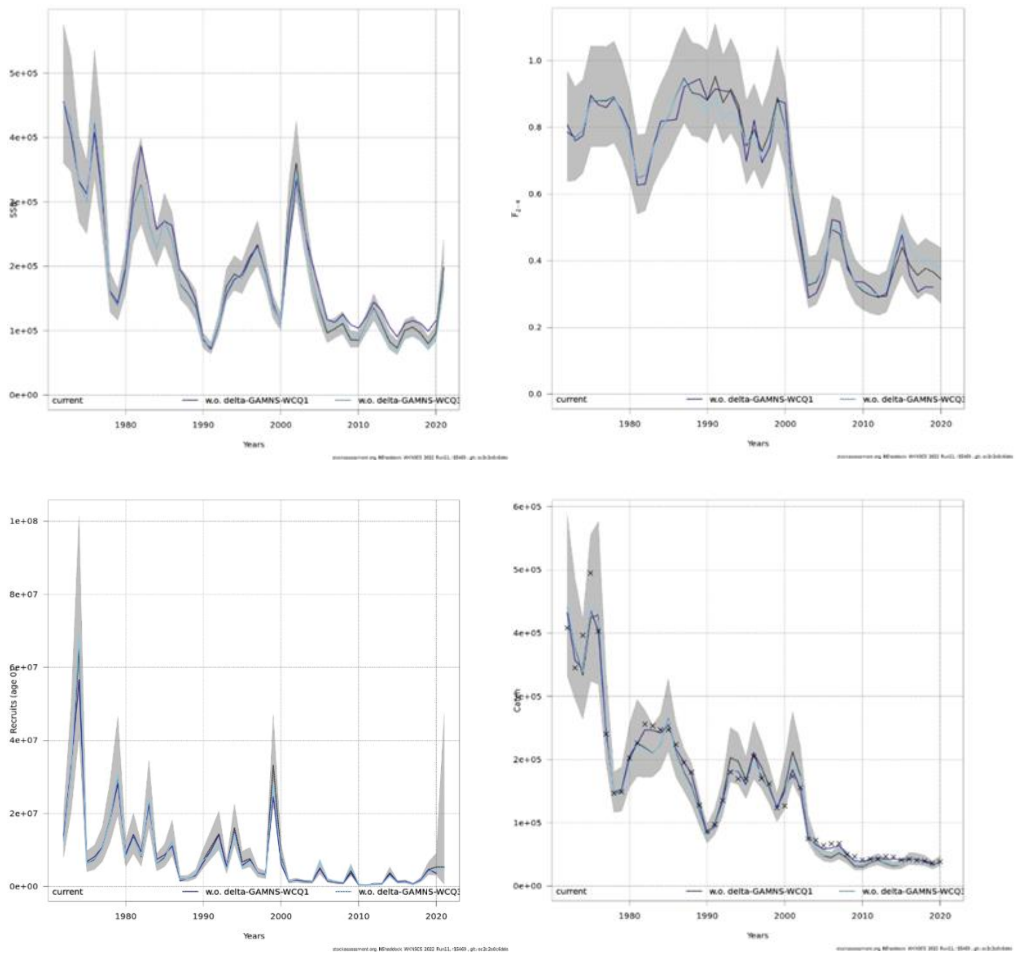


Figure 7.21 Northern Shelf haddock. Results for the final model (NShaddock_WKNSCS_2022_Run11). Leave one out runs for spawning stock biomass (SSB (tonnes), top left), Fishing mortality (F(2-4), top right), recruitment (age 0 (thousands), bottom left) and catch (tonnes, bottom right). The full model run results are indicated by the black line and the 95% confidence intervals are indicated by the grey shaded area. Dark blue and light blue lines indicate model results when either the delta GAM NS-WC Q1 and delta GAM NS-WC Q3+Q4 surveys are removed, respectively. Note that the start year for the delta GAM NS-WC Q1 survey and delta GAM NS-WC Q3+Q4 survey is 1983 and 1991, respectively.

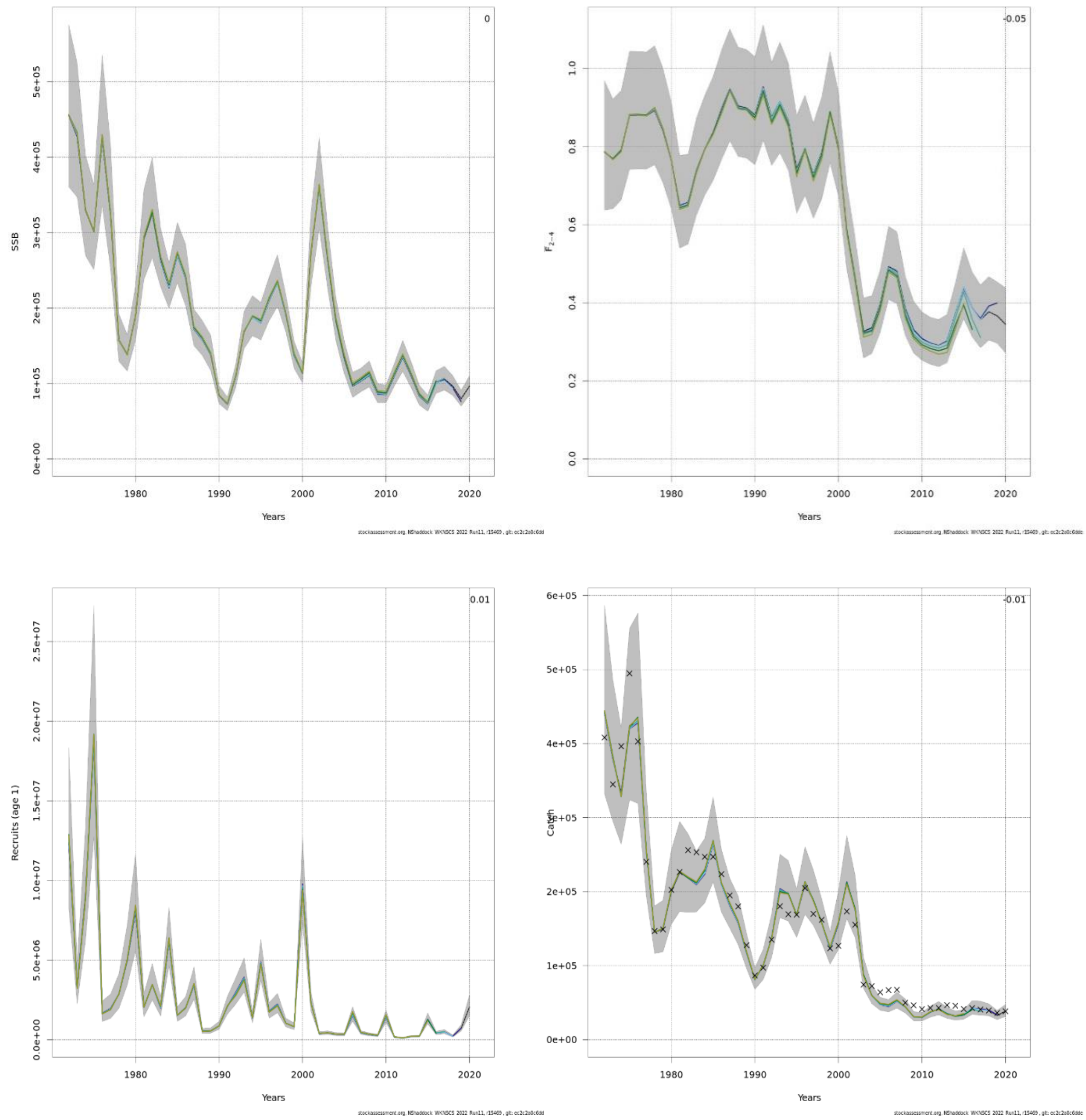


Figure 7.22. Northern Shelf haddock. Results for the final model (NShaddock_WKNSCS_2022_Run11). Retrospective analysis for spawning stock biomass (SSB (tonnes), top left), Fishing mortality (F(2-4), top right), recruitment (age 0 (thousands) , bottom left) and catch (tonnes, bottom right). The full model run results are indicated by the black line and the 95% confidence intervals are indicated by the grey shaded area. Coloured lines indicate model results when the last 5 year's data are removed in succession.

