BENCHMARK WORKSHOP ON SELECTED NORTH SEA AND CELTIC SEA STOCKS (WKBNSCS)

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Contents

i Executive summary

The objective of this benchmark process was to evaluate the assessment methods and data for three stocks: Plaice in Division 7.d (eastern English Channel), turbot in Subarea 4 (North Sea), and whiting in Division 7.a (Irish Sea).

Input data were extensively reviewed during the data workshop. Revisions were made to landings and discard data as well as the methodology behind the derivation of the stock biomass indices, stock and catch weights, maturity estimates and natural mortality for all three stocks. All the terms of reference were covered and an agreement was reached on the data to use for assessments, projections and reference points of each stock reviewed.

Whiting 7.a and plaice 7.d were previously assessed using an Age-Structured Assessment Programme (ASAP) and a statistical catch at age model (AAP) respectively. At the end of the workshop, all three stocks opted for an age-based analytical Stock Assessment Model (SAM). For plaice 7.d, this addressed the strong patterns in residuals of the survey indices and catch. Turbot 4 was already using a SAM model, but changes to the survey indices (including the addition of an industry-science collaborative index, combining several scientific surveys into one index and removing the Dutch commercial LPUE index), and internally modelled weights-at-age resulted in a better fit and resolved the issue of accumulating biomass in the plus group. For whiting 7.a, SAM better accommodated the gradual changes in selectivity that occurred in the fishery over the time series. Recreational catch estimates were included in the assessment for the first time.

For all stocks, model fit, and retrospective model runs revealed no substantial patterns. Sensitivity runs were conducted to investigate to key model assumptions and the workshop agreed on the final model configuration. The workshop further agreed on the methods used to calculate reference points and forecasts. For whiting 7.a, it was deemed necessary to re-evaluate the reference points regularly due to the uncertainty regarding the effect of a regime shift that happened in the Irish Sea. An MSE evaluation to test robustness of these estimates was recommended.

ii Expert group information

Expert group name	Benchmark workshop on the selected North Sea and Celtic Sea stocks (WKBNSCS)
Expert group cycle	Annual
Year cycle started	2024
Reporting year in cycle	1/1
Chair(s)	Daniel Hennen, USA
	Lies Vansteenbrugge, Belgium
Meeting venue(s) and dates	Data evaluation meeting, 19-21 November 2024, online (17 participants)
	Benchmark meeting, 3-7 February 2025, hybrid, ICES HQ, Copenhagen, Denmark (25 participants)

1 Plaice (*Pleuronectes platessa*) in Division 7.d

1.1 Summary

Plaice in Division 27.7d is a stock category 1, it was last benchmarked in 2015 (ICES, 2015) and proposed for benchmark in 2024. The reference points of plaice 7d were updated during the working group WGNSSK in 2022 (ICES, 2022) due to a change in the method of calculation of the FR CGFS index. The main objectives of this benchmark are i/ to address the strong patterns in the residuals of the survey indices and catches, ii/ update biological and catch data, and iii/ test the state–space stock assessment model SAM as a new assessment method since the Aart and Poos model (AAP) is no longer maintained.

At the data compilation workshop, historical time series of landings and discards in InterCatch for the period 2002 – 2023 were updated because of a change in calculations methods of discards (from 2002) and landings at age (in 2020) in the French data. Discards number and discards weight at age were estimated before 2006 since the SAM model requires a complete time series. The FR GFS index was re-calculated due to minor updates in DATRAS. The study of Sauger *et al.*, (2023) on the determination of plaice sexual maturity in the English channel provided new evidences to update the maturity ogive of plaice 7d. Different methods for estimating natural mortality were presented (e.g. Lorenzen, Charnov, Peterson & Wroblewski) and tested using the SAM model during the benchmark. A new recruitment index was developed based on the French survey NOURSEINE which took place in the Bay of Seine (but was eventually not used, as the survey is discontinued in the coming years due to funding issues).

The consideration of plaice migration in the assessment through the removals of 65% of mature individuals of the 1st quarter was discussed during the data compilation workshop. It was decided to keep the current implementation due to the absence of new evidence about the plaice migration and the potential impacts on the assessments of the ple.27.420 stock (North Sea) and ple.7e stock (western English Channel).

During the benchmark, several assessment runs were carried out using the SAM model. Different model setting were tested by modifying model configuration and input data. The SAM model was used to explore the possibility of splitting the FR GFS time series due to a change of the research vessel in 2015. Several assessment runs were performed to compare the different methods for estimating the natural mortality.

It was decided to use the stock assessment model (SAM) to provide advice for plaice 7d stock. The new assessment model is tuned by two age-structured survey indices (FR GFS and UK BTS). For the natural mortality, it was decided to use the Lorenzen method scaled to the mean value of the natural mortality estimated by the Peterson and Wroblewski method (ICES, 2015). Due to changes in the input data and assessment model, all reference points were recalculated. The updated FMSY is estimated at 0.252, which is higher than the previous estimate of 0.156. Compared to the previous AAP assessment model, the spawning stock biomass remains similar, while the estimated fishing mortality is slightly higher.

For the short-term forecast, it was decided to use :

- Mean of the last 3 years average for stock weights, catch weights and biological data.
- Mean of the last 3 years rescaled to F of the final year for the exploitation pattern.
- A resampling (with replacement) of the last 10 years to set the recruitment of the intermediate year onwards. However, the number of years and/or the period could be changed during WGNSSK meetings if needed.

In addition to the information presented in this report chapter, readers could consult the following 5 Working Documents (Annex 3) for further details on the relevant datasets and methods employed in the final assessment model:

1. Halouani G. and Girardin R. 2024. WD_ Ple_7d_biological_data. Update of biological data of plaice (Pleuronectes platessa) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025), November 19-24, 2024; 4pp
2. Halouani G. 2024. WD_ Ple_7d_InterCatch_data. Preparation of catch data for plaice (Pleuronectes platessa) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025), November 19-24, 2024; 12pp
3. Girardin R. WD_ Ple_7d_update_FR_GFS_index. Update FR-GFS survey index time series from DATRAS for plaice (Pleuronectes platessa) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025), November 19-24, 2024; 3pp
4. Halouani G., Girardin R., Vogel C. 2024. WD_ Ple_7d_recruit_index. Calculation of a recruitment index plaice (Pleuronectes platessa) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025), November 19-24, 2024; 18pp
5. Halouani G. 2025. WD_ Ple_7d_reference_points. Preparation of catch data for plaice (Pleuronectes platessa) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025), February 03-07, 2025; 9pp

1.2 Stock identity

1.2.1 Data evaluation meeting

No stock identity work on plaice in Division 7.d was carried out for this meeting. Since WKFLAT 2010 benchmark (ICES, 2010), Q1 migration of mature plaice from division 7.e and area 4 into division 7.d is taking into account in all three stock assessments. 50% of mature plaice caught in division 7d during Q1 are allocated to ple.27.4 stock and 15% of mature plaice caught in division 7d during Q1 are allocated to ple.27.7e stock. Even so, migration most likely fluctuate from year to year, and the percentage of each stock migrating in Division 7.d remains uncertain, there is no recent evidence to change the percentage of migration. This percentage was estimated during WKFLAT in 2010, based on published tagging results and some previous studies (Hunter et al., 2004; Kell et al., 2004). To address this issue, further research is needed on plaice migration and stock identity in the Greater North Sea Ecoregion and maybe in adjacent seas. Furthermore, a stock identification workshop and a benchmark focusing on plaice stock will be required to account for change in migration between plaice 4, 7d and 7e stocks.

1.2.2 Benchmark

It was decided to keep the current implementation of plaice 7d migration due to the absence of new evidence and the potential impacts on the assessments of the ple.27.420 stock (North Sea) and ple.7e stock (western English Channel).

1.3 Catch data

1.3.1 Data evaluation meeting

Plaice is mainly caught in two offshore fisheries, the beam trawl fishery and the mixed demersal fishery using otter trawls (Figure 1.1). The first one is represented by the Belgian beam trawlers (TBB) and mainly operates during the first quarter targeting spawning individuals in the central Eastern Channel. The second offshore fleet is represented by the French otter trawlers (OTB) which operates throughout the Eastern English Channel. A continuous decrease in Plaice 7d catches has been observed in the recent years. The year 2023 recorded the lowest catches since the beginning of the time series (Figure 1.2).

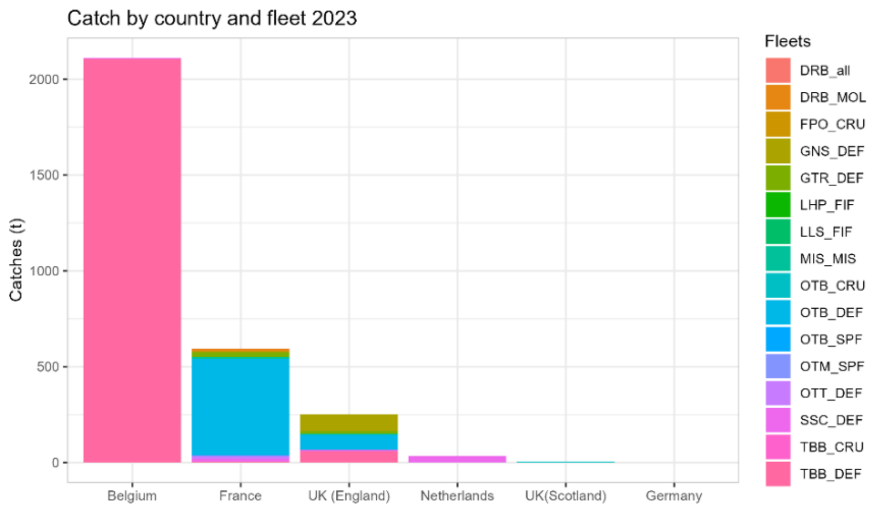

Figure 1.1: Plaice 7d catches by country and fleet in 2023

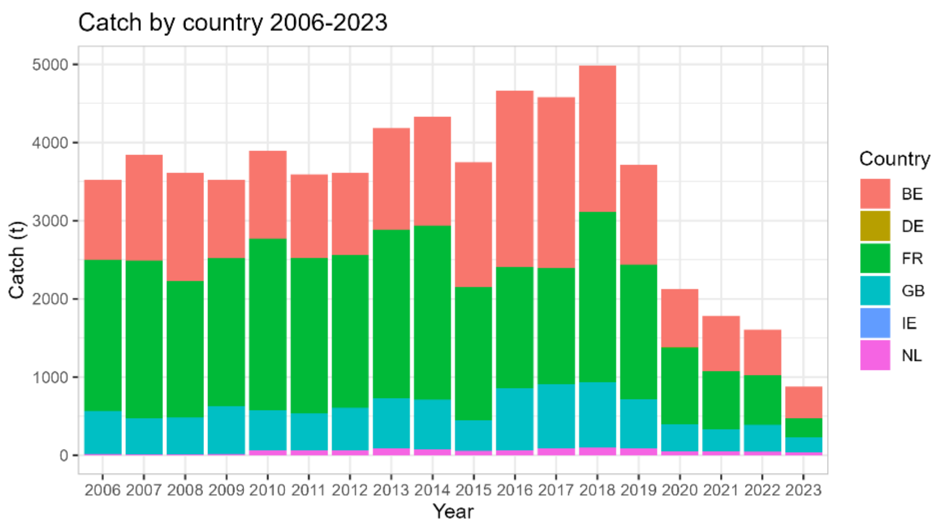

Figure 1.2: Plaice 7d catches by country for the period 2006 – 2023

1.3.2 Benchmark

Historical data from InterCatch over the period 2002 – 2023 were updated (see WD_ Ple_7d_InterCatch_data) due to the update to the French time series of catches. In 2020, some issues in French discards raising procedure and age allocation were identified and fixed for all stocks (Vigneau and Girardin, 2020). Discard raising and age allocation scheme were revised in InterCatch and validated (Table 1.1 and 1.2).

Table 1.1: The new grouping to raise the discards (WKBNSCS 2024)

Season	Unsampled fleets*	Sampled fleets**
Whole year	TBB	TBB
	OTB, OTT	OTB, OTT
	Nets (GNS, GTR)	Nets (GNS, GTR)
	Others (LLS, MIS, DRB, FPO) + Seines (SDN, SSC)	All métiers

* Unsampled fleet are those fleets for which no discards data have been provided.

** Sampled fleet are those fleets for which the discards volumes are known.

Table 1.2: The grouping used for age allocation (same as 2015 benchmark).

Season	Unsampled fleets*	Sampled fleets**
Quartely (Q1, Q2, Q3, Q4) & Yearly***	Nets (GNS, GTR)	Nets (GNS, GTR)
	Trawls (OTB, OTT, TBB), Seines (SDN, SSC)	Trawls (OTB, OTT, TBB), Seines (SDN, SSC)
	Others (OTM,LLS,MIS, DRB,FPO)	All métiers

* Unsampled fleet are those fleets for which no age data have been provided.

** Sampled fleet are those fleets for which the number at age are known.

*** Yearly catch uses all seasons to allocate ages (Q1, Q2, Q3, Q4 and year)

No reliable discard information is available for this stock prior to 2006. In the previous assessment model AAP (Aarts and Poos, 2009) discards numbers at age and discards weights at age were estimated and reconstructed by the model. However, as AAP model is no longer maintained it was decided to test the SAM model (Nielsen and Berg, 2014), hence the need to reconstruct discards before 2006 (Figure 1.3, see WD_ Ple_7d_InterCatch_data). The ratio between discards and landings numbers at age for the period 2006 – 2010 was calculated to reconstruct discards numbers at age since discards ratio is stable for the most discarded age over that period.

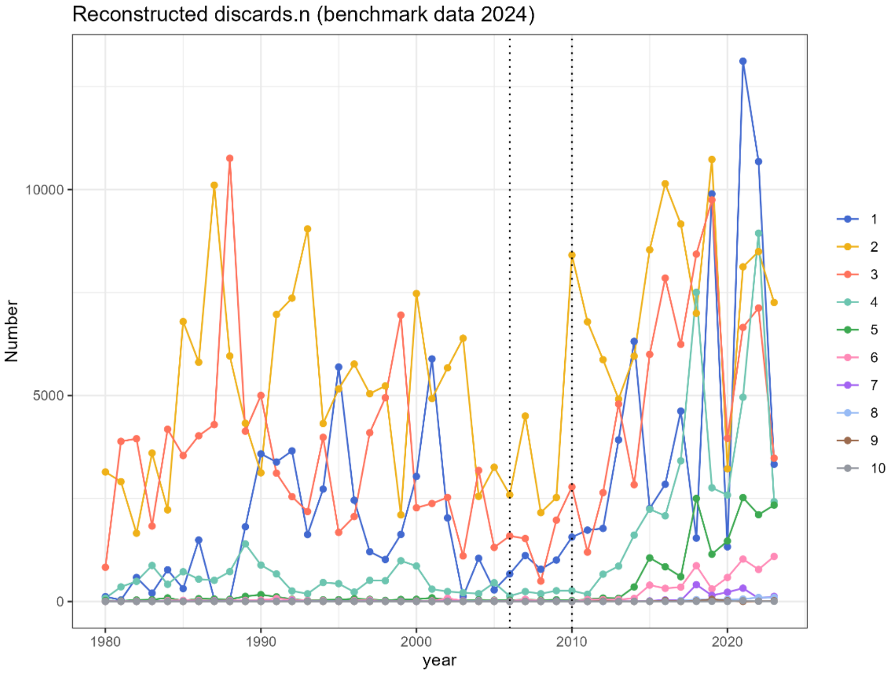

Figure 1.3: The time series of discards number at age for the period 1980 – 2023. The values before 2006 were reconstructed.

The average ratio of discards weight at age to landings weight at age from 2006 to 2010 was used to estimate discards weight at age as a proportion of landings individual weight at age prior to 2006 (Figure 1.4).