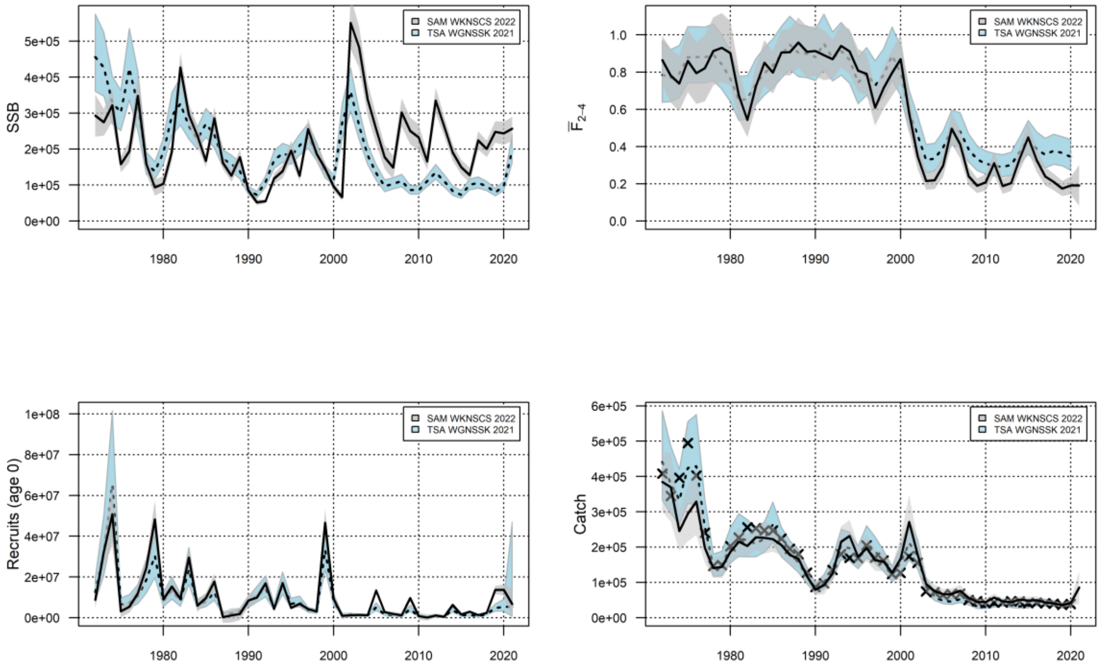


Figure 7.23. Northern Shelf haddock. Estimated spawning stock biomass (SSB, tonnes), fishing mortality (F), recruitment (recruits, age 0 (thousands)) and total catch (tonnes) for the final model run ("SAM WKNSCS 2022"; NShaddock_WKNSCS_2022_Run11) and the previous assessment results ("TSA WGNSSK 2021"; (ICESc, 2021)). The pointwise 95% confidence intervals are indicated by the blue (TSA WGNSSK 2021) and grey (WKNSCS 2022) shaded area.

7.6 Short term projections

There were two issues relating to the forecast settings listed on the issue list. The first was to address inconsistencies in the way the mean weights-at-age are calculated for the catch components and the stock. The second was to consider combining the human consumption (HUC; landings, discards, BMS landings) and the industrial bycatch (IBC) fleets into a single fleet forecast. A third consideration would be to consider changing the software used for the forecast from the deterministic MFDP previously used to the stochastic SAM model forecast to keep consistent with the assessment outputs. These issues are addressed in detail in WD-10 though a summary is given below.

7.6.1 Mean weights-at-age

The mean weights-at-age used in the forecast are derived through a linear extrapolation of mean weights-at-age by cohort (Jaworski, 2011, ICES, 2014). In the current procedure, the extrapolations are done separately for landings, discards+BMS (combined) and total catch.

Weights at age a for cohort c are fitted with the linear model:

$$W_{a,c} = \alpha_c + \beta_c a$$

Where parameter α_c and β_c are cohort-specific. These parameters are then used to predict the mean weights at older ages. A simple mean of the weights-at-age for the last 3 data years is used for recent cohorts that have less than 3 data points as estimates of the model parameters cannot be generated reliably for these cohorts. A simple 3-year mean is also used to generate forecast weights for the industrial bycatch component. The mean weights-at-age in the stock for the forecast are set equal to those in the total catch. However, because the forecast weights are extrapolated separately for each catch component and for total catch the resulting mean weights are often not consistent with each other (i.e. forecast weights for the total catch do not always fall between the forecast weights for landings and discards).

To address this inconsistency the procedure was updated. The linear extrapolation method is applied by cohort to generate forecast weights for landings and discards+BMS. A simple 3-year mean is again used to calculate the forecast weights for industrial bycatch. However, the forecast weights for these three components were then combined together in a weighted mean to derived the forecast weights for the total catch. The 3-year mean proportion of the catch that corresponded to landings, discards+BMS and industrial bycatch were used as weightings. This updated methodology ensures consistency in the forecast weights between each catch component and the total catch. Similar to the method used to derive the mean stock weights-at-age for the assessment, the catch-stock correction factors (derived in WD-2) were applied to the forecast weights for the total catch to obtain forecast weights for the stock.

7.6.2 Multi-fleet vs. single fleet

The current forecasting procedure conducts a multi-fleet projection as catches for the HUC and IBC fleets are managed separately. However, industrial bycatch catches have decreased over time and have been considerably low for many years (less than 1000 tonnes since 2004 which corresponds to less than 1% of total catch). As a result, a recommendation from ADGNS was made to combine these fleets for forecasting purposes to simplify the advice production process. However, catches of IBC were higher than expected in 2020 (1077 tonnes). Nevertheless, this higher than usual IBC catch presents an ideal opportunity to assess the impact of combining the fleets in the forecast projections.

To conduct a single fleet MFDP projection, the IBC data were combined with the discards+BMS component of the HUC catch in the calculation of the forecast mean weights and the partial F's (used to split the projected catches into the catch components (e.g. landings and discards+BMS+IBC)). Additionally, the TAC constraint applied in the intermediate year was applied to all catch as opposed to just the HUC catch. Otherwise, all other forecast inputs remained the same as for a mutli-fleet projection as detailed at WKHAD (ICES, 2014). A comparison of the results of the single and multi-fleet projections found little difference in the projected catches, fishing mortality and spawning stock biomasses (SSB) between the two projections. Overall, these small differences in the projection results indicate that the ADGNS recommendation for a single fleet forecast can be followed, particularly given that catches of IBC were substantially higher in 2020.

7.6.3 SAM forecast setting and inputs

As the assessment model has changed to SAM the forecasting software will also be changed to SAM to ensure consistency between the assessment and forecast projection. Using SAM also allows for a stochastic projection whereas MFDP only provides a deterministic projection. It should be noted that SAM has the capability to project multiple fleets if a change back to a multi-fleet projection is needed in the future.

The new settings and inputs to the SAM forecast are listed in Table 7.16. The majority of these inputs are the same as used in the current procedure. However, some changes are needed to allow for a stochastic projection. These include:

- Initial stock size: simulated from the estimated distribution at the start of the intermediate year.
- Recruitment assumption: recruitment for the intermediate year onwards is sampled, with replacement, from 2000 to the final year of catch data. Sampling with replacement allows for information on the frequency of large year classes to be included in the projections. The decision to restrict the sampling period to 2000 onwards arises from the perceived reduction in recruitment level during that time period compared to the rest of the time-series. This decision also keeps the forecast assumption for recruitment consistent with that used for calculating the reference points (see section 7.8).
- Exploitation pattern: mean of final 3 data years, rescaled to the final year F. This is the default setting for SAM forecasts.

Table 7.16. Northern Shelf haddock. Forecast settings for SAM projection.

Input	Details
Initial stock size	Simulated from the estimated distribution at the start of the intermediate year (including covariances)
Maturity	Mean of final 3 data years
Natural mortality	Mean of final 3 data years
F and M before spawning	Taken as 0
Mean weights-at-age in the catch	Jaworski cohort modelling method
Mean weights-at-age in the stock	Application of catch-survey correction factors to mean weights-at-age in the catch
Exploitation pattern	Mean of final 3 data years, rescaled to final year F
Intermediate year assumptions	Decided each year at WG
Recruitment assumption	Recruitment for the intermediate year onwards is sampled, with replacement, from 2000 to the final year of catch data
Procedure for splitting catches	Partial Fs at age for catch components estimated using final data three-year mean catch proportions (i.e. landings fraction)

7.7 Appropriate Reference Points (MSY)

New reference points for Northern Shelf haddock were estimated for the new SAM assessment model, which was agreed upon at WKNSCS 2022. This was done in a stepwise process, using the EqSim analysis (standardized ICES code) and ICES technical guidelines (ICES, 2021b), detailed in the sections below. These new reference points were then compared to the current ones last derived at WGNSSK 2016 (ICES, 2016a) (see WD-11 for full details).

7.7.1 Settings

The setting used in the EqSim runs are summarised in Table 7.17. SigmaSSB from the new SAM run was 0.1 in 2021. Since this value was below 0.2, the default values of 0.2 was used instead for sigmaSSB, as done previously (ICESa, 2016). For both biological data and fisheries selectivity, the most recent 10 years were found to be most representative, and re-sampling from the last 10 years was used in EqSim. Both these settings are consistent with what was done previously (ICESa, 2016).

Since Northern Shelf haddock seems to have been experiencing a lower productivity since 2000, as shown by the shift in values of recruits over SSB ratio (Figure 7.24), only values from 2000 onwards were included in EqSim to simulate the stock recruitment relationship. This is consistent with the decision of WGNSSK in 2016, who noted that recruitment appeared to be declining and that it would be unwise to assume that a very large recruitment is likely in the near future (ICESb, 2016). Autocorrelation in recruitment was not significant and therefore was not included.

In all EqSim simulations, a segmented regression was used as the stock-recruit relationship. Since B_{lim} was defined using the whole time-series of recruits and SSB values, but only values from 2000 onwards were used in EqSim, it was decided to fix the breakpoint of the segmented regression at B_{lim} rather than it being freely estimated.

Table 7.17. Northern Shelf haddock. Summary of setting used in EqSim runs

Input	Details
Biological data	Mean of the last 10 years
Fishing selectivity	Mean of the last 10 years
sigmaSSB	0.2 (default value)
F_{cv}	0.212
F_{phi}	0.423
Recruitment	No autocorrection. Time-series truncated to 2000 onwards.
Stock-recruit relationship	Segmented regression. Breakpoint fixed at B_{lim}

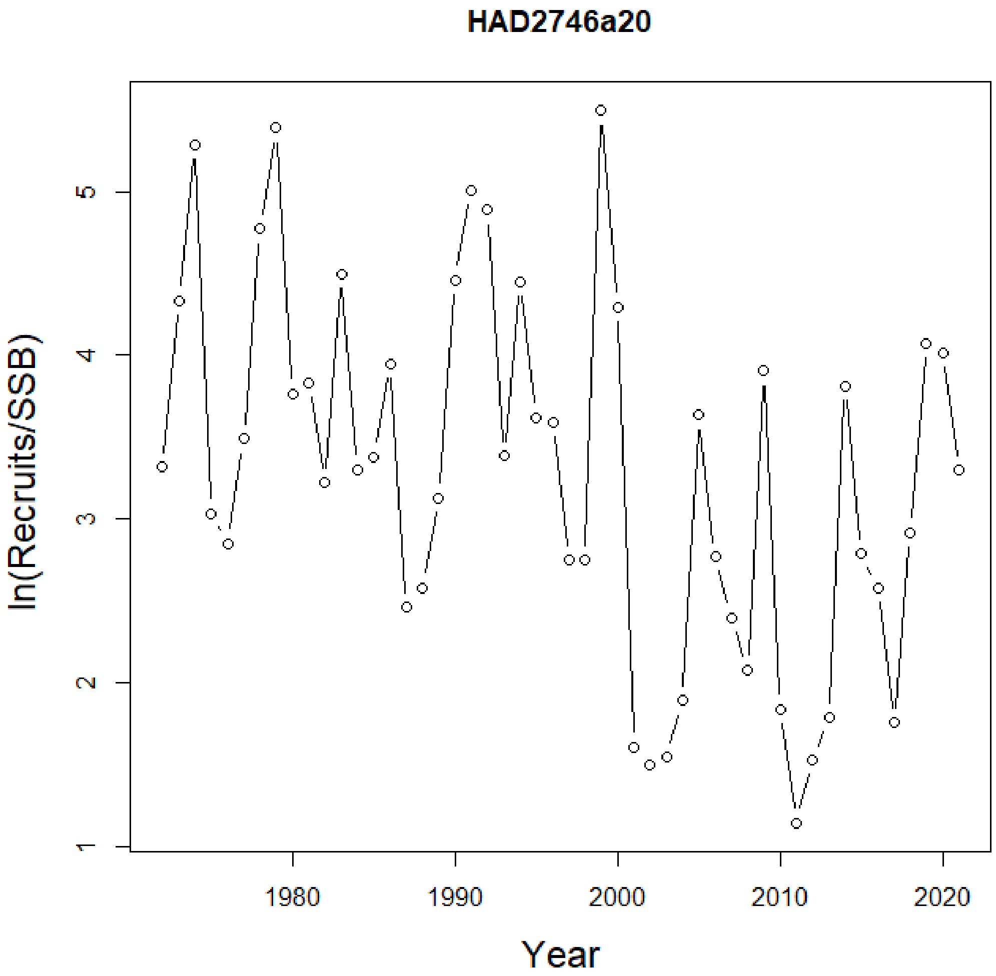


Figure 7.24. Northern Shelf haddock. Time-series of recruits over SSB ratio, on a log scale.

7.7.2 Estimating B_{lim}, F_{lim} and PA reference points

B_{lim} is an important reference point from which other precautionary reference points are derived. Haddock is a species with sporadic large year classes. Following ICES technical guidelines (ICESb, 2021), we therefore categorize Northern Shelf haddock as a Type 1 stock and B_{lim} should be the lowest SSB to produce a large recruitment. Based on the results from the new SAM model, this SSB occurred in 1999 when a SSB of 136,541 tonnes produced just over 30 billion recruits (Figure 7.25). Therefore, here B_{lim} = 136,541 tonnes. The 1999-year class falls just over the 95th percentile for recruitment size. B_{pa} was estimated based on B_{lim} as follows, where the default value of 0.2 was used for sigmaSSB:

B_{pa}=B_{lim}*exp(1.645*sigmaSSB)

The B_{pa} value obtained based on B_{lim} was B_{pa} = 189 734 tonnes.

To estimate F_{lim}, EqSim was run without assessment/advice error, without the advice rule, and with a segmented regression with the breakpoint fixed at B_{lim} to model recruitment in EqSim. The resulting F_{lim} (F_{50}) obtained was 0.434.