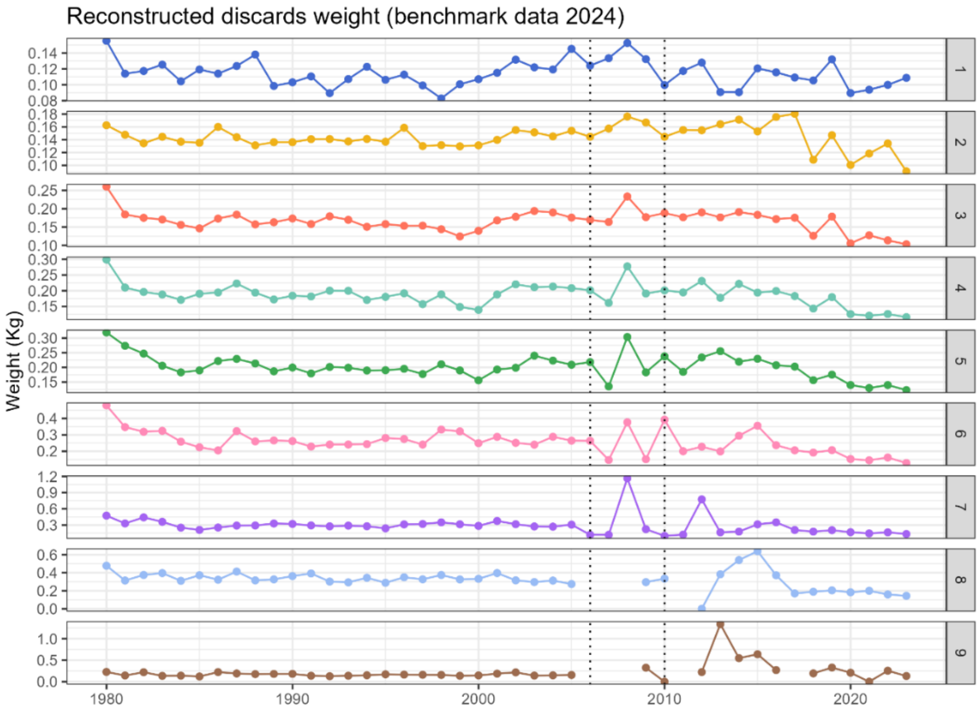

Figure 1.4: The time series of discards weight at age for the period 1980 – 2023. The values before 2006 were reconstructed.

Recreational catches of plaice in the eastern English Channel were not included in the assessment since they represent less than 1% of commercial catch.

1.4 Biological parameters

1.4.1 Data evaluation meeting

1.4.1.1 Maturity

The previous maturity ogive was estimated using macroscopic observation of gonads (ICES, 2010). A recent study of Sauger *et al.*, (2023) compared the estimation of maturity ogives based on macroscopic observations with using quantitative histological analyses for several stocks in the English Channel. The comparison of the two methods showed that for the ple.27.7d stock the macroscopic visual method misclassified some individuals that had spawned but were considered as immature (Sauger *et al.*, 2023). Therefore, it was decided to use the new maturity ogive based on histological analysis for plaice 7d for the whole time series (Figure 1.5, Table 1.3). The possibility of using a time-varying maturity ogive was explored but since no trend is observed in the FR GFS survey data or UK commercial and survey data (More details in the WD_Ple_7d_biological_data), it was decided to keep a constant maturity ogive through time.

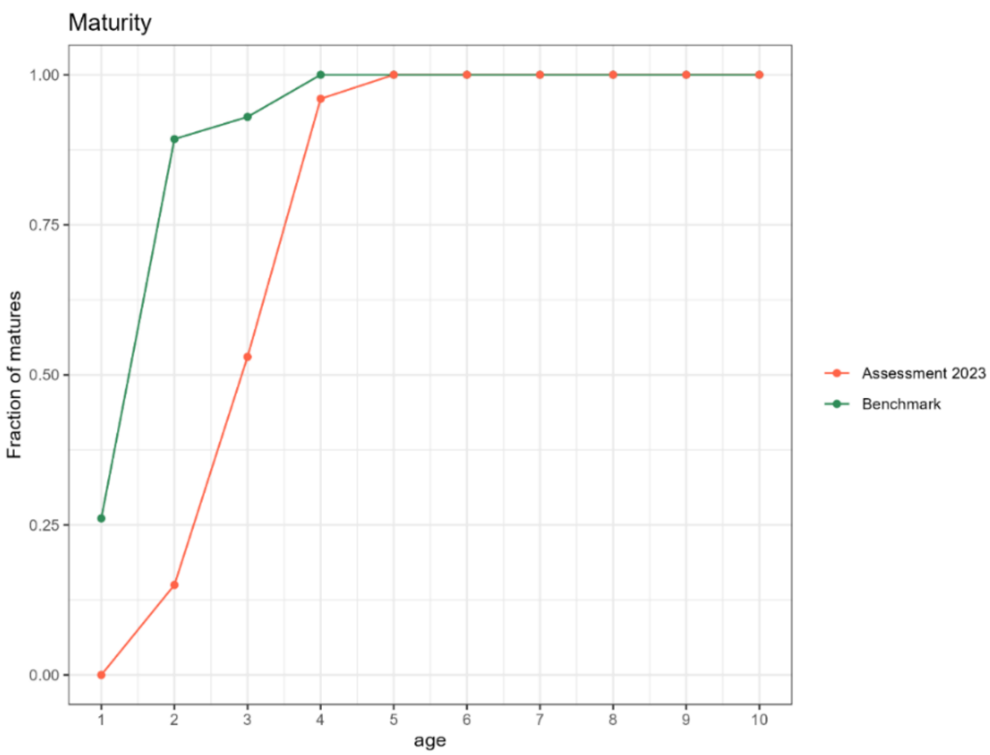

Figure 1.5 : The fraction of matures used in WGNSSK 2024 estimated using a visual method (red) and the fraction of matures estimated using a histological method (green)

Table 1.3: Comparison of maturity ogive used in WGNSSK 2024 and the one from (Sauger *et al.*, 2023) accepted during this benchmark.

Maturity at age	1	2	3	4	5	6	7
WGNSSK 2024	0	0.15	0.53	0.96	1	1	1
WKBNSCS 2025	0.2609	0.8929	0.9298	1	1	1	1

1.4.1.2 Stock individual weight at age

Stock weights at age are assumed to be the Q2 landings weights at age. Q1 data were not used due to adults migrating from the south of the North Sea and western English Channel. These weights at age show a distinct trend between 2013 and 2018 which consists of a general decrease for older ages. The comparison between the current benchmark data and those of the 2023 assessment (ICES, 2024) did not revealed a significant change (see the WD_ Ple_7d_InterCatch_data on catch data (Figures 11 and 12)).

1.4.1.3 Natural mortality

It was decided to apply a constant natural mortality at age for plaice 7d. Several methods based on weight at age at age were explored to derive the natural mortality (see WD_ Ple_7d_biological_data on biological parameters). A sensitivity analysis was conducted in SAM to select the most appropriate method (Lorenzen, Charnov, Peterson & Wroblewski) by comparing their SAM likelihood profile.

1.5 Indices of abundance

1.5.1 Data evaluation meeting

Two survey indices are currently used in ple.27.7d stock assessment (ICES, 2024), the UK BTS from Q3 [B2453] and FR GFS from Q4 [G3425] running since 1989 and 1990 respectively (Figure 1.6). Only age 1-6 are included in the assessment. FR GFS DATRAS data were updated, and abundance at age re-estimated using the same delta-GAM as used previously (Berg *et al.*, 2014; ICES, 2022). No significant changes were noticed in the indices of abundance at age (see WD_ Ple_7d_update_FR_GFS_index). The two indices are tested during the benchmark. Given the change of the research vessel in 2015 for the FR GFS survey, the sampling design was adjusted to accommodate the new vessel. Therefore, it was decided to test the split of FR GFS time series (from 1990-2014 and 2015-onwards) during the benchmark to evaluate the response of the assessment model.

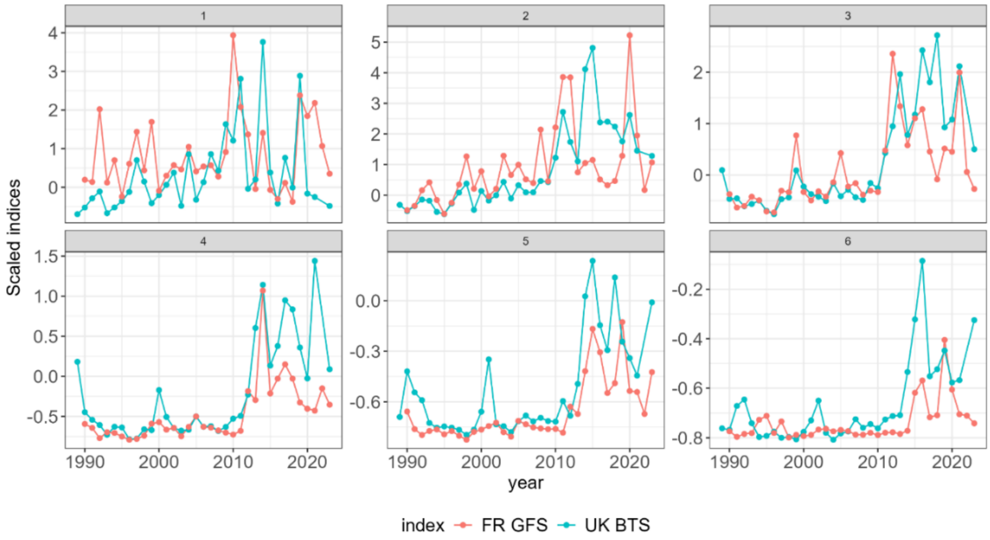

Figure 1.6: Comparison of FR GFS and UK BTS rescaled abundance index at age of ple.27.7d stock from 1989-2023.

A new recruitment index was developed based on the French survey NOURSEINE which took place in the Bay of Seine (known to be a nursery ground for flatfishes) (Vogel and Morin, 2015). The sampling area of the NOURSEINE survey is represented in Figure 1.7. Using sdmTMB (Anderson *et al.*, 2024) a tweedie GLMM was used to estimate age 1 abundance index for ple.27.7d stock (Figure 1.8) (more details in the WD_ Ple_7d_recruit_index).

Given the fact that several years are missing (Figure 1.8) and it is already known that the survey will be discontinued at least for the next two years (2026, 2027) due to funding issues, it was decided to test the impact of that index on the assessment without considering including it.

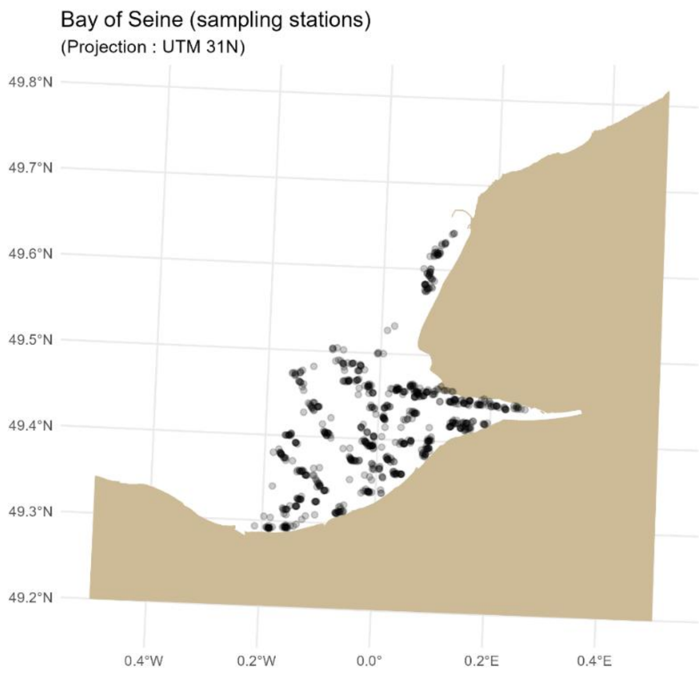

Figure 1.7: NOURSEINE survey sampling locations between 1995-2023

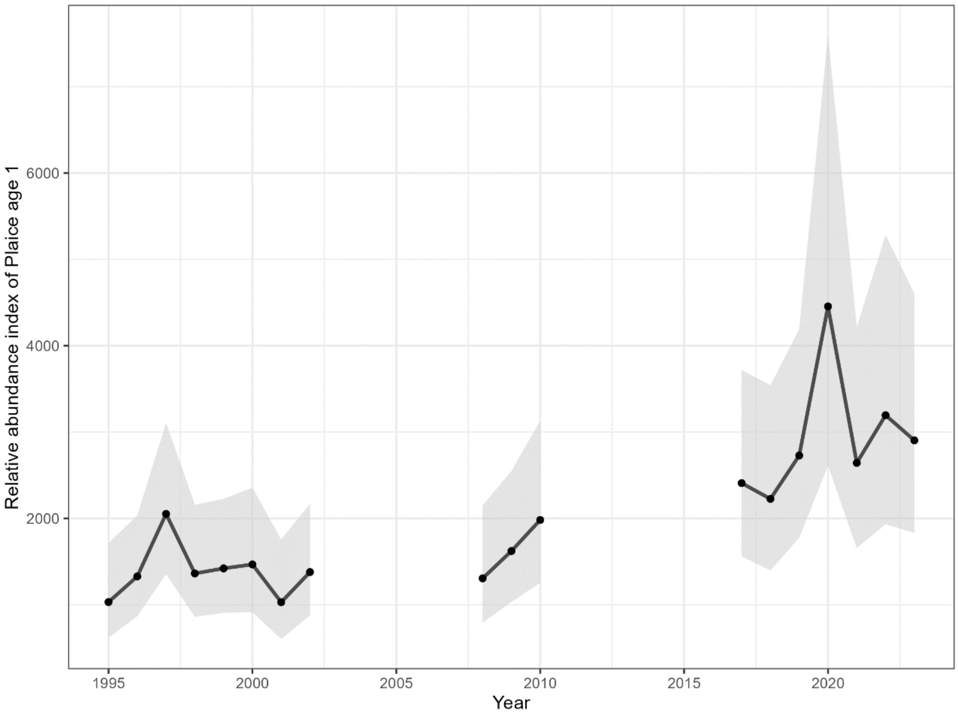

Figure 1.8: NOURSEINE Plaice 7d stock estimated recruitment index (age 1).

1.5.2 Benchmark

The NOURSEINE recruitment index was tested during the benchmark (WKBNCS 2025), however adding this index in the assessment as a third survey tuning fleet affected model convergence. It was decided to not include it in the assessment specially as the survey will be discontinued in the next years. The comparison of the NOURSEINE recruitment index with age 1 numbers from SAM model showed a good agreement (Figure 1.9).

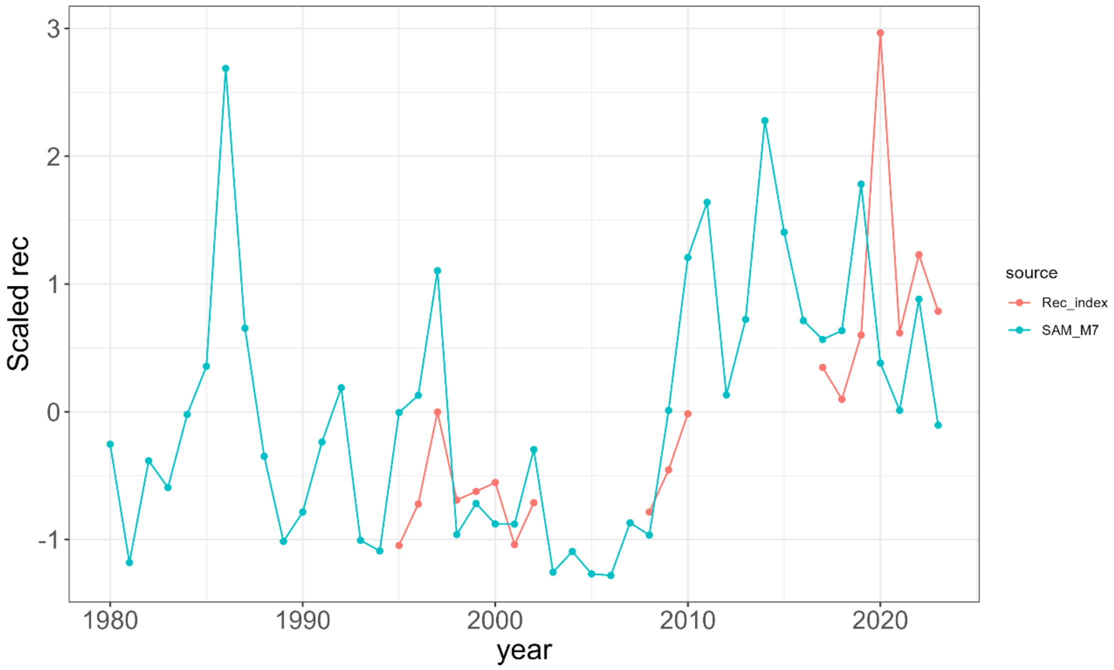

Figure 1.9: Comparison of the NOURSEINE recruitment index and age 1 from the SAM model

1.6 Assessment method

1.6.1 Testing input data and model settings

Table 1.4 summarizes the assessment runs explored during WKBNCS 2025 in February 2025.