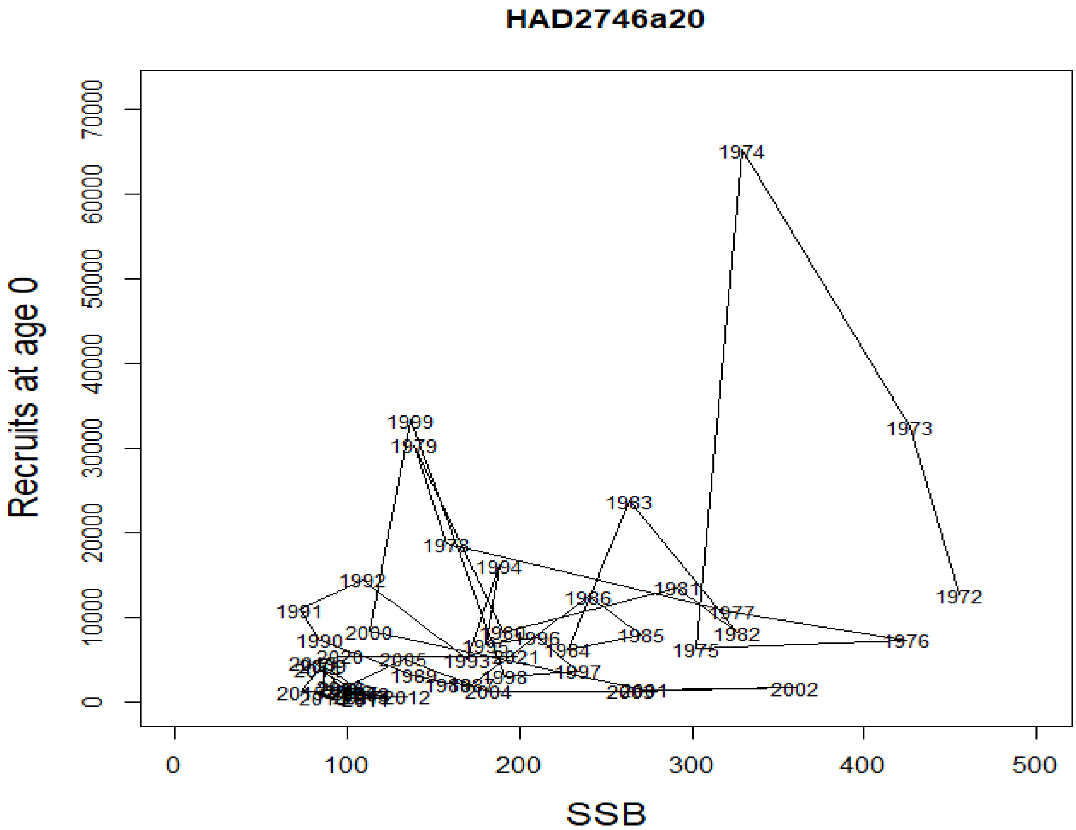


Figure 7.25. Northern Shelf haddock. Age 0 recruits (millions) against SSB (1000 tonnes).

7.7.3 Estimating F_{MSY}, $F_{p.05}$ and F_{pa}

To estimate the unconstrained F_{MSY}, the EqSim was run without the advice rule (i.e. no MSY $B_{trigger}$), with assessment and advice error using the default values $(F_{cv}, F_{phi}) = (0.212, 0.423)$ as suggested by WKMSYREF4 (ICES, 2015), and with a segmented relationship with a breakpoint fixed at B_{lim} (Figure 7.26). The resulting unconstrained F_{MSY} obtained (median MSY for lanF) was $F_{MSY} = 0.271$.

To ensure consistency between the precautionary and the MSY frameworks, F_{MSY} is not allowed to be above $F_{p.05}$; therefore, if the initial F_{MSY} value is above $F_{p.05}$, F_{MSY} is reduced to $F_{p.05}$. $F_{p.05}$ was calculated by running EqSim with assessment/advice error, with advice rule, and with a segmented regression with breaking point fixed at B_{lim} to ensure that the long-term risk of SSB<B_{lim} of any F used does not exceed 5% when applying the advice rule. $F_{p.05}$ was estimated to be 0.242. Therefore, as explained above, $F_{pa} = F_{p.05} = 0.242$. Additionally, since F_{MSY} (0.271) is higher than $F_{p.05}$ (0.242), F_{MSY} is capped at $F_{p.05}$ and $F_{MSY} = 0.242$.

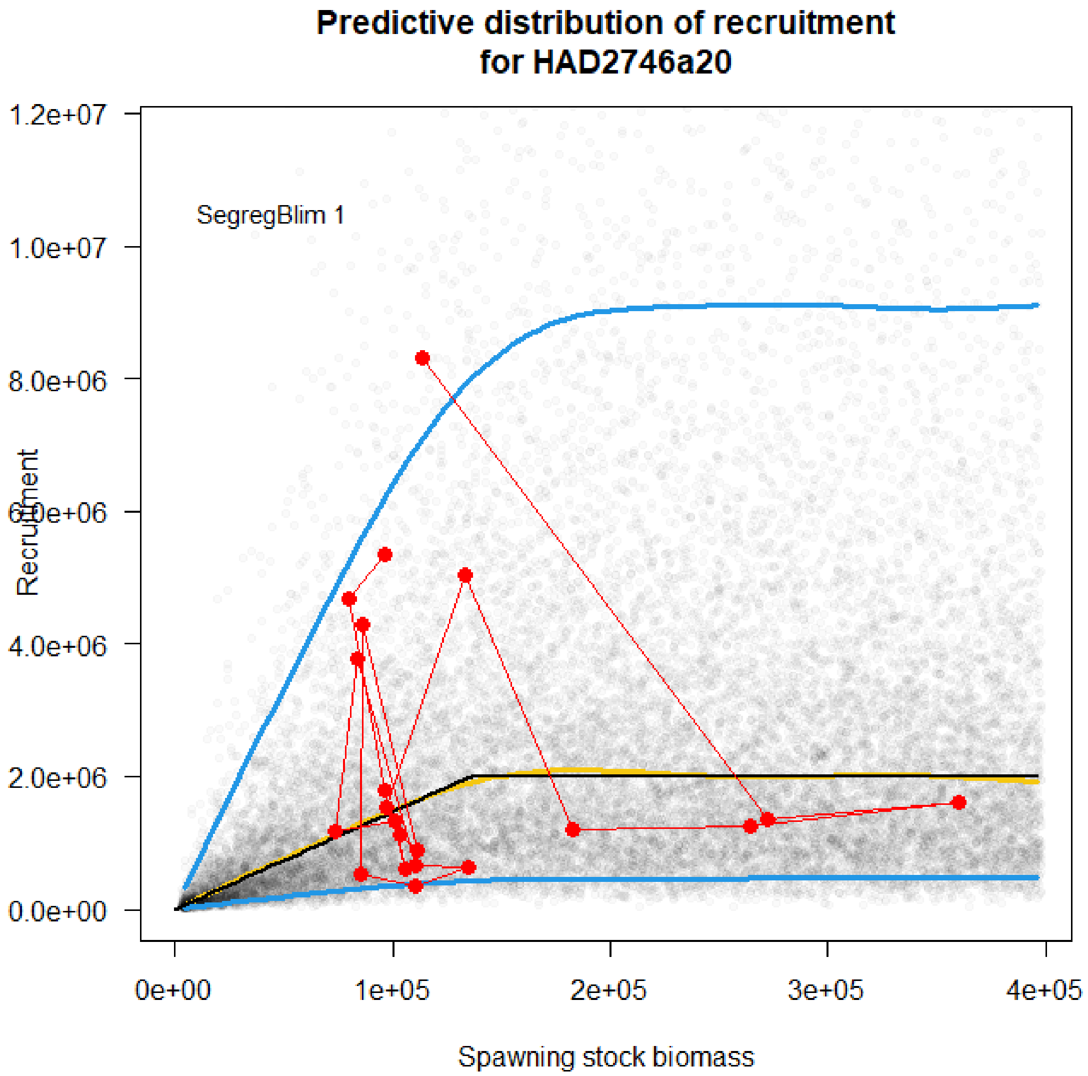


Figure 7.26. Northern Shelf haddock. Segmented regression using a breakpoint fixed at Blim to fit the spawning stock-recruitment relationship. SSB is in tonnes, recruitment is in thousands.

7.7.4 Estimating MSY $B_{trigger}$

MSY $B_{trigger}$ is a lower bound of the SSB distribution when the stock is fished at F_{MSY} (ICES, 2021b). As stated in the ICES techincal guidelines, recent fishing mortality estimates need to be considered to set MSY $B_{trigger}$ as for most stocks that lack data on fishing at F_{MSY}, MSY $B_{trigger}$ is set at B_{pa}. Here, the stock has been fished above F_{MSY} (0.271) for the last 5 years. Therefore, according to the ICES techincial guidelines our MSY $B_{trigger}$ is equal to B_{pa}, MSY $B_{trigger}$ = 189,734 tonnes.

7.7.5 F_{MSY} ranges

The initially estimated F_{MSY} (0.271) was higher than $F_{p.05}$ (0.242) (Figure 7.27). F_{MSY} is therefore capped at 0.242, and so is $F_{MSYupper}$. The F_{MSY} ranges are given in Table 7.18.