Different configurations of the SAM model were tested including changes in:

- The model settings:
    - Coupling of the survey catchability parameters
    - Coupling of process variance parameters for log(F)-process
    - Coupling of the variance parameters for observations
    - Covariance structure for each fleet
    - Coupling of correlation parameters
    - Changing fleet covariance structure, survey catchability coupling, coupling of the observation variance parameters
- Input Data:
    - Splitting FR GFS index
    - Testing the likelihood profile of different methods of calculation of the natural mortality (i.e Charnov, Lorenzen and Peterson & Wroblewski)

Table 1.4 The different model setting and data explored during (WKBNCS 2025). the change in parameters between consecutive SAM configurations is highlighted in red.

SAM Configuration	M1	M2	M3	M4	M5	M6	M7	M8
Fbar range	3-6	3-6	3-6	3-6	3-6	3-6	3-6	3-6
The + group	1 0 0	1 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0	1 0 0
Coupling of the F states processes	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Correlation of F across ages	2 AR(1)	2 AR(1)	2 AR(1)	2 AR(1)	2 AR(1)	2 AR(1)	2 AR(1)	2 AR(1)
Coupling of the survey catchability parameters	-1 -1 -1 -1 -1 -1 -1 0 1 2 3 4 5 -1 6 7 8 9 10 11 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 2 2 2 -1 3 4 4 5 5 6 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 2 2 2 -1 3 4 4 5 5 6 -1 7 8 9 10 11 12 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 2 2 2 -1 3 4 4 5 5 6 -1 7 8 9 10 11 12 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 2 2 2 -1 3 4 4 5 5 6 -1 7 8 9 10 11 12 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 2 2 2 -1 3 4 4 5 5 6 -1 7 8 8 9 9 10 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 3 4 4 -1 5 6 6 7 7 8 -1	-1 -1 -1 -1 -1 -1 -1 0 1 2 3 4 4 -1 5 6 6 7 7 8 -1
Coupling of process variance parameters for log(F)-process	0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 1 1 1 1 1 1	0 1 1 1 1 1 1	0 1 1 1 1 1 1

SAM Configuration	M1	M2	M3	M4	M5	M6	M7	M8
Coupling of the variance parameters for observations	0 0 0 0 0 0 0 1 1 1 1 1 1 -1 2 2 2 2 2 2 -1	0 1 2 2 2 2 2 4 4 4 4 4 -1 6 6 6 6 6 -1	0 1 2 2 2 2 2 4 4 4 4 4 -1 6 6 6 6 6 -1 7 8 8 8 8 8 -1	0 1 2 2 2 2 2 4 4 4 4 4 -1 6 6 6 6 6 -1 7 8 8 8 8 8 -1	0 1 2 2 2 2 2 4 4 4 4 4 -1 6 6 6 6 6 -1 7 8 8 8 8 8 -1	0 1 1 1 1 1 1 2 3 3 3 3 3 -1 4 5 5 5 5 5 -1 6 7 7 7 7 7 -1	0 1 1 1 1 1 1 2 3 3 3 3 3 -1 4 5 5 5 5 5 -1	0 1 1 1 1 1 1 2 3 3 3 3 3 -1 4 5 5 5 5 5 -1
Covariance structure for each fleet	“ID” “ID” “ID”	"US" "AR" "AR"	"US" "AR" "AR" "AR"	"US" "AR" "AR" "AR"	"US" "AR" "AR" "AR"	"ID" "ID" "ID" "ID"	"ID" “AR" “US"	"ID" “AR" “AR"
Coupling of correlation parameters	NA	0 1 1 2 2 -1 0 3 3 4 4 -1	0 1 1 2 2 -1 0 3 3 4 4 -1 0 5 5 6 6 -1	0 1 1 2 2 -1 0 3 3 4 4 -1 0 5 5 6 6 -1	0 1 1 2 2 -1 0 3 3 4 4 -1 0 5 5 6 6 -1	NA	0 1 1 2 2 -1	0 1 1 2 2 -1 3 4 4 5 5 -1
Data	Lorenzen Natural Mortality	Lorenzen Natural Mortality	Lorenzen Natural Mortality	Peterson Natural Mortality	Scaled Lorenzen Natural Mortality	Scaled Lorenzen Natural Mortality	Scaled Lorenzen Natural Mortality	Scaled Lorenzen Natural Mortality
	Complete FR GFS index	Complete FR GFS index	Splitting FR GFS index	Splitting FR GFS index	Splitting FR GFS index	Splitting FR GFS index	Complete FR GFS index	Complete FR GFS index

Different methods for estimating the natural mortality were compared by building their likelihood profile using the SAM model. The analysis was done by scaling the estimated natural mortality by age of each method (Figure 1.10) to a range of natural mortalities from 0.2 to 0.7. The natural mortality of Peterson & Wroblewski presented in the figure 1.10 corresponds to the one estimated during the 2015 benchmark (ICES, 2015) and was used in the last assessment WGNSSK 2024. This method was not applied to the new biological data during WKBNCS 2025, as it requires individual dry weights, which were unavailable at the time. Figure 1.11 shows that Lorenzen and Peterson & Wroblewski have a similar performance. It was agreed to use Lorenzen method (it performs slightly better than Peterson & Wroblewski). Due to the high value of the natural mortality estimated by Lorenzen, a scaled Lorenzen mortality to the mean value of the natural mortality of the previous assessment (ICES, 2024) was also tested in SAM (Table 1.4).

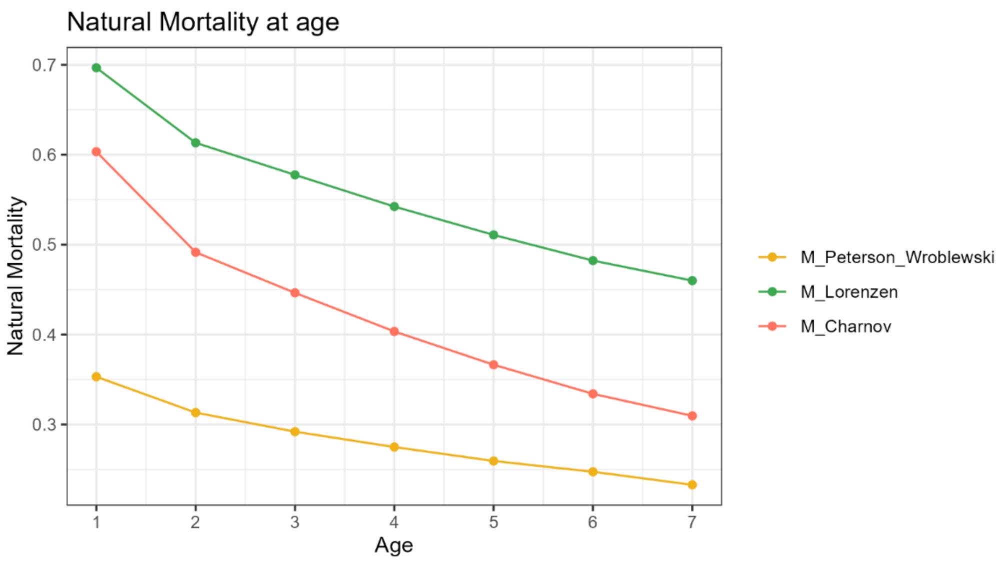

Figure 1.10: The natural mortality by age calculated using 3 methods (Peterson & Wroblewski, Charnov and Lorenzen). The Peterson & Wroblewski natural mortality is the one used in the last assessment WGNSSK 2024 (ICES, 2024).

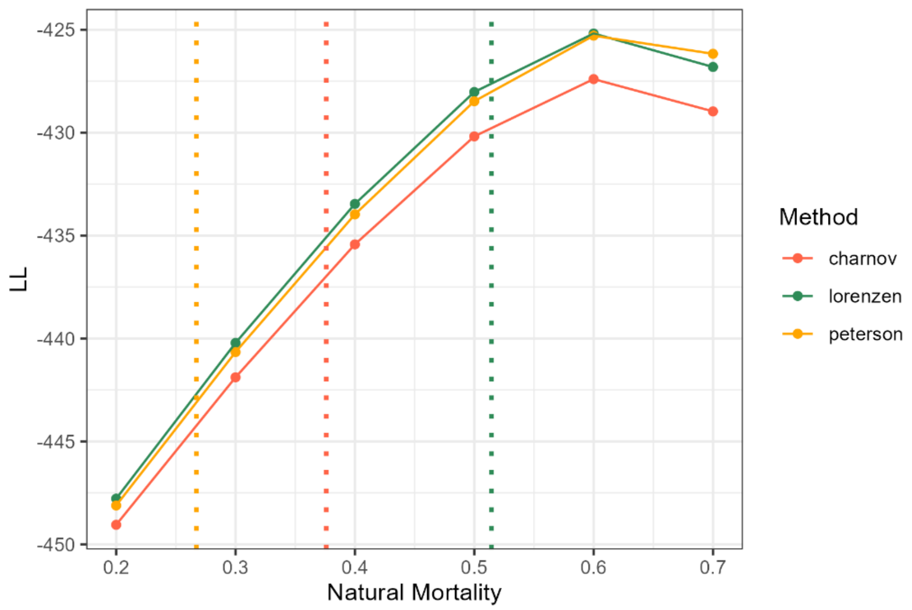

Figure 1.11: The likelihood profile of the different methods of estimation of the natural mortality calculated using the SAM model. The dotted lines represents the mean natural mortality of each method.

1.6.2 Final model settings

One of the objectives of this benchmark was to evaluate the performance of the SAM model using the updated biological and catch data.

The key characteristic of SAM is its integration of both **process models** covering survival, recruitment, and fishing mortality (which represent the system's internal states) and observation models for catch and tuning data. The random effects formulation within its hierarchical state-space modelling framework enables efficient handling of missing observations. Additionally, SAM provides flexibility in defining different model configurations and parameterizing both process and observation models.

The table 1.5 presents model diagnostics of the different assessment runs presented during (WKBNCS 2025). The selection of the best model was based on the AIC and a sensitivity analysis (a simulation validation procedure: simulate from model and re-estimate) in order to ensure model convergence. Two models (M1 and M2) were excluded since the estimated biomass was not credible (10 times higher than the previous assessment (WGNSSK 2024)) and the associated Fishing mortality was too low (close to 0) due to the high natural mortality estimated by the Lorenzen method.

Table 1.5: Model diagnostics of the different assessment runs

SAM configurations	log(L)	Number parameters	AIC	Sensitivity analysis	Observations
M1	-580.8868	19	1199.7736	Convergence	Non credible values of biomass (very high) associated to very low F close to 0 due to a high natural mortality
M2	-451.7111	43	989.4223	Convergence	Non credible values of biomass (very high) associated to very low F close to 0 due to a high natural mortality
M3	-431.6420	54	971.2841	Error	
M4	-446.3208	54	1000.6417	Error	
M5	-445.9233	54	999.8467	Error	
M6	-515.8363	24	1079.6726	Convergence	
M7	-478.0983	38	1032.1967	Convergence	
M8	**-487.2086**	**26**	**1026.417**	**Convergence**	**The final model**

The final SAM model as decided during the WKBNCS workshop corresponds to the configuration of model M8 (Tables 1.4, and 1.5). It includes :

- The updated catch data from 2002;
- The reconstructed discards number at age and discards weight at age before 2006;
- The revised maturity ogive;
- Two survey tuning indices: the UK BTS [B2453] and FR GFS [G3425];
- The revised natural mortality calculated using the Lorenzen method and scaled to the mean natural mortality used in the previous assessment WGNSSK 2024 (ICES, 2024);
- The plus group remained at age 7+. None of the age-structured tuning fleets included a plusgroup;
- The Fbar range remained : 3 – 6

The final SAM model estimated the catches reasonably well, all observed catches are inside the confidence bounds) (Figure 1.12). The SSB has a similar pattern to catches in recent years, showing a downward trend since 2018 (Figure 1.13). The fishing mortality and the recruitment didn't show a clear trend since 2017 (Figures 1.14 and 1.15). However, there is a higher uncertainty on the recruitment of the recent years in comparison to the beginning of the time series (Figure 1.15).

A final validation of the M8 model configuration was performed by examining one-step-ahead residuals for total catches, and survey indices (Figure 1.16), process residuals (Figure 1.17), retrospective analyses (Figure 1.18), Mohn's rho diagnostics and leave-one-out fits (Figure 1.19). Model stability and convergence were evaluated using parametric bootstrap simulations and jitter analyses (Figure 1.20).

Except for age 2 in the UK BTS survey, process errors and residuals did not exhibit a particular pattern, representing a clear improvement compared to the residuals of the AAP model in the previous assessment (ICES, 2024).

The leave one out analyses did not show conflicting trends in SSB and recruitment. The removal of FR GFS index resulted in an increase of F in the middle of the time series (1990-2005) but it remains in the interval of confidence.

The retrospective Mohn's rho diagnostics are good and still within acceptable limits

- SSB Mohn's rho = -0.017
- Recruitment Mohn's rho = -0.041
- Fbar Mohn's rho = -0.023.

Model stability and convergence were confirmed through a simulation study using parametric bootstrap (Figure 1.20).

The final SAM model configuration is summarised below:

Final SAM configuration
Where a matrix is specified rows corresponds to fleets and columns to ages. Same number indicates same parameter used. Numbers (integers) starts from zero and must be consecutive. Negative numbers indicate that the parameter is not included in the model $minAge # The minimium age class in the assessment 1 $maxAge # The maximum age class in the assessment 7 $maxAgePlusGroup # Is last age group considered a plus group for each fleet (1 yes, or 0 no). 1 0 0 $keyLogFsta # Coupling of the fishing mortality states processes for each age (normally only the first row (= fleet) is used). Sequential numbers indicate that the fishing mortality is estimated individually for those ages; if the same number is used for two or more ages, F is bound for those ages (assumed to be the same). Binding fully selected ages will result in a flat selection pattern for those ages. 0 1 2 3 4 5 6 -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. 2 $keyLogFpar # Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by F). -1 -1 -1 -1 -1 -1 -1 0 1 2 3 4 4 -1 5 6 6 7 7 8 -1

Final SAM configuration
$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 $keyVarF # Coupling of process variance parameters for log(F)-process (F normally applies to the first (fishing) fleet; therefore only first row is used) 0 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. It is advisable to have at least the first age class (recruitment) separate, because recruitment is a different process than survival. 0 1 1 1 1 1 1 $keyVarLogP $keyVarObs # Coupling of the variance parameters for the observations. First row refers to the coupling of the variance parameters for the catch data observations by age Second and further rows refers to coupling of the variance parameters for the index data observations by age 0 1 1 1 1 1 1 2 3 3 3 3 3 -1 4 5 5 5 5 5 -1 $obsCorStruct # Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). "ID" "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).