Table 7.18. Northern Shelf haddock. FMSY ranges.

Reference point	Value	Technical basis
$F_{MSYlower}$	0.186	$F_{p.05lower}$ (EqSim)
F_{MSY}	0.24	$F_{p.05}$ (capped)
$F_{MSYupper}$	0.24	$F_{p.05}$ (capped)

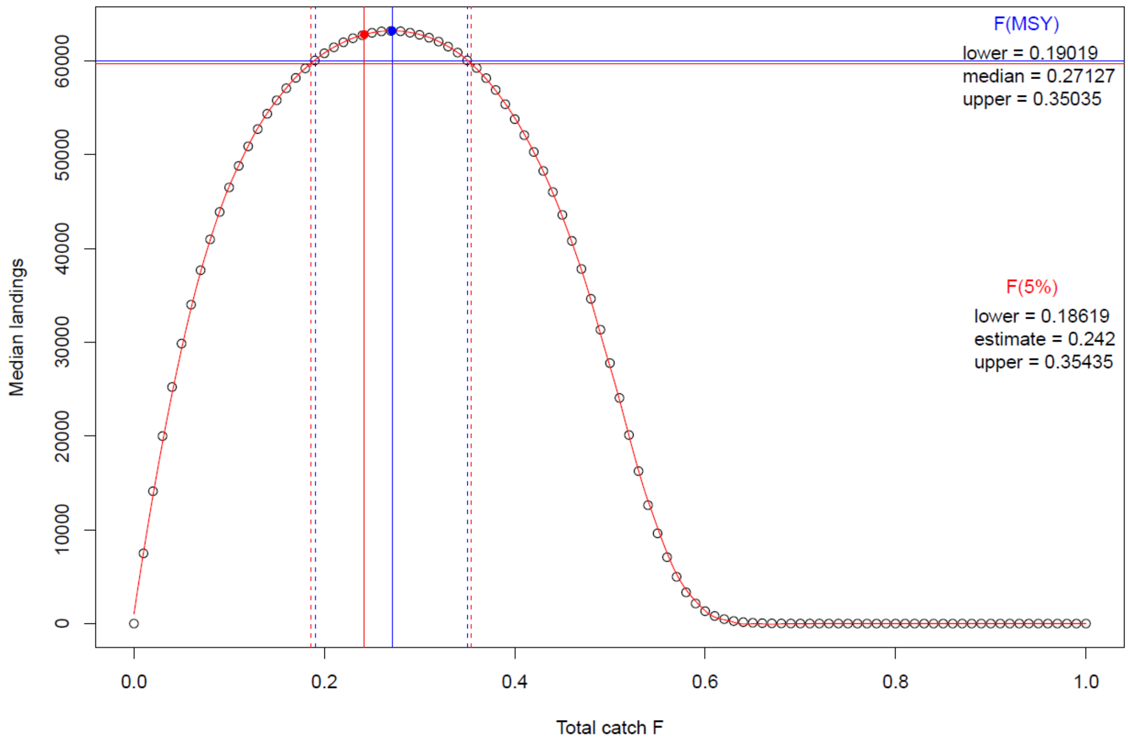


Figure 7.27. Northern Shelf haddock. Median yield curve and upper and lower ranges (vertical dashed lines) for F_{msy}=0.271 (blue), as well as F_{pa} =$F_{p.05}$ (red). Landings are in tonnes.

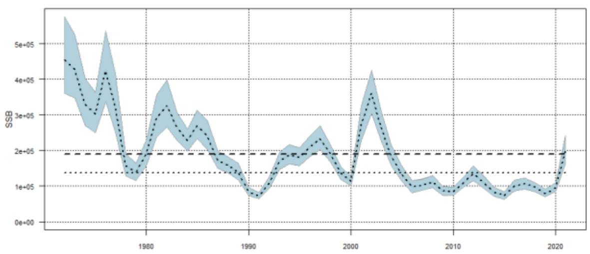
7.7.6 Comparison with previous reference points

The main difference between the previous and the new reference points obtained here is that the new values are higher overall due to a rescaling of the new assessment (see section 7.6.4.4). Previously, the F_{MSY} and $F_{MSYupper}$ were estimated to be above $F_{p.05}$. Therefore both F_{MSY} and $F_{MSYupper}$ were capped at $F_{p.05}$ (0.194) (ICES, 2016a). $F_{MSYlower}$ was in turn redefined as the lower fishing mortality providing 95% of the yield at $F_{p.05}$ ($F_{p.05lower}$) to obtain MSY ranges (Table 7.19). Here, the F_{MSY} estimated was also found to be above $F_{p.05}$. Therefore, F_{MSY} and $F_{MSYupper}$ are both capped at $F_{p.05}$. In summary, both the F_{MSY} and F_{MSY} ranges obtained here are larger than the ones previously estimated which is consistent with the higher fishing mortality values estimated by the new assessment model (Table 7.19).

B_{pa} and B_{lim} have also increased compared to previous values. This is because of the change in the SSB time-series in the new assessment. The new maturity ogives, where a substantial proportion of fish now become mature at age 2 rather than age 3, result in a smoother SSB time-series compared to the old assessment. This means that the low points in the time-series are not as low as they were before. This results in higher values of B_{lim} and B_{pa} (which is derived from B_{lim}) for the new assessment. This changes the perception of the stock status in recent years as shown in Figure 7.28. The SSB over the last 20 years was considered to be above MSY $B_{trigger}$ in the previous assessment whereas the SSB from the new assessment is now considered to be below B_{lim} in most years. This perception is consistent with the change in maturity as more mature fish are now needed to produce a similar size of recruitment. Recruitment over the last 20 years has been much reduced compared to the early part of the time-series, even in the previous assessment, and so the perception that the stock size has been below B_{lim} during that period is consistent with this viewpoint. SSB in 2021 is considered to be above the new MSY $B_{trigger}$ reference point due to two, consecutive, relatively large, incoming year classes. The new perception of the stock, in conjuction with the new reference points, offers an opportunity to properly protect these cohorts as they age into the fishery.

Table 7.19. Northern Shelf haddock. New reference points compared to the values derived at the 2016 inter-benchmark (ICESa, 2016).

Reference point	New values	Values from 2016 inter-benchmark
$F_{MSYlower}$	0.186	0.167
F_{MSY}	0.24	0.194
$F_{MSYupper}$	0.24	0.194
MSY $B_{trigger}$	189734 tonnes	132000 tonnes
B_{pa}	189734 tonnes	132000 tonnes
B_{lim}	136541 tonnes	94000 tonnes
F_{pa}	0.24	0.194
F_{lim}	0.43	0.384
$F_{p.05}$	0.24	0.194
$F_{MSY\_unconstr}$	0.27	0.24



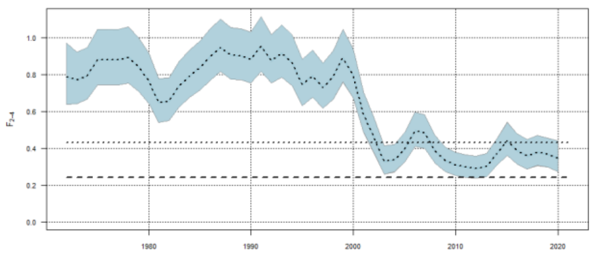


Figure 7.28. Northern Shelf haddock. New reference points compared to the new assessment results (black dashed line locating within the blue shading) for SSB (tonnes, left) and Fbar (right). The pointwise 95% confidence intervals for the assessment results are indicated by the blue shaded area. B_{lim} and MSY $B_{trigger}$ are indicated with the horizontal dotted and dashed lines, respectively, in the SSB plot (left). F_{lim} and F_{MSY} are indicated with the horizontal dotted and dashed lines, respectively, in the Fbar plot (right).

7.8 Future Research and data requirements

There are a number of future research directions relating to this stock. A specific outcome of this benchmark is that the residual pattern from the assessment results suggests that a change in the plus group age range should be considered. Most of the input datasets have data available up to age 15 though the reliability of this data should be assessed before evaluating the use of a new plus group age in the assessment model.