Final SAM configuration

#1-2 2-3 3-4 4-5 5-6 6-7

NA NA NA NA NA NA

0 1 1 2 2 -1

3 4 4 5 5 -1

$stockRecruitmentModelCode

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

0

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

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

$fbarRange

lowest and higest age included in Fbar

3 6

$keyBiomassTreat

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

-1 -1 -1

$obsLikelihoodFlag

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

"LN" "LN" "LN"

Final SAM configuration
$fixVarToWeight # If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight). Can be specified fleetwise. 0 0 0 $fracMixF # The fraction of t(3) distribution used in logF increment distribution 0 $fracMixN # The fraction of t(3) distribution used in logN increment distribution (for each age group) 0 0 0 0 0 0 0 $fracMixObs # A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet 0 0 0 $constRecBreaks # For stock-recruitment code 3: Vector of break years between which recruitment is at constant level. The break year is included in the left interval. For spline stock-recruitment: Vector of log-ssb knots. $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 NA -1 -1 -1 -1 -1 -1 NA $stockWeightModel # Integer code describing the treatment of stock wt in the model (0 use as known, 1 use as observations to inform stock wt process (GMRF with cohort and within year correlations)), 2 to add extra correlation to +group 0 $keyStockWeightMean # Coupling of stock-weight process mean parameters (not used if stockWeightModel==0) NA NA NA NA NA NA NA

Final SAM configuration

$keyStockWeightObsVar

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

NA NA NA NA NA NA NA

$catchWeightModel

Integer code describing the treatment of catch wt in the model (0 use as known, 1 use as observations to inform catch wt process (GMRF with cohort and within year correlations)), 2 to add extra correlation to +group

0

$keyCatchWeightMean

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

NA NA NA NA NA NA NA

$keyCatchWeightObsVar

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

NA NA NA NA NA NA NA

$matureModel

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

0

$keyMatureMean

Coupling of mature process mean parameters (not used if matureModel==0)

NA NA NA NA NA NA NA

$mortalityModel

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

0

$keyMortalityMean

NA NA NA NA NA NA NA

Final SAM configuration
$keyMortalityObsVar # Coupling of natural mortality observation variance parameters (not used if mortality Model==0) NA NA NA NA NA NA NA $keyXtraSd # An integer matrix with 4 columns (fleet year age coupling), which allows additional uncertainty to be estimated for the specified observations $logNMeanAssumption 0 0 $initState 0

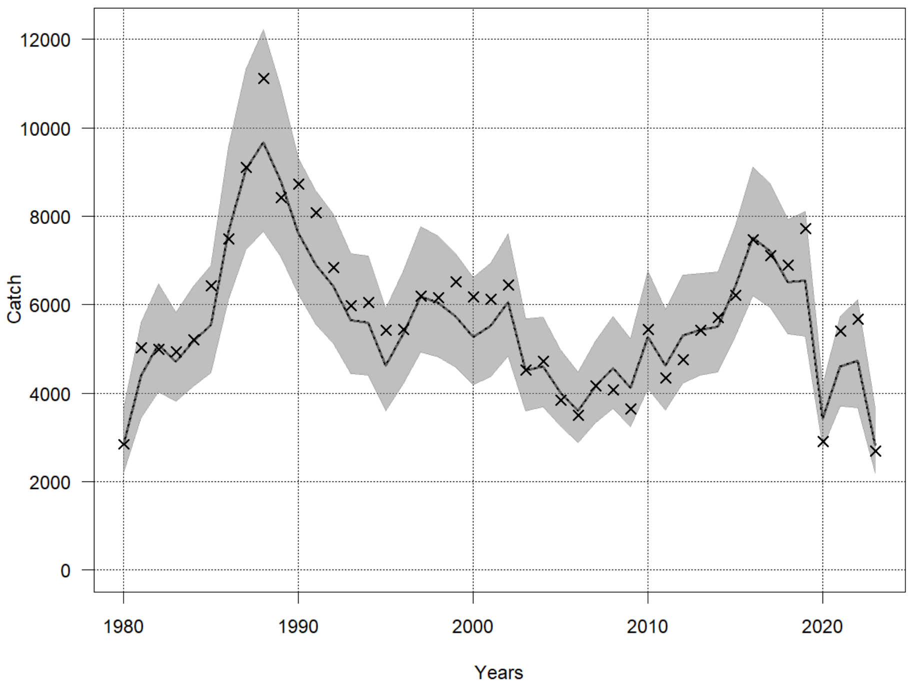

Figure 1.12: Total catches from the final SAM model (black line) compared to observed catches. The shaded area corresponds to 95% confidence intervals.

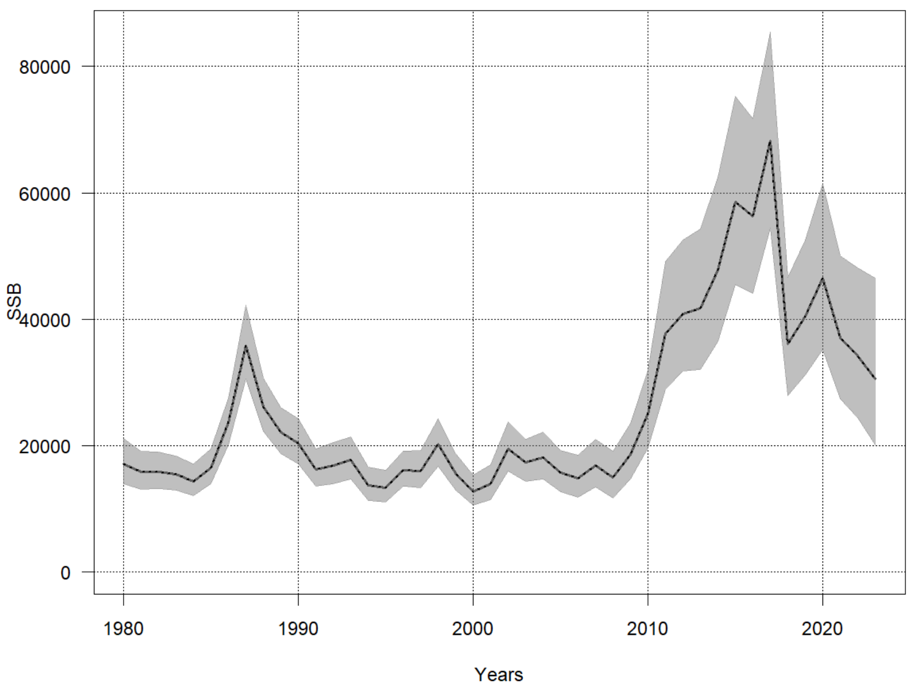

Figure 1.13: The estimated SSB of the final SAM model (black line). The shaded area corresponds to 95% confidence intervals.

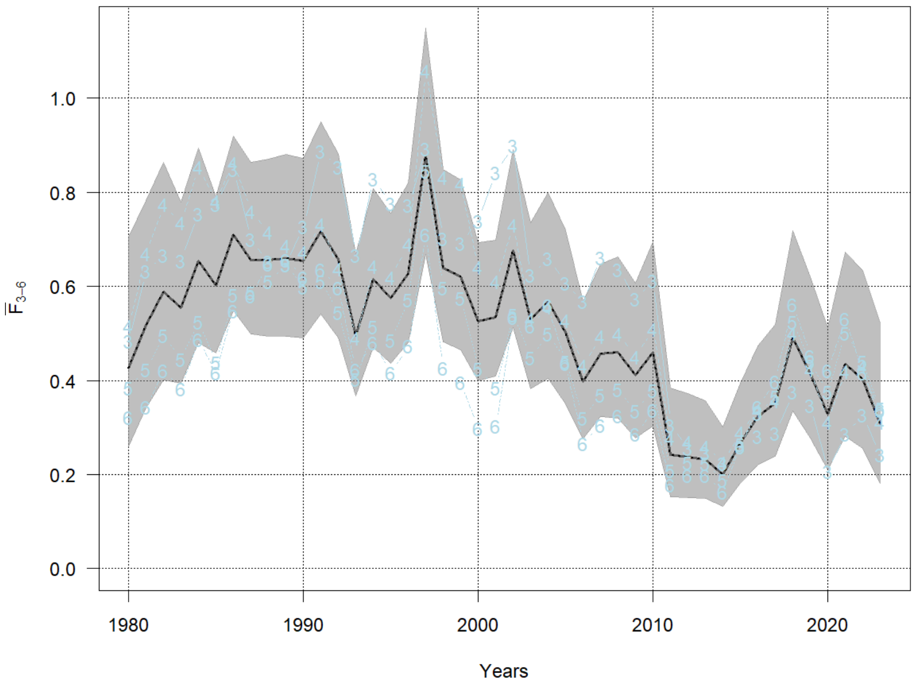

Figure 1.14: Fbar(3-6) from the final SAM (black line) and F at age (light blue lines). The shaded area corresponds to 95% confidence intervals.

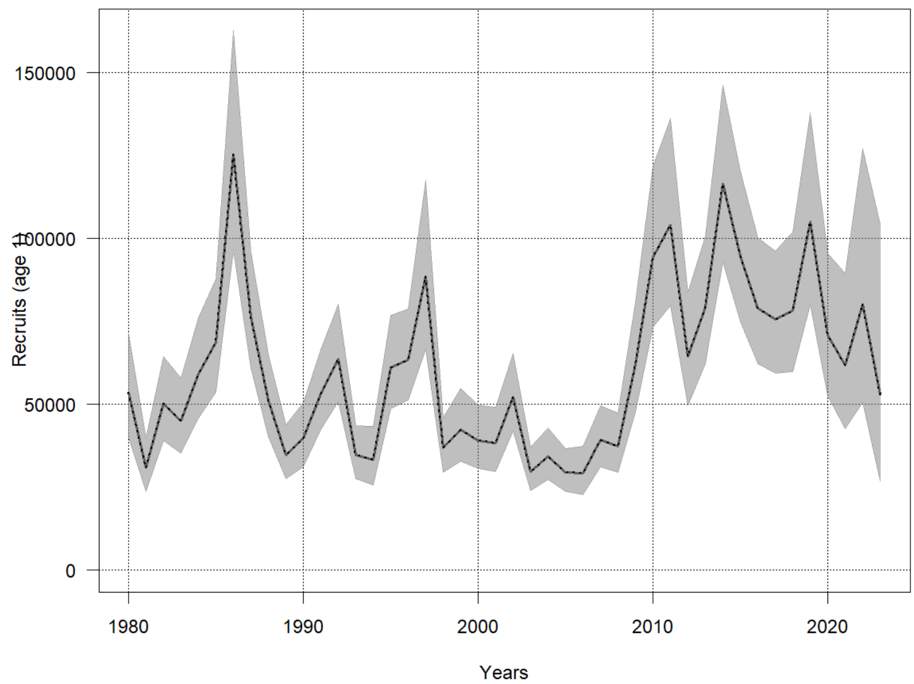

Figure 1.15: The recruitment (age 1) of the final SAM model (black line). The shaded area corresponds to 95% confidence intervals.

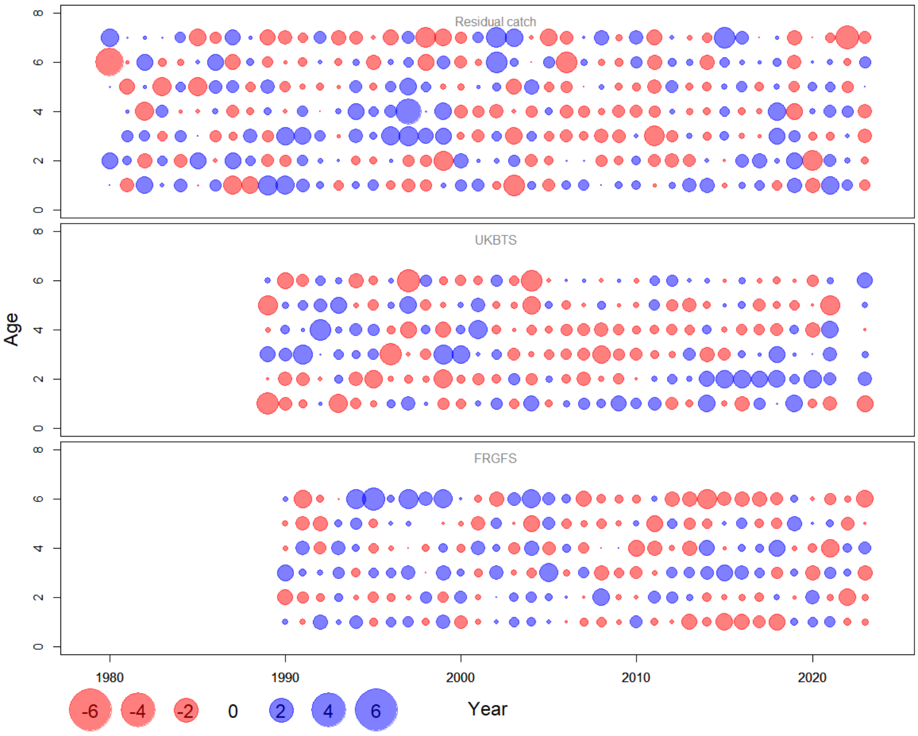

Figure 1.16: One step ahead (OSA) residuals for the total catch (top), UK BTS index (middle), FR GFS index (bottom). Blue circles indicate positive residuals and red circles negative residuals.

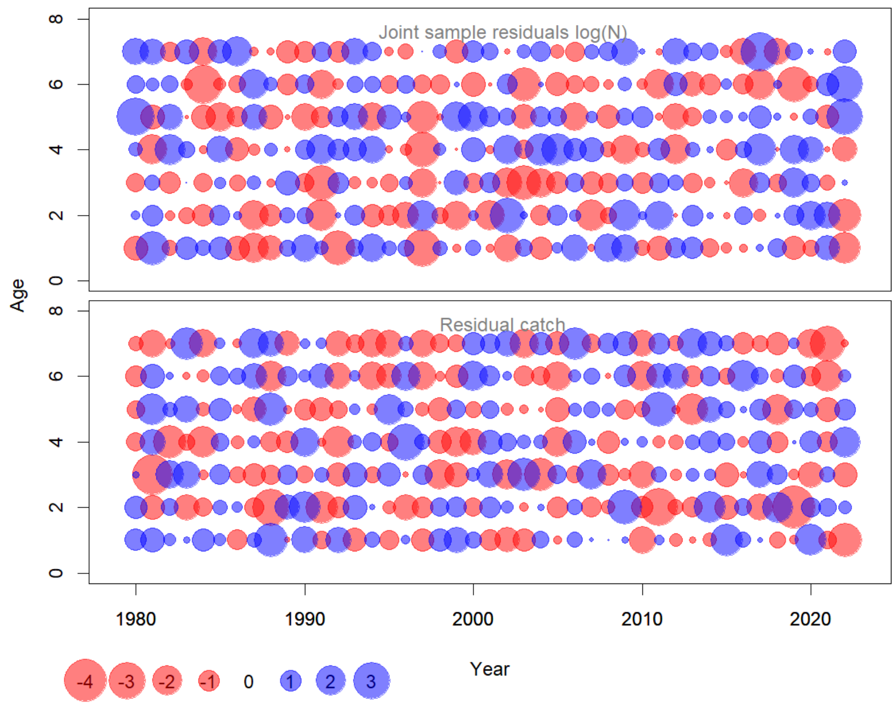

Figure 1.17: Process residuals of the survival (logN) (top) and F (bottom). Blue circles indicate positive residuals and red circles negative residuals.

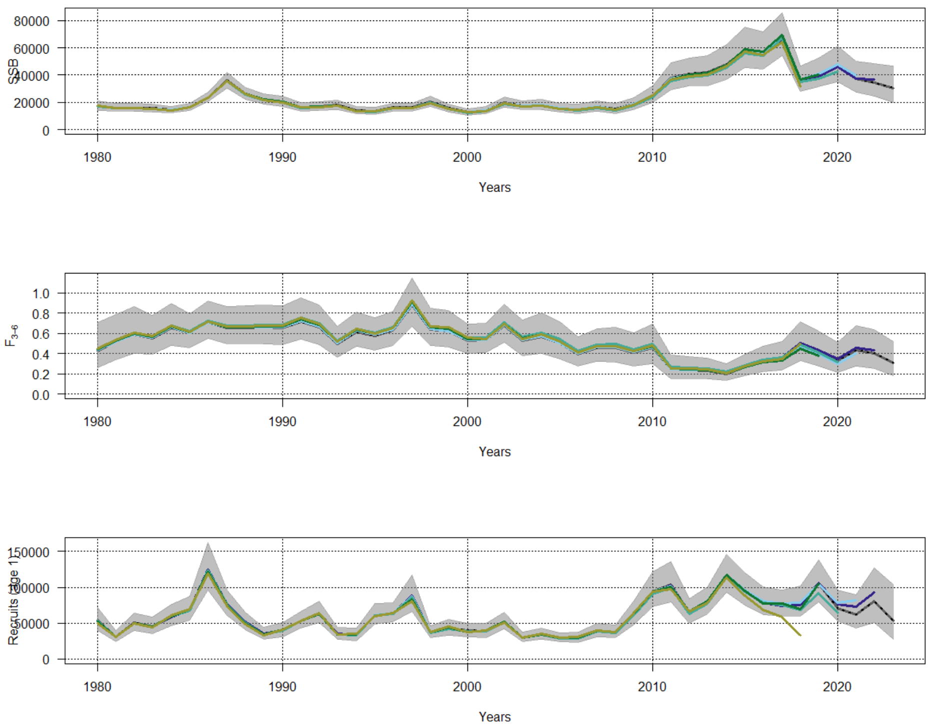

Figure 1.18. Retrospective estimates (five years) from the final SAM model: SSB (top), Fbar (3-6) (middle) average and recruitment (bottom).

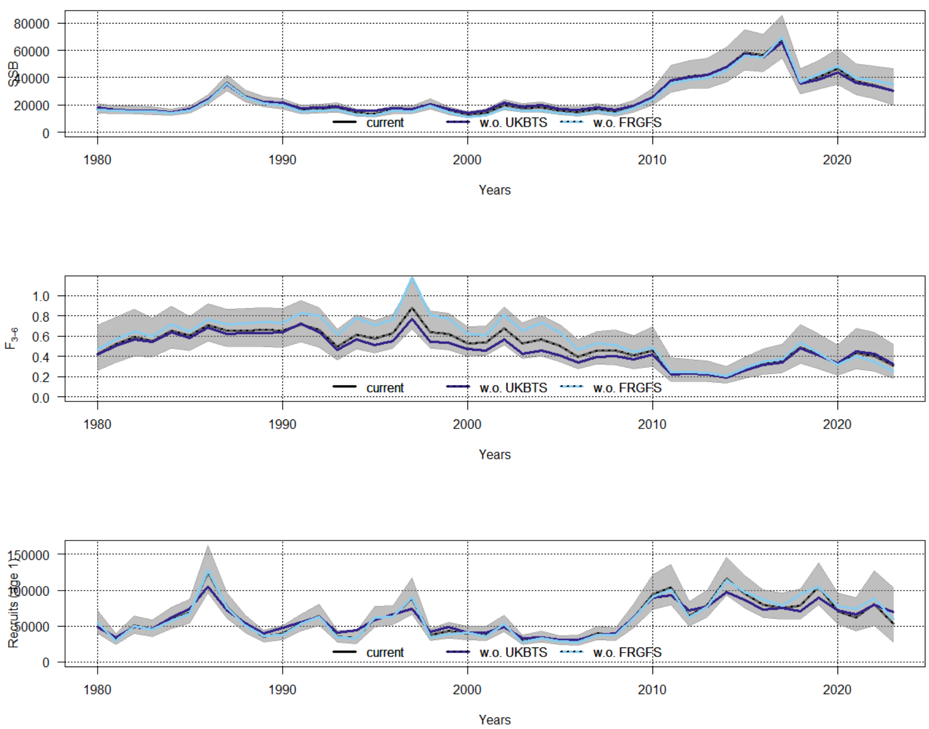

Figure 1.19: Leave-one-out estimates from the final SAM assessment showing SSB (top), Fbar (3-6) (middle) and recruitment (bottom).

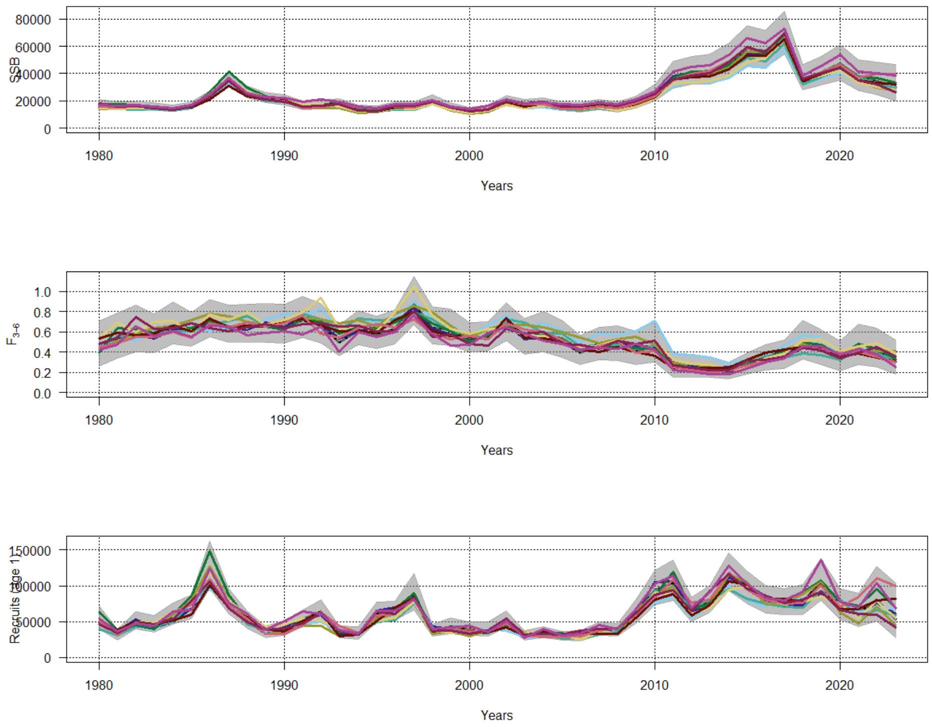

Figure 1.20: Simulation study analysis (parametric bootstrap) for SSB, Fbar and Recruits (age 1).

1.7 Biological reference points

The new reference points were recalculated based on the results of the final assessment (Model M8) (Table 1.6). The Eqsim methodology was applied following the ICES technical guidelines (ICES, 2021). Model settings and data selection are detailed in the WD_ Ple_7d_Reference_points.

The stock recruitment relationship was classified as type 2 (Stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired) based on the recruitment period 1980 – 2022. All analyses were conduct using Beverton and Holt and the segmented regression SRR, except for the estimation of (B_{lim}) for which only the segmented regression SRR was used. Therefore, the biomass limit reference point (B_{lim}) was set to be the inflection point of the segmented regression curve, being 25082 tonnes. B_{pa} was then derived following the Precautionary Approach $B_{pa} = B_{\lim} \times \exp(1.645 \times sigmaSSB)$ the sigmaSSB was estimated in the SAM model (sigmaSSB = 0.2098) resulting in B_{pa} 35421 tonnes. The F_{lim} was calculated using a segmented regression with a breakpoint fixed at B_{lim} and SSB precautionary reference point fixed at B_{pa} (without advice error and without advice rule). The estimated F_{lim} was equal to 0.533. The initial F_{MSY} was derived from Eqsim simulations using the estimated B_{lim} and B_{pa} and setting $B_{trigger}$ to zero (with advice error) leading to a F_{MSY} = 0.252. MSY $B_{trigger}$ was set to B_{pa} (35421tonnes) as the stock was not fished at or below F_{MSY} for 5 years or more. The F_{pa} was calculated using Eqsim analysis based on the estimated reference points B_{lim}, B_{pa}, $B_{trigger}$ with advice error which resulted in Fpa = 0.308 (Figures 1.21 and , 1.22).

Table 1.6: The new reference points calculated during WKBNCS compared to the previous reference points (ICES, 2022).

Reference points	WKBNCS (2025)	WGNSSK (2022)
$B_{trigger}$	35421	37761
F_{MSY}	0.252	0.156
B_{lim}	25082	27174
B_{pa}	35421	37761
F_{lim}	0.533	0.381
F_{pa}	0.308	0.238
lF_{MSY}	0.183	0.113
uF_{MSY}	0.308	0.224

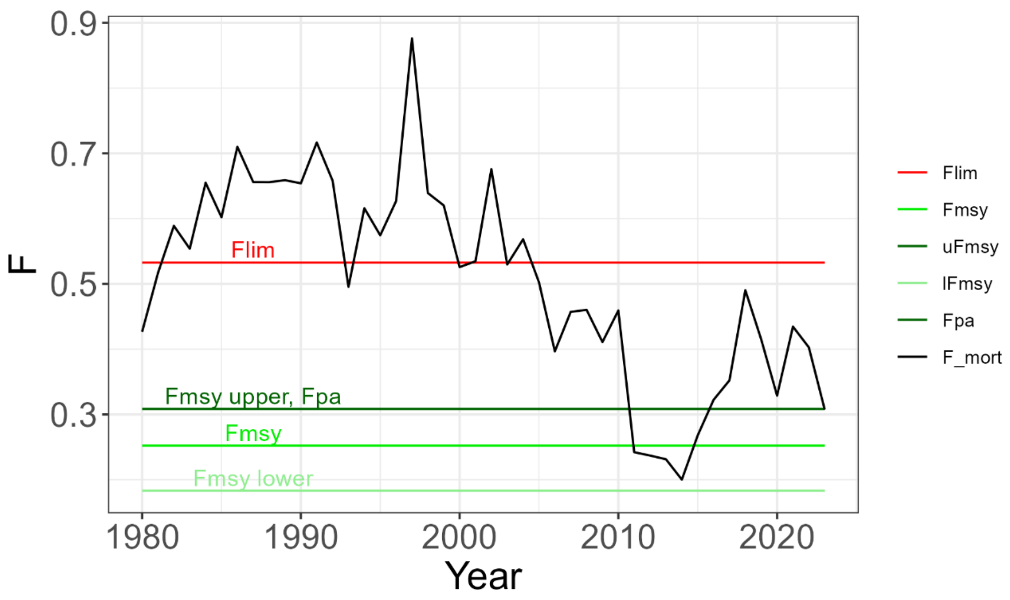

Figure 1.21: Fishing mortality and reference points (F_{lim}, F_{MSY}, $F_{MSYupper}$, $F_{MSYlower}$ and F_{pa})

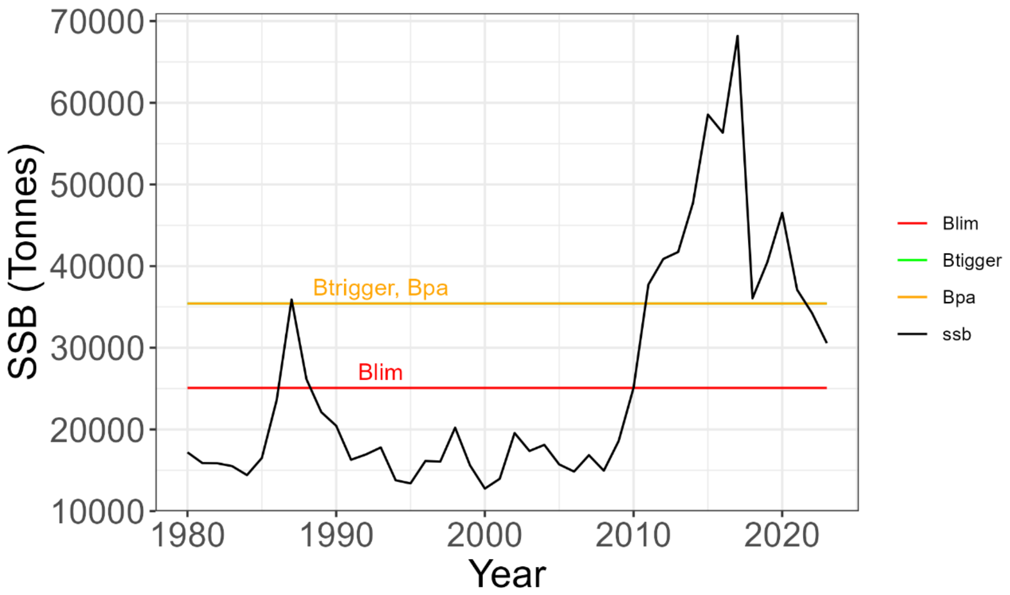

Figure 1.22: SSB and reference points ($B_{trigger}$, B_{pa} and B_{lim})

1.8 Forecast settings

The short-term forecast was conducted using the stockassessment R package. Forecast settings are summarized in the table 1.7.

Table 1.7: Summary of short-term forecast settings

Forecast settings	
Stock weights	Mean of the last 3 years
Catch weights	
Maturity	
Natural mortality	
Recruitment years*	Resampling of the last 10 years. (Recruitment assumption : Rec of the intermediate year onwards is sampled, with replacement)
Exploitation pattern*	Mean of final 3 years rescaled to F of the final year
Number of simulations	1000

***Recruitment years could be changed during the assessment group in the case of an important change in the recruitment dynamics.**

During the assessment working group, the catch of the intermediate year is calculated taking into account plaice migration and discards exemptions and compared to the TAC. Then, there are two options to choose the fishing mortality of the intermediate year :

- Catch intermediate year < TAC : status quo fishing mortality (F_{sq})
  - o if Fbar exhibits no trend over the last 3 years, the mean Fbar from this period is used as the intermediate year assumption.
  - o if Fbar shows an increasing or decreasing trend over the last 3 years, it is scaled to the last data year, meaning the Fbar for the intermediate years remains the same as in the last data year.
- Catch intermediate year > TAC : TAC constraint

In the intermediate year, Fbar is calculated under the assumption that the TAC will be fully fished.

1.9 Recommendations for the future

The main recommendations from WKBNCS 2025 consists in :

- To WGNSSK and WGCSE: The organization of a stock ID and a benchmark workshop in the next years dedicated to the 3 plaice stocks : the ple.7d (eastern English Channel), ple.27.420 (North Sea) and ple.7e (western English Channel) to further investigate the implementation of plaice migration.
- To WGNSSK: Setting up a standardized procedure for taking into account the Landings Obligation (LO) in the forecast for all stocks under LO, especially for those with a high discard ratio in order to facilitate the choice of the fishing mortality in the intermediate year.

1.10 References

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1.11 Reviewers report

The ple.27.7d assessment was last benchmarked in 2015 using AAP, which is no longer maintained. The last update for ple.27.7d occurred in 2023. The current benchmark updated biological and catch data and used SAM (Nielsen and Berg, 2014) as an assessment framework.

Catch data were derived from the beam trawl and mixed demersal fisheries. Catch is composed of landings and discards. Discards are assumed based on expanded discard ratios collected by fishery observers, because much of the English Channel fleet is not obligated to land plaice. English Channel plaice are panmictic and in order to account for movement, 65% of the first quarter catch is subtracted from the total.

Biological parameters including natural mortality (M) and maturity were updated for this assessment. Updated maturity data indicate plaice are maturing earlier than previously. Natural mortality was changed from time and age invariant to age dependent. Catch and stock weights were recomputed, including new estimates of historical discard weights-at-age.

The benchmark assessment was conducted in SAM and the final model was developed in a stepwise manner from "default" configuration. Initial modifications included adding age dependent M, altering the covariance structure, coupling of process variance parameters, and coupling catchability parameters. Using the best configuration from the initial step, several alternative models were fit and then discarded due to poor diagnostic results. These included splitting the French GFS index, which had a vessel change in 2015 and alternative forms of age varying M.

The final model included AR1 random effects for each of the survey fleets (UK BTS and French GFS), with some coupling between adjacent age pairs, and relatively few total parameters based on coupling process and observation variance parameters across all ages.

The final model (M8) performed well relative to a suite of diagnostic tests. None of the process error variance estimates were larger or smaller than might be expected. The one-step-ahead (OSA) residuals were generally normally distributed and exhibited no detectable patterns. The self-test simulation, which simulates data conditioned on the random effects, did not highlight any issues in the plots of population processes. A jitter analysis in which the initial parameter values of the model were shifted, demonstrated that the model was robust to deviations in starting parameter values. There was no retrospective pattern, and the leave-one-out test indicated that the model was also robust to the loss of either survey.

Model 8 produced reasonable estimates of spawning stock biomass, fishing mortality and recruitment and should be considered sufficient for use in generating management advice.