There were also two outcomes from the previous benchmark which were not addressed at this benchmark. Firstly, SSB is used to indicate both reproductive potential and harvestable biomass though it may be a poor proxy for both. The suggestion from the last benchmark was to investigate indices of reproductive potential and methods to use them in management advice. Potential data requirements for this would be weight-at-age and fecundity/egg condition data. Secondly, the stock is considered to be homogenous throughout Subarea 27.4 and Division 27.6.a, but relevant sub-stock structure is known to exist and should be explored further. Potential areas of research include using otolith micro-chemistry, tagging data, and the spatial range of genetic data to investigate sub-stock structure. Further to this, the sub-stock structure of various aspects of ecosystem drivers are not fully understood and include environmental and biological effects on growth, maturity/fecundity and predation. A key aspect needing further investigation is the drivers of recruitment variability, considering recent research on the impact of trophic mismatch as a driver of recruitment success in other North Sea fish stocks. A logical progression of this work would be to consider the likely response of the stock to the impacts of climate change. This research would then inform on the ecosystem drivers that are of primary concern in designing informative operating models for use with long-term forecasts and management strategy evaluation.

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Annex 2: Resolution

WKNSCS 2022 - Benchmark Workshop for fish stocks in the North Sea and Celtic Sea

2019/2/FRSG26 A **Benchmark Workshop for fish stocks in the North Sea and Celtic Sea 2022** (WKNSCS), chaired by External Chair Daniel Duplisea (Canada)* and ICES Chair Gudmundur Thordarson, (Iceland)*, and attended by two invited external experts Kristiina Hommik (Estonia)*, and Vanessa Trijoulet, (Denmark)* will be established and will meet online 22 – 24 November 2021 for a data evaluation meeting and at ICES HQ, Copenhagen, Denmark and online, for a 5 day Benchmark meeting 7–11 February 2022 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:
   i. Stock identity and migration issues;
   ii. Life-history data. For sole, fluctuations in mean weights at age will be explored;
   iii. Review current sampling levels and adjust stratification levels for landings and discards accordingly;
   iv. Examine alternative assessment models to the current model
   v. Explore impact of all tuning fleets on assessment estimates;
   vi. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook;
   vii. Examine mixed fisheries interaction;

b) Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

c) Re-examine and update (if necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

d) Develop recommendations for future improving of the assessment methodology and data collection;

e) As part of the evaluation:
   i) Conduct a 3 day data evaluation workshop. Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;
   ii) Following the Data evaluation, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting.

Stocks	**Stock leader**
cod.27.7a	Pia Schuchert
ple.27.7fg	Vladimir Laptikhovsky
had.27.46a20	Harriet Cole
ple.27.4	Chun Chen
her.27.6a7bc	Afra Egan

Annex 3: Reviewers' comments

The benchmark was organized in two online meetings, a data evaluation workshop (DEWK) in November and the benchmark meeting in February. Six stocks needed to be reviewed since one stock (6a7bc herring) was split into two stocks (6aN and 6aS7bc). It needs to be understood that it is very difficult to provide a thorough review of data and models in a 5-day benchmark when 6 stocks need reviewing. Benchmarks with so many stocks need to be avoided in the future, and more time needs to be given to the assessment teams between the DEWK and the benchmark. In our opinion, a thorough benchmark should be a full week meeting per stock when no work is needed by reviewers outside of that meeting week.

In some cases, we felt like we were too involved in the assessment process and that more support should have been given to the assessors from their institute to prepare and understand models and data. We suggest avoiding having only one person per stock during the benchmark meeting, as this puts a lot of strain on the assessor, and we also believe that it has an effect on the quality of the outcome.

When estimating the reference points, most stocks used the default value for sigma in the calculation of Bpa because the standard deviation in SSB the last year of assessment was smaller. This is apparently a rule commonly used in ICES, which is not in the written ICES guidelines for estimation of reference points. Also, there were discussions during the benchmark about the use of observed or estimated catches when estimating reference points in EqSim. It was agreed that the estimated catches should be used if they are different from observed catches. However, it was unclear how large this difference should be to make the choice. Again, this is not mentioned in ICES guidelines, and it makes it difficult taking decisions during benchmarks. It was also recommended to have an example code for calculating reference points using EqSim, as people are using hand-down scripts and some details in the code or functions are not fully understood nor explained. Therefore, having one example script with clear description would be helpful for people (especially for those who are using EqSim for the first time) and would also streamline the process of calculating reference points. We understand that the reference point system is under restructuring in ICES, hence availability of good and detailed examples is necessary also for the future, independent of model/software used for reference point calculations.

Before and during the benchmark, it was difficult to get a hold of the working documents, presentations, and model scripts. The reviewers should not keep asking the assessment teams to provide these documents during the week and it should be the responsibility of the assessment team to provide these documents to the reviewers. There was also a lack of transparency on how the data was extracted from Intercatch and raised for use in the models. This process could therefore not be reviewed. The time frame did not allow for us to review survey data, notably when GAMs were used to combine surveys. This is an important limitation of the review process since these data can affect the perception of the stocks.

For future benchmarks it has to be made very clear what is expected from the assessment teams during the DEWK. In one case, model runs were presented without having any specific details about the data presented. It needs to be made clear that, independent of the amount of changes introduced to the data, data needs to be presented and talked through for each stock, as the reviewers and the workshop participants might not be familiar with that specific stock and data. Understanding the data and its caveats is crucial for the assessment process and model tuning. We felt that due to the high amount of stocks and limited time, some of the details of data usage and model tunings were not discussed as thoroughly as needed. And this in turn caused reiterating discussion in the group. For example, for one stock, changes in the assumption for natural mortality used in the model were requested on the last day of the meeting, despite the model being fully reviewed and validated on day 2. This is in our opinion bad practice and should be avoided.

We allowed time in between the two meetings to review the stocks given the short amount of time during the benchmark week and the number of stocks to review, which is exceptional. We recognize that the assessment teams made huge efforts to present acceptable data and models. However, many of the stocks were not ready ahead of the benchmark. Most of the models and working documents were provided during the benchmark week and therefore most of the review had to take place during the benchmark meeting. We therefore felt like we had to rush to decisions on models and data without having the full time needed to provide a proper review. This review has therefore to be taken into consideration knowing these above-mentioned limitations.

Northern Shelf haddock

Prior assessment model for this stock was TSA. The main reason for benchmarking this stock was to replace TSA by another assessment model due to maintenance on TSA being unavailable in the near future. The assessment team chose to move to a SAM model given that it is also a state-space model such as TSA. Plans were made to also present a comparison of the assessment with TSA and SURBAR at the benchmark. However, the latter was not presented due to lack of time during the week.

In addition to the changes of the assessment model there were also changes to the input data. Previously stock weights were considered the same as catch weights, however this assumption caused overestimation of SSB. From Northern Shelf Q1 survey correction factors were calculated and applied to commercial catch weight data to obtain stock weights. Maturity ogive was also updated from knife-edge from age 3 to time-and-age varying maturity ogive calculated from survey data. In addition, GAM models were created for Q1 surveys and a combined index for Q3 and Q4 surveys. Survey indices were combined to provide more complete representation of the population compared to the respective indices used on their own. The internal consistency for combined surveys were better compared to the individual indices. Natural mortality estimates were updated from the latest SMS key run.

The model was reviewed at the beginning of the benchmark week. Model configuration started by recreating the previous TSA model and tuning SAM to improve residuals and retrospective patterns. The choice of model configuration was consistent with improvement of the residuals notably for the fishing mortality process. The residuals were less good for the plusgroup but could not be improved by changing model configuration. Retrospective patterns were satisfactory. Some suggestions for sensitivity analysis were made during the meeting and concluded on the model being robust to these changes.

For the choices regarding reference points, we believe the decisions are sound. Reference points were estimated in EqSim and followed the ICES guidelines. The Northern Shelf haddock was classified as spasmodic stock (type 1) and Blim was defined as lowest SSB where large R is observed. Blim value was defined based on the whole available time series; however stock-recruitment pairs used in the EqSim modelling included only time series starting from 2000 onwards. This adjustment was approved, as it is believed that the conditions for recruitment have changed and currently the stock is in a low recruitment period. Observed catches were used in EqSim rather than estimated catches despite the estimated catch being different from observed catch for age 0 at the end of the time series. The assessment team re-run the reference points with estimated catch also and it did not make a difference except slightly in the lower range of Fmsy so the observed catches were kept for reference point estimation. The model and reference points were validated for use in advice.