The WK considered a series of options for setting biological reference points. Ple.27.7d is considered a Type 2 stock, as it shows a wide range of spawning stock biomass levels and evidence of low recruitment. The recruitment time series was noisy and without pattern, so the entire series was included in reference point calculations. Stock weights-at-age and fishery selectivity at age have changed rapidly in recent years. The WG chose the most recent 5 years for use in reference point calculations, in order to be representative of current conditions. 2500 EQsim runs indicated that a Beverton Holt model produced a better fit to the simulated stock recruitment relationship than segmented regression, although both were used for all reference point calculations other than B_{lim}. Ple.27.7d has been fished above F_{MSY} for several years and so MSY $B_{trigger}$ was set to B_{pa}, according to the ICES Technical Guidelines. Similarly, F_{MSY}_unconstrained was less than F_{pa}, so F_{MSY} was set to the F_{MSY}_unconstrained value.

The WG decided to use the last 10 years of recruitment to generate short term forecasts. The other forecast settings, such as stock weights, catch weights and selectivity were based on the last three years because these quantities were changing rapidly over time. Maturity and natural mortality were constant over time in the model so no choice of time period was required.

The WG spent some time considering the intermediate year catch assumption, which is complex for ple.27.7d. The intermediate year catch assumption is complicated by fish movement and the uncertainty caused by discard catch accounting. Ple.27.7d is primarily a bycatch stock and one area of concern is the catch accounting of discards for the purposes of quota monitoring. Discards are approximately three times larger than landings in magnitude. A large proportion of the fleet is under a landings obligation exemption, which means that discards must be estimated based on analysis of fisheries observer data. This analysis is not possible for the intermediate year, because of time constraints. This wide-spread landings obligation exemption is potentially concerning because all discarded plaice are assumed to survive. This implies that no level of plaice bycatch can trigger in-season management measures.

<u>Recommendations</u> from reviewers:

- Investigate a spatial model for plaice. The stock is mixed such that fish from different stock areas are fished together. Although movement rates between areas is unknown, failing to properly account for movement among areas is a potential source of bias. It is possible that attempting to estimate movement rates may result in less biased results than not accounting for movement, or using assumed movement rates. This question could be investigated using simulation.
- Consider how the landings obligation exemption for plaice could be modified to allow for TAC based management. Discards are currently assumed to have 100% survival, which is clearly unrealistic. Other stocks under landings obligation exemption make different assumptions. Perhaps all these stocks could be considered together and some adjustment to the regulations made, in order to standardize treatment and allow for better tactical management.

- The Review panel was somewhat confused by ICES preference for using EQSIM to generate reference points and forecasts, rather than the assessment model framework. SAM contains all the necessary machinery to generate both reference points and projections. More importantly, it seems clear that any autocorrelated processes should be continued into the forecast period. As far as we know, EQSIM does not do this while SAM does. Ignoring autocorrelation in the forecast period risks producing biased projections of those processes. SAM also likely provides estimates of the uncertainty around reference points and forecasts that are more consistent with those estimated in the assessment model.

The stock assessment for plaice in 7d met the terms of reference and can be used to provide management advice. The assessment methods workshop went smoothly and finished on time, largely due to the preparation and diligence of the assessment teams. The external reviewers would like to thank Anders Nielsen for attending the workshop and providing invaluable advice on SAM configuration and analysis and Dorleta Garcia for providing advice on ICES reference point guidelines during the meeting.

2 Turbot (*Scophthalmus maximus*) in Subarea 4

2.1 Summary

The last benchmark for North Sea turbot took place in 2018, where the stock was upgraded from Category 3 to Category 1, allowing for a full age-based stock assessment using the SAM state-space assessment model. The current benchmark enhanced the North Sea turbot SAM assessment by providing new survey indices, making improvements to maturity, natural mortality, and weight-at-age data while providing new reference points.

To address issues caused by a lack of reliable survey data for the North Sea turbot assessment, a new quarter 3 survey carried out by commercial trawlers (BSAS) was evaluated. Developed by scientists and fishers, this survey specifically targets turbot and brill and provides data from 2019 onward. Its inclusion in the assessment model eliminates the need for the previous commercial LPUE index which featured issues with double counting and caused residual patterns.

The quarter 3 North Sea beam trawl surveys (BTS) were combined with the SNS and DYFS coastal surveys via Delta-GAM to form the BTS+COAST. This was kept separate to the BSAS (tweedie model) index which is characterized by different methodology as a commercial survey index. Models included both time-invariant and time-variant components, using depth, gear, ship and year as effects, and swept area as offset.

To account for gaps in biological information, stock and catch weights were modeled using an internal method within SAM, applying a Gaussian Markov Random Field (GMRF) approach to estimate weights-at-age. This provides more stable weight-at-age calculations compared to the previous time-varying Von Bertalanffy smoothing method.

The natural mortality vector, previously set as a constant (0.2), was replaced by an age-varying vector following Lorenzen (1996). The increased natural mortality estimates for younger individuals resulted in the model compensating by significantly increasing estimated recruitment across the entire time period. The maturity ogive was also updated, now based on quarter 2

(peak spawning) samples from 2001–2023, replacing the previous ogive derived from 2003–2009 data across all quarters.

In the final assessment model, catch data received the highest weighting, followed by BSAS and BTS+COAST. Due to the limited five-year time series in BSAS, a full five-year retrospective analysis is not yet appropriate. However, Mohn's Rho values from a three-year retrospective analysis fall within acceptable ICES guidelines. As BSAS accumulates more data, a full five-year retrospective analysis will become feasible.

A Type 5 stock-recruitment relationship was adopted, indicating no clear link between spawning stock biomass (SSB) and recruitment. Under this approach, B_{lim} is set to $B_{emperical}$, calculated as the mean of the lowest three SSB values above median recruitment. Forecast settings use GMRF-projected weights-at-age. Stock projections in Eqsim were based on a segmented regression, resulting in an F_{MSY} estimate of 0.386.

In addition to the information presented in this report, further details can be found in the following five working documents (Annex 3):

1. van de Pol, L., 2025. WD Update to natural mortality for turbot (*Scophthalmus maximus*) in the Subarea 27.4 (North Sea). Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2025), February 03-07, 2024;5 pp.
2. Tiano, J. 2024. WD Update to maturity for turbot (*Scophthalmus maximus*) in the Subarea 27.4 (North Sea). Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2025), November 19–21, 2024;3 pp.
3. Tiano, J. 2025. WD Updated survey indices developed for turbot (*Scophthalmus maximus*) in the Subarea 27.4 (North Sea). Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2025), February 03-07, 2024;43 pp.
4. Tiano, J. 2025. WD Update to weight-at-age for turbot (*Scophthalmus maximus*) in the Subarea 27.4 (North Sea). Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2025), February 03-07, 2024;6 pp.
5. Villagra, D. 2024. Development modelled combined survey exploitable biomass index for turbot in the North Sea (ICES divisions 27.4 a-c) using scientific and industry based surveys. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2025), November 19–21, 2024;19 pp.

2.2 Stock identity

No review of stock identity was carried out for this benchmark. There is some evidence that the population of turbot in Subarea 4 is at least partly connected to turbot in division 3.a (Skagerrak and Kattegat; Le Moan, 2019). However, further research is needed to determine the extent of this connectivity and its implications for stock structure. Currently, there is insufficient information to confidently support merging the North Sea and Skagerrak-Kattegat stocks. Consequently, the existing stock structure aligns with the turbot stock structures defined for the Northeast Atlantic in IBPNew 2012 (Figure 2.1).

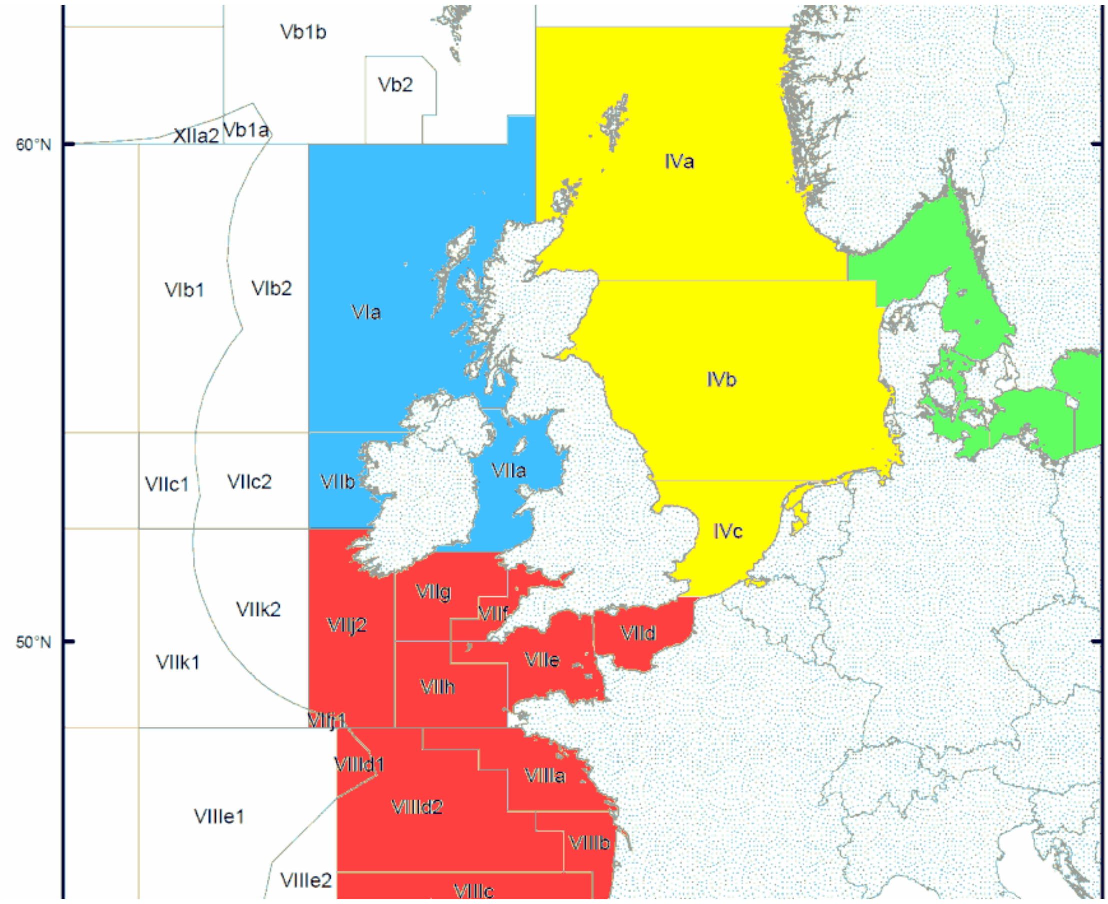

Figure 2.1. Stock structure of turbot in the Northeast Atlantic.

2.3 Catch data

2.3.1 Data evaluation meeting

North Sea turbot is characterized by several years of missing catch-at-age data from most of the 1990's to 2003 (Figure 2.2). In preparation for the data compilation, the catch and stock weight-at-age matrices were updated in order to provide data for any missing years in the dataset. Biological data for weights from catch data were made available for 2003 (NL), 2005 (DK,BE), and 2006 (DK, BE) from the benchmark data call. This allowed the estimation of stock weights at age and landings weights at age for these years through InterCatch. The raising procedure followed the annual raising procedure conducted for each new year of data for the turbot stock assessment. Allocations to calculate the age structure were conducted within métier per quarter where possible. If by quarter was not possible, available quarters were grouped (Table 2.1).

Table 2.1. Age allocation for weight-at-age estimates conducted in InterCatch.

Group	Allocation
TBB < 100mm	Within metier, all quarter
TBB > 100mm	Within metier, all quarter
OTB < 100mm	Within metier, all quarter
OTB > 100mm	Within metier, all quarter

OTB/TBB < 70mm	All, all quarter
SSC > 100mm	All, all quarter
SSC < 100mm	All, all quarter
GNS/GTR	All, all quarter
Rest	All, all quarter

2.3.2 Benchmark

Prior to the data compilation workshop, catch data for 2003 and stock weights for 2003, 2005, and 2006 were incorporated. During the benchmark workshop, no major changes were made to the catch data. However, due to concerns about unrealistically low catch-weights at age in the plus group for 2003, this data was omitted to prevent underestimation of the catch weight-at-age for that period.

2.4 Biological parameters

2.4.1 Data evaluation meeting

2.4.1.1 Maturity

The assessment of the tur.27.4 stock has used a maturity vector based on the female maturity ogive based on data from 2004 to 2009 developed during IBPNEW (ICES, 2012), due to inconsistent data for males and issues with historical data. In preparation for the data evaluation meeting, multiple maturity data was explored using multiple data sources from 2001 – 2023.

Potential temporal changes in maturity were analysed. Maturity data from Quarter 2, derived from length and converted to age, indicated no significant temporal changes. Ultimately, it was decided to update the current maturity ogive for North Sea turbot using maturity data from the peak spawning period. This update incorporates Dutch market samples (2003–2023) and data from a Belgian commercial sampling program (2017–2023).

2.4.1.2 Catch and stock weights-at-age

Landings weight-at-age data is available from 1981 - 1990 from the DATUBRAS database (Boon and Delbare, 2000) and also in 1998, and 2004 to 2023 from Dutch market samples. Stock weights are estimated as the catch weights in Q2, coinciding with peak spawning of the stock. Hence, stock weights estimates are available for the same time period as catch weights, but excluding the years 2005 and 2006 where no samples were available in the second quarter. In addition to this, average weights-at-age for the stock during the period 1976–1979 are available from Weber (1979).

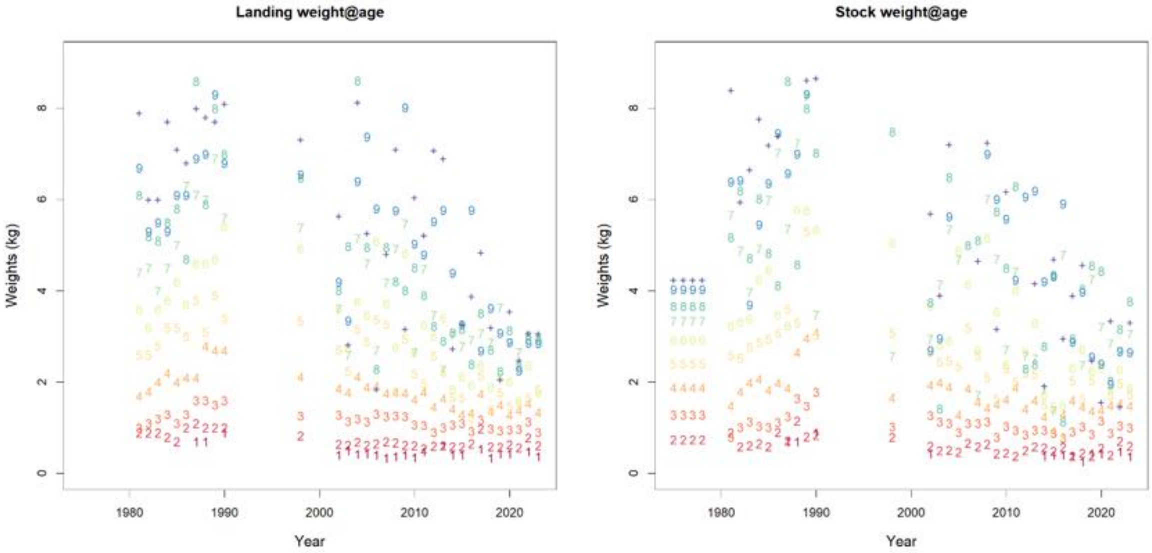

Figure 2.2. Raw landings weights-at-age data (left). Raw stock weights-at-age data (right).

Previous individual weights-at-age for the North Sea turbot stock assessment were based on a time-varying growth model to smooth over the missing data years (Figure 2.3; ICES, 2018). This was a two-step process which where time varying length at age is first estimated using a von Bertalanffy model where length-at-age a (in mm) in a given year t is calculated:

$$L_{a,t} = L_{\infty,t}(1-\exp(-K(a - a_0)))$$

where L_∞,t is the asymptotic length in year t, K is a curvature parameter, and $a0$ deter-mines the point in time when the fish has zero length. Stock weights-at-age in a given year Wa,tS (in kg) are calculated using an allometric growth model:

$$W^S_{a,t} = \alpha\, L_{a,t}^{\beta}$$

With parameters α= 0.00001508 and β=3.090, as estimated by Bedford *et al.* (1986). Catch weights-at-age $W^C_{a,t}$ are linked to stock weights-at-age by a simple age-independent scaling factor such that $W^C_{a,t}=\gamma W^S_{a,t}$.

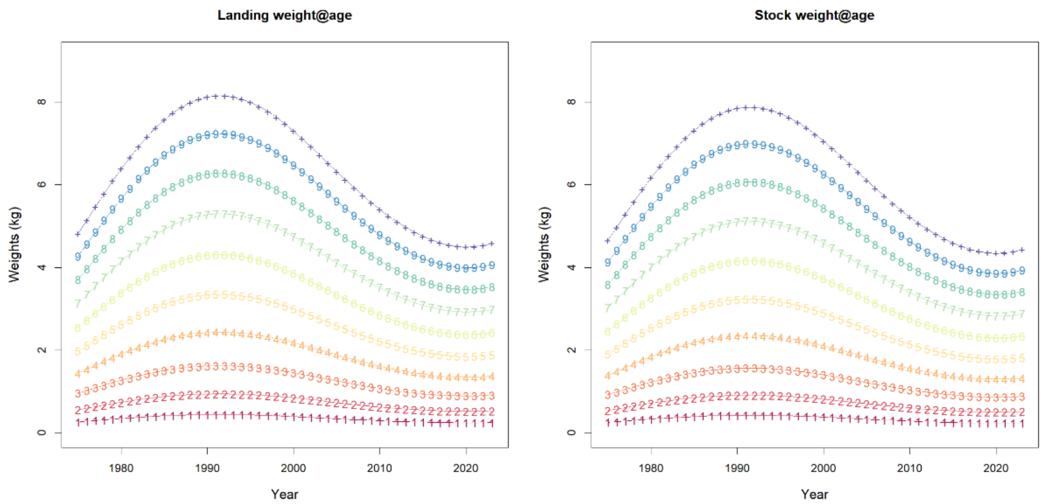

Figure 2.3. Landings weight-at-age assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (left). Stock weights (Q2 catch weights) assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (right). Linf$_t$ is a 5 parameter/knot spline in this example.

Due to the limited number of knots (5), there were concerns that the models were smoothing over years with important weight-at-age fluctuations. Additionally, the yearly updating of the modelled weight-at-age values could lead potentially growing retrospective patterns in SSB. Adopting a more stable method of weight-at-age estimation could reduce this risk. Therefore, the landing and stock weights-at-age were also estimated using an increased number of knots for the $Linf_t$. Figure 2.4 gives the estimated landing and stock weights-at-age when 15 knots are used in the estimation.

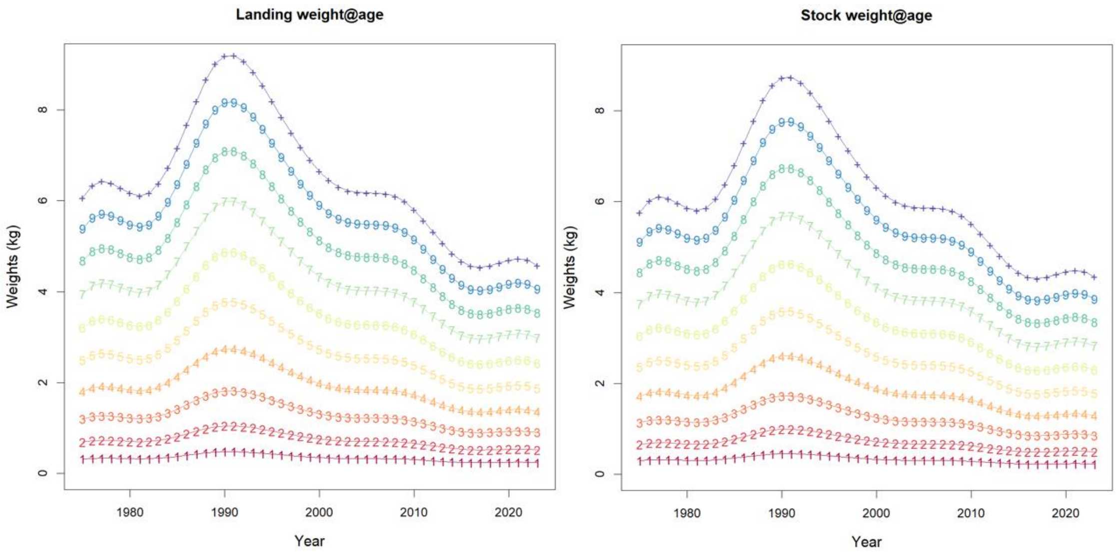

Figure 2.4. Landings weight-at-age assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (left). Stock weights (Q2 catch weights) assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (right). Linf$_t$ is a 15 parameter/knot spline in this example

2.4.1.2 Natural mortality

A constant natural mortality rate of M=0.2 has been used for all ages and years in North Sea turbot assessments (ICES, 2012; ICES, 2017). During the data evaluation meeting , several options for age-varying natural mortality estimates were presented. Of these methods, the ones deemed most appropriate were further investigate for implementation in the assessment model. Firstly, Lorenzen (2022) proposed a method of estimating age-varying natural mortality based on the relation between body size and natural mortality:

$$M(a) = M_{L_\infty} \cdot (1 - e^{-K\cdot(a-a_0)})^c$$

Where a is the age, a_0 is the age at length L=0, $M_{L\infty}$ is the natural mortality at asymptotic length L_{inf}, K is the von Bertalanffy growth rate, and c is the allometric scaling factor. Parameters a_0 and K were calculated using length and age data from combined quarter 3-4 North Sea survey data (IBTS, BTS, SNS, DYFS, BSAS) from 1991 – 2023, commercial catches from the Belgian sea sampling program from 2017-2023, and market sampling data from the Netherlands from 2003 to 2023, and a typical assumption of -1 was used for the allometric scaling factor (Lorenzen, 2022). To obtain an estimate of the natural mortality at asymptotic length (M_{L_∞}), the method proposed by Then (2015) was applied, which gives the relationship between maximum age (T_{max}) and natural mortality:

$$\acute{M} = 4.899 \cdot {T_{max}}^{-0.916}$$

The maximum age of turbot found in the survey data, commercial catch sampling and market sampling was 19, resulting in a natural mortality estimate of 0.33.

Lorenzen (1996) proposed a relationship between body weight and natural mortality. For natural ecosystems, the relationship between body weight-at-age (W_a) and natural mortality-at-age (M_a) is given as:

$$M_a = 3.00 \cdot W_a{}^{-0.288}$$

Here, the mean weight-at-age was calculated from samples in the survey data, commercial catches and market sampling to calculate M_a.

Figure 2.5 gives an overview of the different natural mortality estimates.

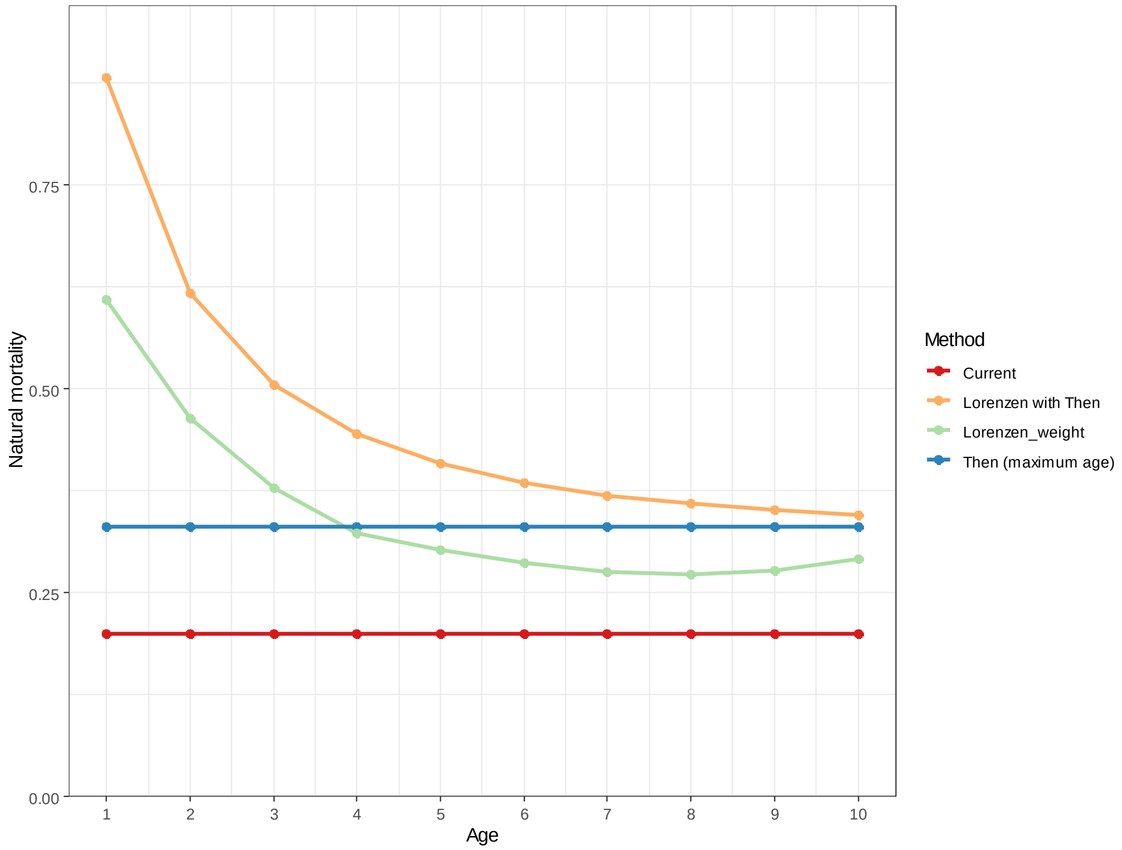

Figure 2.5. Natural mortality estimates based on Lorenzen's (2022) length-based method scaled to Then's (2015) method based on maximum age in the population, Lorenzen's (1996) weight-based method and the current constant natural mortality of 0.2.

Survey data was also used to calculate yearly estimates of natural mortality-at-age, but given the limited yearly sample sizes and limited effect on natural mortality, especially for older fish, this method was not explored further.

2.4.2 Benchmark

2.4.2.1 Maturity

For the benchmark, the maturity ogive was updated to incorporate additional years of data and samples specifically collected during peak spawning season (Q2). The updated maturity ogive for North Sea turbot uses quarter 2 data from Dutch market samples from 2003 – 2023 and samples from a Belgian commercial sampling program from 2017 – 2023 consisting of 7385 sampled female turbot. A maturity ogive was generated using a binomial generalized linear model (GLM) with a logit link. Ogives were fitted as a function of length using the R package *sizeMat* and was subsequently converted to age (Figure 2.6).

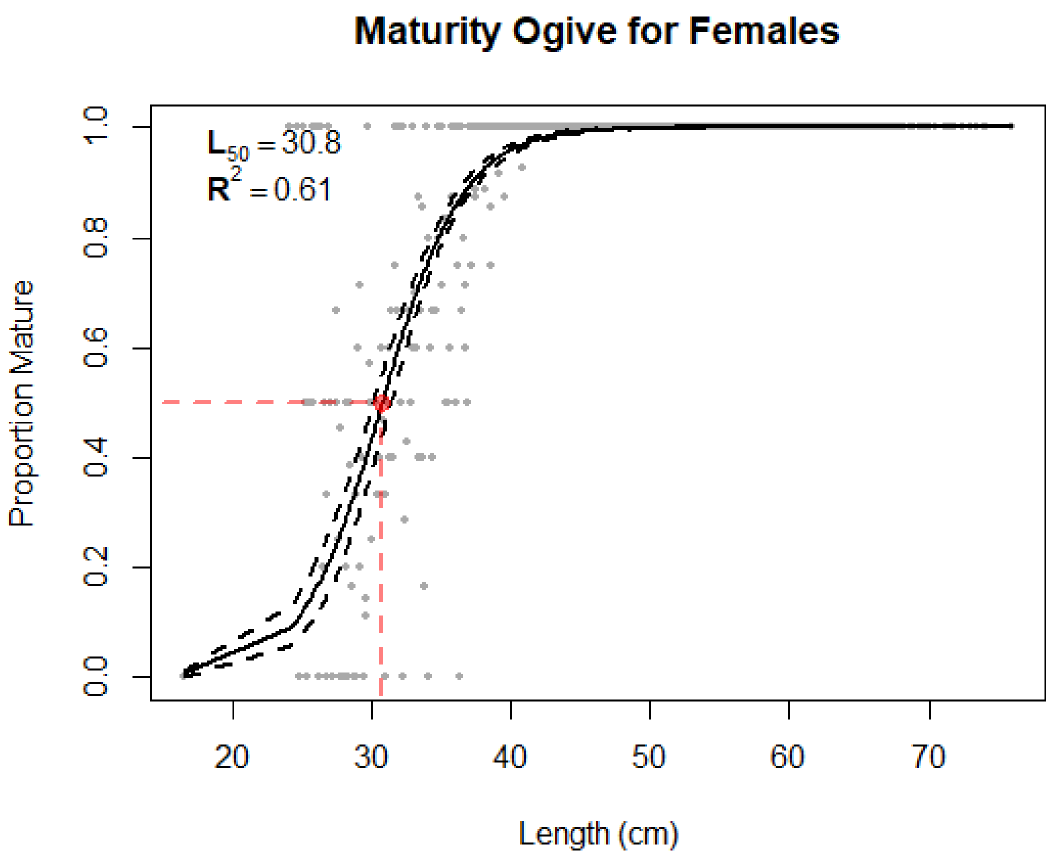

Figure 2.6. Maturity ogive for female North Sea turbot based on the proportion mature at length.

In comparison to the previous maturity ogive, the updated ogive suggests a slightly lower proportion of maturing females at age 2 (from 4 to 1%) and a higher percentage of mature turbot aged 3 (58% compared to 47% in the previous ogive; Table 2.2).

Table 2.2 Comparison of proportion mature at age with previous maturity ogive and updated version.

Age	1	2	3	4	5	6	7	8+
Previous (2004-2009)	0	0.04	0.47	0.95	1	1	1	1
Updated (2003-2023)	0	0.01	0.58	0.98	1	1	1	1

2.4.2.2 Catch and stock weights-at-age

In addition to trialing the time varying growth models with added flexibility (knots) to estimate catch and stock weights at age, it was decided during the benchmark workshop to trial an approach estimating the weights-at-age internally in the SAM stock assessment model. With this approach, the raw catch and stock weights-at-age are provided and the assessment model estimates weights-at-age for missing and future years using a Gaussian Markov Random Field (GMRF) model that incorporates the correlations in age, year and cohort. Amongst 34 different candidate models trialed in a DTU study forecasting biological parameters internally within SAM, this method was shown to be the best at predicting SSB 1 – 3 years ahead (*personal comm. Anders Nielsen*).

In addition to estimating biological data within missing years, this approach also allows for model-based catch and stock weights-at-age to be used in forecast simulations. After the inspecting the modeled catch and stock weights at age generated by the GMRF approach and careful discussion with the group, it was decided to choose this method for estimating weights at age for the North Sea turbot stock assessment model (Figures 2.7 and 2.8).