Different decisions were discussed regarding forecast assumptions. All decisions were consistent. There were discussions on going into single fleet or multifleet forecasts to account for the bycatch fleet separately and on projections of the mean weights at age. We recommend looking in the future into a multifleet SAM if relevant, i.e., notably when different TACs are given to different fleets, and looking at estimation of mean weights in SAM as a process so it is projected forward as part of the forecast directly.

6a7bc herring (6aN herring and 6aS7bc herring)

The rationale for splitting the stocks has good grounds because both stocks are genetically different as confirmed in the study reported in the EASME report (Farrell et al., 2021). Of course, this is a biological problem rather than a management problem.

Some assessment models (SAM, ASAP, SURBAR) were configured and reviewed before the benchmark, but the assessments for both herring stocks suffer from an inconsistency in their data.

Indeed, the MSHAS survey is the only survey that is split using the genetic data but only for the period 2014-2020. According to the genetics, 6aN herring are autumn spawners that are not different from North Sea herring (NSAS), 6aS7bc are winter spawners but there exists a later spawning component too. There is a large proportion of spring spawning herring in 6aN that are unassigned genetically and are believed to be a mix of 6aN spring spawners and 6aS7bc spring spawners (late spawning component). The rest of the data (catch, other surveys) is not split following genetics because genetic samples have not been collected. As a result, the data is split following a horizontal geographical line separating 6aN and 6aS.

In the case of 6aS7bc herring, a SAM and an ASAP model were tested. ASAP was difficult to configure and needed some assumptions to be made notably in terms of selectivity blocks. SAM did converge but the experts did not trust the model due to catchability for the MSHAS survey being very large. The survey being indicative of trends, this may still be acceptable, notably because the model trusted the stock recovery in the recent period given by the survey. However, given the inconsistency in the data, a category 3 assessment based on the genetically split MSHAS seemed more appropriate.

In the case of 6aN herring, a SAM model was initially configured and reviewed before the benchmark. This model only used 2 of the 4 surveys that were available. However, during the benchmark it was realized that the argument for using 2 surveys was more due to making the model give a believable perception of the stock rather than a good rationale for selecting the surveys. Also, it is believed that the IBTS Q1 survey used in the assessment is a mix of stocks, not only 6aN herring. The model was giving very different stock perceptions depending on the data used in the assessment model so could not be used as indicative of trends. For these reasons and the lack of time during the meeting, the stock moved to a category 3 assessment.

We would like to point out that the tremendous amount of work that has been done for both stocks in preparing the data and fitting different assessment models was not a waste of time and was very useful in understanding the data needs for the future, notably in terms of genetic sampling. Both stocks would have benefited from more time to look at the data to use in the assessments and this should be done in the future.

Both the 6aN and 6aS7bc herring stocks were moved to category 3 assessment, and for both of the stocks the new ICES data-limited stock guidelines were applied. Specific harvest control rules are determined based on the von Bertalanffy growth parameter k value. For 6aN herring, the MSHAS genetically split survey data was used to calculate growth parameter k. The genetically split data is available from 2014 onwards, however for growth calculations data starting from 2019 was used, as the genetic samples collected before 2019 consisted mainly of the mature individuals, possibly giving a biased view. Usage of MSHAS genetically split data was deemed most appropriate. For 6aS7bs herring, the growth parameter k was calculated using the commercial length-at-age data starting from 2000. Growth curve was also fitted using the MSHAS genetically split data, however the estimated k value was much higher (0.5 vs 0.32, MSHAS and commercial data, respectively). Issue here is not that the k=0.5 is unrealistic but that based on such a k value the stock would be categorized as short-lived species based on the new guidelines, and this not the case. Hence it was deemed that the usage of commercial data for k calculation is more appropriate, as the data set is much larger and age groups are better represented. Based on the calculated k values (0.33 for her6aN, 0.32 for her6aS7bc), advice for the stocks is given based on the constant-harvest-rule (chr) method.

Another important aspect of the new rules is the mean length indicator and its corresponding reference point. The default assumption for the reference point, M/k=1.5 was rejected and replaced with an adjusted M/k value which corresponds to the estimated k and average M value of mature individuals. This adjustment was suggested and approved as if the population's true M/k value is below the default value of 1.5 then the corresponding reference point would be underestimated, leading more easily to the conclusion of not overfishing when actually overfishing is taking place.

The new proposed harvest control rules are sensitive to the assumptions of k value. It should be investigated how to react in cases where the estimated k value can be high, but the species is not short-lived. We believe it would also be beneficial to have guidance on the k calculation as this plays a crucial role in the new rules for DL stocks (e.g., example code for calculation or for best practices). In addition, the mean length indicator might not be sensitive enough to pick up the changes in fishing intensity, e.g., for most of the years the stocks were categorized as not overfished, even though it’s known that the stocks are at a very low level due to previous overfishing. Currently used time series for both of the stocks were very short (2014-2020), and it seemed that this also caused problems with the chr-rule. In addition, the chr rule uses a ratio of catch/abundance index, and currently monitoring TAC is in place for these stocks, potentially biasing the relationship between catch and abundance index. It would be beneficial to see how sensitive the chr-rule is to the time-series length.

There are still some concerns regarding both stocks. Notably the fact that the herring experts did not believe the perception of the stock in the assessment models. Indeed, the MSHAS is believed to be a good survey for both stocks given that it is split using genetic data. According to MSHAS, the 6aS7bc stock should be larger than the 6aN stock because it presents larger indices. However, both the SAM assessments and the initial category 3 calculation led to the contrary. There may be a problem with having a monitoring catch on both stocks that is not representative of what can actually be caught in the area. These issues need to be investigated in the future.

Irish Sea cod

Data was updated compared to the previous assessment and a choice has been made by the assessment team to move from an ASAP model to SS3 to allow for the use of 4 years of UK recreational catch in the model due to the fact that they represent a large proportion of the current catch. Irish recreational catch could not be collected. The model could not allow estimating the recreational catch as a separate fleet, certainly because the data was too short. It was therefore chosen to add the recreational catch to commercial catch in the model and estimate combined catches in the recent period.

In addition to adding recreational data, the natural mortality values were re-evaluated using the information from a tagging study. For younger ages (age 0 and 1), the M estimates were kept the same as previously (calculated using Lorenzen method), for ages 2+ the M values were updated using the Brownie model, giving a constant value of 0.65 which is 2-3x higher compared to what was previously used. The decision for choosing M was a bit unclear and it seemed that the choice of a high M value for older ages was made partially to account for the migration of older fish away from the Irish Sea. It should be noted that having this some-what artificially high M value for older ages affects the assessment outputs and reference point calculation.

It was not possible for us to re-run the model during the benchmark week, however SS3 experts were helping the assessment team and were present during the meeting to answer questions. Given the timeframe of the meeting we had to trust the experts that the model and data were correct. Changes to the model configuration were made during the benchmark week and diagnostics such as retrospective patterns were drastically improved compared to the first version of the model presented.

We believe that the choices made regarding the reference points are sound. The reference points were estimated with EqSim following ICES guidelines, but the productivity of the stock is very dependent on environmental factors such as temperature. Recruitment success decreases with increases in temperature, and it makes it difficult to choose relevant Blim values. Based on the stock-recruitment relationship the stock was categorized as Type 1 stock, spasmodic stock. Blim value was calculated based on the whole time series, the reasoning behind the choice of Blim was sound. Information about biology and fishing was taken from the last 10 years of data, default assumption in the ICES framework. The model and reference points were deemed valid for advice.

In our opinion, the decisions made for the short-term predictions were sound and consistent. Assumptions on R were taken as geometric mean of the last 10 years where R has been low, to plausibly depict the near future. Usual assumptions of a three-year average were made for biological parameters (weight, M, etc.).

Given the addition of recreational catches compared to the previous assessment, we recommend that the advice sheet should clearly state that the catch (and F) now includes UK recreational catches.

North Sea plaice

North Sea plaice was last benchmarked in 2017, and since that an age-structured smoother based stock assessment model (AAP), based on Aarts and Poos (2009) has been used. The assessment had issues with strong residual patterns in the AAP model which ultimately led to change of assessment model. The assessment model used in total 6 survey indices, however in recent years it was noticed that there were controversial signals from the BTS and IBTSQ3 surveys. Plaice has a strong spatial distribution where older and larger fish are found near the Scottish coast, and younger individuals are found near the eastern side of North Sea. This led to the combination of the two surveys, BTS and IBTSQ3, which gave better coverage of the whole stock area. The internal consistency for this new combined survey was very good. However, it was still noticeable that the consistency has decreased for older ages, and the reason behind this is not well understood.

Different SAM assessments were reviewed prior to the benchmark week and different suggestions were made to the stock assessor to improve the configuration. The main issue prior to the meeting was that there was an unrealistic large number of age plusgroup fish estimated by the model and because they were not caught by fishers the fishing selectivity was decreasing and F was very low for this age group. At this point the natural mortality (M) used in the model was the same as the last benchmark (0.1 for all ages and years). A sensitivity analysis around M was planned for the benchmark, testing Lorenzen and Peterson methods for extracting age and time-varying M values in addition to the original value of M=0.1. Profiling of the model with scalers on natural mortality showed a best fit with M around 0.25 when the model was configured up to age 9+ and 0.3 when up to 10+. The model was run with M=0.1, M taken from calculations by Lorenzen method, and M taken from calculations by Peterson method. Using Peterson M removed the inconsistency in the plusgroup numbers and was the closest to 0.3 on average. This option was then put forward as input data to the model.

It has to be noted that some changes were made in the final model presented at the benchmark in terms of data (M recalculated due to mistakes and stock weights) and configuration, compared to the model used to validate Peterson M. The problem of large numbers of fish in the plusgroup age when M=0.1 was not present with the final model. However, the model profiling still leads to M=0.33 (10+). The justification for using Petersen M is then only partially valid with the final model and could be revisited in the next benchmark if relevant. It has to be noted that going back to M=0.1 would lead to bad retrospective patterns and therefore a reconfiguration of the model. It is therefore difficult to predict what would be the consequences of reconfiguring the model. Given that the stock is predated by cod and grey seals that are both predators in the SMS model, some work could be done in the future to include plaice as prey in the North Sea SMS model and get better estimates of M.

During the model configuration process, the stock assessor noticed that if the selectivity parameters are set free for the combined BTS+IBTSQ3 survey then the model would estimate a dome-shaped selectivity. The stock experts did not believe in this as both surveys do catch older fish than the current 10+ group, in addition retrospective analysis showed that the selectivity is changing from year to year (same dome-shaped but scaled up and down). This led to fixing the selectivity for ages 5-10+. This setting was accepted, however the justification of this should have more ground.

The residuals for the final model selection were acceptable, although some patterns were still present for older ages in the catch and BTS+IBTSQ3 combined survey. Elimination of those patterns with model configuration settings was not feasible. Compared to the previous AAP model where the final age group was 9+, the current SAM model plusgroup was extended to 10+. During the later stages of the benchmark it was brought out that there is data available for older ages, however it was never explored to extend the plusgroup even more. Extending the age matrix of catch could be beneficial and resolve some of the residual patterns seen currently, as well as the problem of older ages accumulating into a plusgroup. It was recommended to explore this option during the next benchmark.

The leave-one-out analysis caused concern, as the stock perception was only driven by one survey, the BTS+IBTSQ3 combined survey, even though in total 5 surveys are included in the assessment. Without this combined survey index, the model would estimate stock SSB to be 3x lower compared to the final model estimation. We raised our concern, as if anything happens with the combined survey index then this has a massive impact on the assessment and perception of the stock. Especially considering that it was brought out how the ability to track older ages in the survey has decreased in recent years, while at the same time the relevance of older ages in population increases due to the lowered F on those ages. The stock assessor and plaice experts did not share the concern, as the BTS survey is specifically designed to monitor flatfishes, and should have a higher weight in the model, as it gives the best overview of the changes in the stock. The main argument for accepting the discrepancy in the leave-one-out runs is that the BTS+IBTSQ3 survey samples the stock in the entire North Sea and indicates that older fish migrate in the northwest part of the North Sea while the catch and the other surveys used in the model are only coming from catches in the southeast part of the North Sea (mainly Dutch and Danish fleets). It is therefore believed that the BTS+IBTSQ3 survey is a better indication of the entire stock size. However, this issue is worth mentioning in the stock advice since part of the stock might not be available to the fishery.

Even though the calculation of M based on the Peterson method was agreed by the reviewers and group in the early stages of the benchmark, on the last day of the meeting it was again brought up by the group that more justification is needed for using age- and time-varying M in the assessment. This discussion concluded with changing the time varying M to time invariant values which are calculated as average of the currently estimated values per age. Changes in M values were very minor and hence the changes in SSB, F and R were barely detectable.

The final model presents acceptable residuals and retrospective patterns and is therefore considered suitable for advice.

Regarding the decisions made for the reference point calculations we believe these are sound and justified. The stock was categorized as type 5, the choice for Blim was systematically done within the context of the ICES guidelines. The reference points were calculated using EqSim. Biological assumptions needed for reference point calculation were made based on last three years data, to reflect the very varying values. Fishing pattern is described by the latest 10 years (ICES default), however it's important to note that the behaviour of the fishery has changed compared to pre-2000's and is currently changing again. Hence it is difficult to accurately depict the future scenario. The reference points were deemed valid for advice.

There was not enough time during the meeting to agree on the forecast assumptions, so it was decided to be pursued over correspondence.

Plaice 7fg

Prior assessment model for this stock was a surplus production model (SPiCT) despite age-structured data being available for this stock due to difficulty getting an age-structured model to converge at the last benchmark. This benchmark therefore focused on getting an age-structured model (SAM) to converge rather than changing the data for the stock.

During the data compilation workshop and benchmark meeting the data and respective models were presented with catch data that started from 1989. It is worth mentioning that the landings data extends back to 1977, however this data was not presented nor used in the assessment. It was pointed out that there were no good arguments for excluding the earlier landings data. The exclusion of this data was accepted because the current procedure for extrapolating discards before 2004 is constructed in a way which leads to zero discard in a certain age class if landings for that age class were zero. Usage of this method is questionable for older years, as the landings for age 1 were recorded as zero but the early 2000 discards analysis shows that age 1 is highly discarded, and there is no evidence to suggest a substantially different fishing practice in the late 70s and 80's compared to current situation. Due to the time limitations, it was agreed that shortened time series is used in the assessment. It was noted that the discard extrapolation method might need to be re-evaluated and a longer time series should be investigated in future benchmarks.

Model configuration was agreed and reviewed following sensitivity analysis just before the benchmark meeting. For all four surveys (2 commercial indices, 2 survey indices), an AR(1) structure was assumed due to strong year effects in all indices. Residuals were not perfect but could not get improved without making the model unstable and worsening the retrospective patterns.

Overall, it was difficult to follow changes in data before and during the meeting, as the data kept changing due to mistakes in extracting or copying data, and it was never specifically brought out what had exactly changed.

During the meeting it was realized that there were problems with the data used for mean weights in the model. This was corrected and the model rerun. This did not change the model diagnostics so the outputs of the model were taken forward for estimation of reference points.

The stock showed no indication of a relationship between stock size and recruitment; hence the stock was categorized as type 5 and initial Blim was set as Bloss (lowest observed SSB), following the ICES guidelines. Estimation of Fmsy was strained, and output of the estimation was questioned. Different Blim assumptions were looked at; however the results were still unsatisfactory. It was decided that there is not enough time to validate the reference points in this meeting, and it was agreed that the reference point validation would be done during another separate review process.

During the review of the reference point calculation, it was noted that the range of Fbar (3-6) was not re-evaluated at the benchmark and should have been looked at given that a lot of age 2 plaice are taken in the catch. This was not responsible for the difficulty in estimating reference points but should be looked at in the next benchmark.