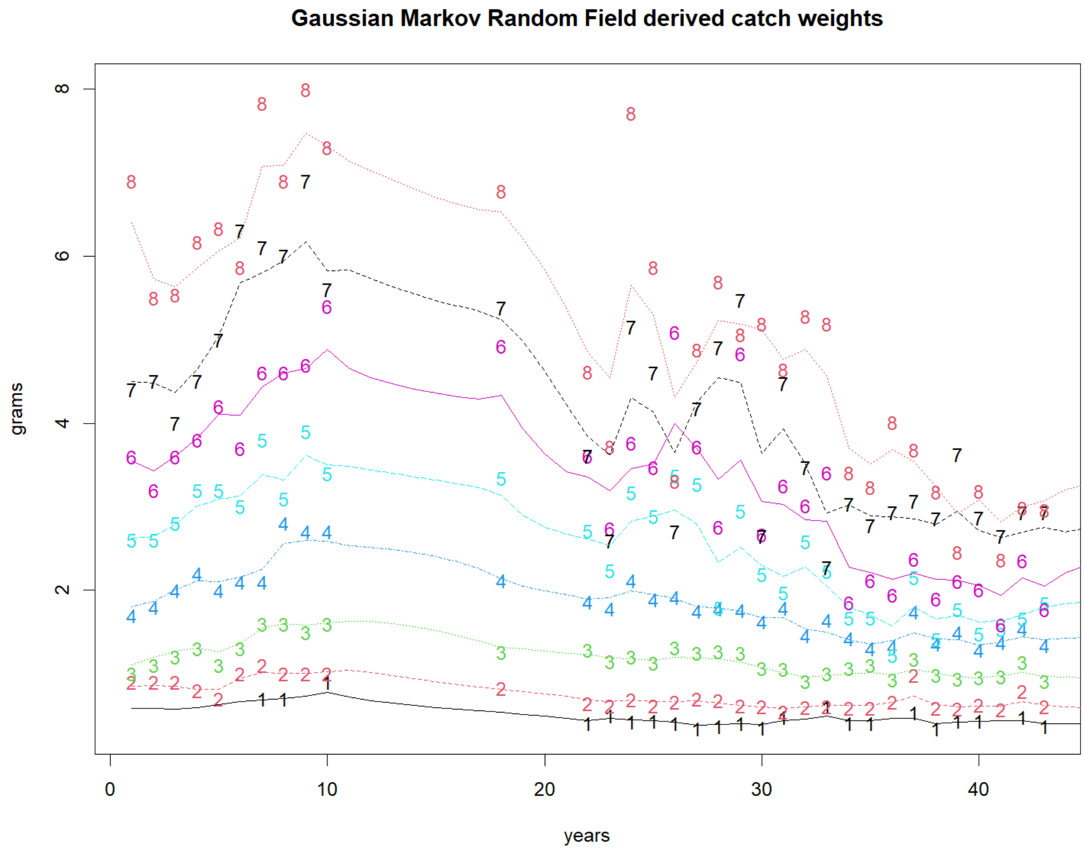

Figure 2.7. Raw catch weight at age data (numbers specifying ages) and modeled catch weights at age using the GMRF estimation method within the SAM model.

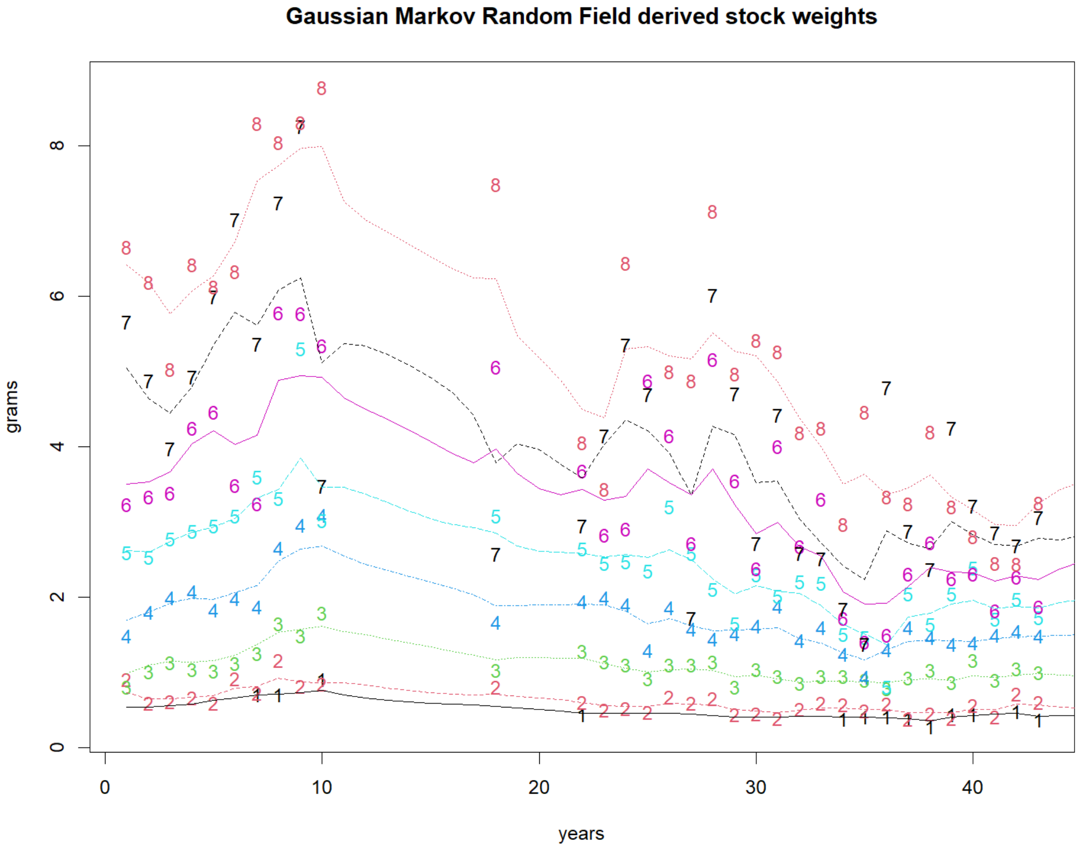

Figure 2.8. Raw stock weight at age data derived from quarter 2 commercial samples (numbers specifying ages) and modeled stock weights at age using the GMRF estimation method within the SAM model.

2.4.2.3 Natural mortality

During the benchmark, model runs with updated age-varying natural mortality were implemented as the final step after choosing the final survey configuration and weights-at-age settings. After discussing the most realistic scenarios for natural mortality in North Sea turbot, the method for age-varying natural mortality presented in Lorenzen (1996) was chosen. The new vector for natural mortality shows much higher natural mortality for younger aged fish, with a sharp decline for intermediate aged individuals and slightly increased natural mortality for older individuals (Figure 2.9). Initially, weights-at-age were derived from a von Bertanlanffy growth model applied to the weight and age data, but using the mean weights was thought to give more realistic values of mean weight-at-age.

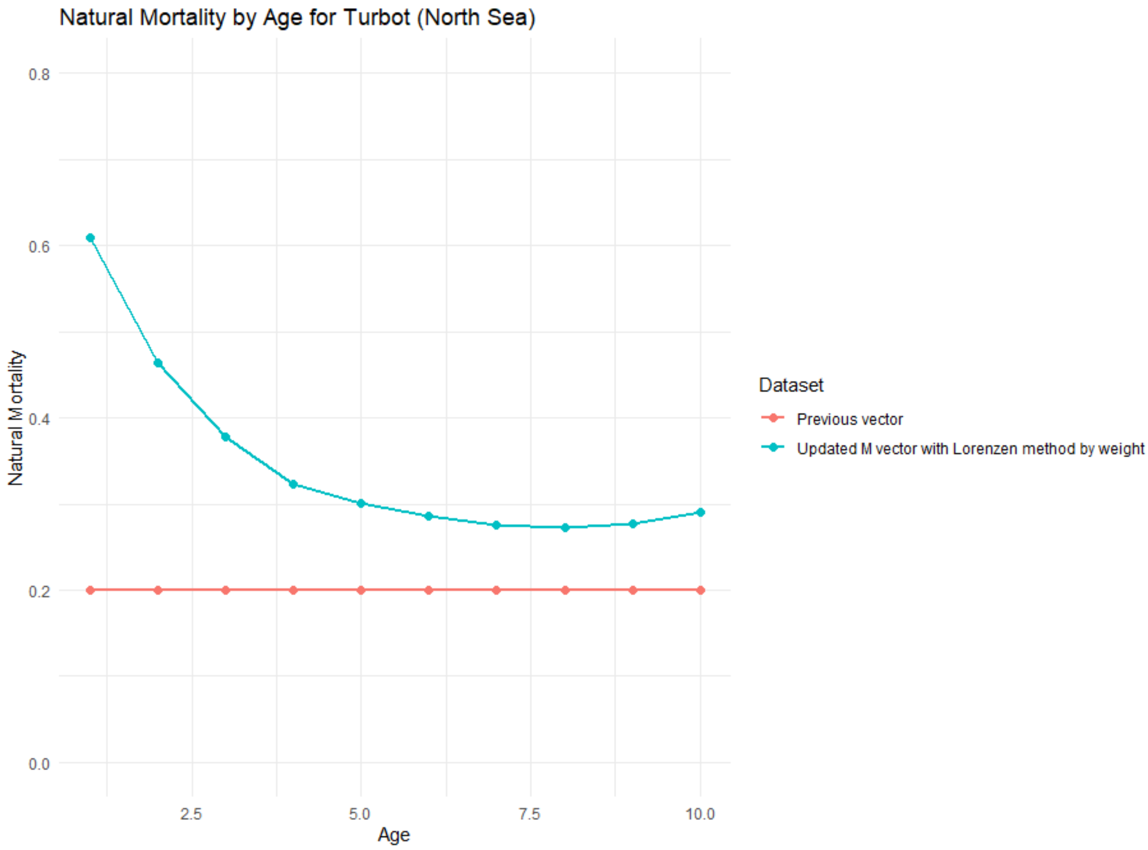

Figure 2.9. Updated natural mortality vector used in in the tur.27.4 benchmark (blue). The weight-based method for deriving age-varying natural mortality from Lorenzen (1996) was adopted for the North Sea turbot stock assessment.

2.5 Indices of abundance

2.5.1 Data evaluation meeting

2.5.1.1 Scientific survey indices

Since IBP Turbot in 2018, three indices of abundance have informed the North Sea turbot SAM assessment: the Beam Trawl Survey performed on the RV Isis, (BTS-ISIS), the Sole Net Survey (SNS) and a Dutch North Sea fisheries derived LPUE (ICES, 2018). Although these surveys offer relevant information for North Sea turbot, catchabilities for older ages are notably low, and internal consistencies between the surveys are weak. Consequently, the scientific surveys hold a lower influence on the assessment outcomes compared to the LPUE index and fisheries catch data. In recent years, the reduced fishing effort and area coverage of Dutch beam trawl fisheries have raised concerns about the reliability of the NL LPUE as an unbiased indicator for the turbot assessment. A scientific survey utilizing Dutch commercial fishing vessels was established in 2018 to improve survey indices for turbot and brill in the North Sea. This Dutch 'industry survey' (BSAS) has been designed to collect data in key areas for evaluating turbot stock status.

To develop new modelled indices for North Sea turbot, the R package *surveyIndex* was used. To replace the stratified mean CPUE-based BTS-ISIS index currently used in the North Sea turbot assessment, a combined index using BTS surveys from all relevant North Sea countries (NL, GB, BE, DE) was developed. To account for younger age classes which are currently informed in the assessment by the CPUE-based SNS survey, a combined model-based index using both SNS and DYFS surveys (NL, DE, BE) was developed. A model-based index for BSAS was developed using the same methodology as for the other scientific surveys. Additionally several options combining different indices were developed for model runs during the benchmark. These included runs with all surveys combined into one index, a configuration with the commercial BSAS index was separate from merged scientific surveys (BTS, SNS, DYFS) as well as an option combining inshore surveys (DYFS+SNS) and offshore surveys (BTS+BSAS; Table 2.3).

Table 2.3. Different combinations of indices to run during the 2025 North Sea turbot benchmark

Model Run Description:				
Indices used	**All separated surveys except COAST (DYFS+SNS)**			
	BTS (1991-2023)	BSAS (1991-2023)	COAST (1991-2023)	
	BTS (1991-2023)	BSAS (1991-2023)	COAST (1991-2023)	LPUE (1995-2023)
	Combining BTS and BSAS after 2019			
	BTS (1991-2023)	COAST (2003-2023)	BTS/BSAS combined (2019-2023)	
	BTS (1991-2018)	COAST (2003-2023)	BTS/BSAS combined (2019-2023)	LPUE (1995-2023)
	Everything combined			
	BTS/COAST combined (1991-2018)	BSAS/BTS/COAST combined (2019-2023)		
	BTS/COAST combined (1991-2018)	BSAS/BTS/COAST combined (2019-2023)	LPUE (1995-2023)	
	***Combine BTS and COAST and have BSAS separate**			
	BTS/COAST combined (1991-2023)	BSAS (1991-2023)		
	BTS/COAST combined (1991-2023)	BSAS (1991-2023)	LPUE (1995-2023)	

**Combined scientific surveys and separate BSAS survey selected for final benchmark assessment*

Model selection was guided by AIC (Akaike's Information Criterion) and BIC (Bayesian Information Criterion) to identify the best performing model. “Delta-GAM” hurdle models which feature a presence/absence component modelled with a logistic distribution combined with a positive abundance model component using either lognormal or gamma distributions, were compared with models using Tweedie distributions (Berg et al., 2014).

The abundance-at-age indices were modelled using the following formulation:

$$log(N_{age}) = B0 + f1(lon, lat) + f2(lon, lat, Year) + f3(Depth) + f4(Ship) + B1 * Gear + B2 * Year + \log(SweptArea + 1)$$

where:

- N_{age} is the expected count for individuals at each age.
- $B0$ is the intercept term, representing the baseline abundance at age.
- $f1(lon, lat)$ is a time-invariant spatial effect, modelled using a two-dimensional Duchon spline with penalties for smoothness.

- $f2(lon, lat)$ is a time-varying spatial effect, modelled using a Duchon spline varying by year with basis dimension: $k = 10$.
- $f3(Depth)$ is a smooth function of depth, modelled with thin-plate regression splines with basis dimension: $k = 6$.
- $f4(Ship)$ represents a random effect for different vessels carrying out the survey.
- $B1$ *and* $B2$ are fixed effects for gear type and year, respectively.
- log ($SweptArea + 1$) is an offset term to standardize for the survey area coverage, ensuring estimates are comparable.

Final models for all surveys included independent time-invariant and time-varying spatial components (Table 2.4). The spatial components included Duchon (bs= 'ds') splines with specified smoothness parameters. Final models also included a random effect for ship and a smooth term for depth using a thin plate spline with shrinkage basis (bs= 'ts'). The depth component uses the same k setting as the North Sea sole index models which also uses the BTS, SNS, and DYFS surveys (ICES, 2024).

Delta models featuring lognormal variance structures exhibited lower model AIC scores for BTS and COAST (DYFS+SNS) indices compared to Delta models with gamma or tweedie variance structures. In contrast, the BSAS indices using tweedie models displayed lower AIC scores when using tweedie models compared to either delta model.

Table 2.4. Comparison of goodness of fit of various survey models used for BSAS, applied to a combination of all surveys. Exploration of options was carried out on the time-invariant models to decrease the computational needs. Note: BSAS models lack a specific 'gear' effect as the survey operates using the same gear type. Models that include any other surveys include a gear component as a fixed effect.

Model	description	simplified formula	AIC
TIV+ship	time-invariant spatial effect + ship	*Year + Ship + s(lon,lat,bs='ds',m=c(1,0.5),k) + offset(log(SweptArea))*	*6033*
TIV+rShip	time-invariant spatial effect + random(ship)	*Year + s(Ship,bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + offset(log(SweptArea))*	*6016*
TIV+TV+ rShip	time-invariant and time-varying spatial effects + random(ship)	*Year + s(Ship, bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + s(lon,lat,bs='ds',m=c(1,0.5),k=10,by=Year,id=1) + offset(log(SweptArea))*	*5991*
TIV+TV+ depth	time-invariant and time-varying spatial effect + random(ship) + depth	*Year + s(Ship, bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + s(lon,lat,bs='ds',m=c(1,0.5),k=10,by=Year,id=1) + s(Depth,bs='ts',k=6) + offset(log(SweptArea))*	***5886***

2.5.1.2 Commercial index: LPUE biomass index

The Dutch landings per unit effort (LPUE) biomass index is currently the only commercial index used for North Sea turbot (Figure 2.10). Concerns exist about its relatively high weighting in the assessment, as well as the effect of changes in the Dutch beam trawl fleet on the representativeness of the index (ICES, 2018). The LPUE statistical model includes interactions in space, time and gear. Raw LPUE's are calculated per trip and per ICES rectangle. The fishing effort per rectangle is then taken as a weighting factor in the analysis.

LPUE = te(Longitude, Latitude, by = as.factor(year), k = 5) + as.factor (year, k = 10) + gear

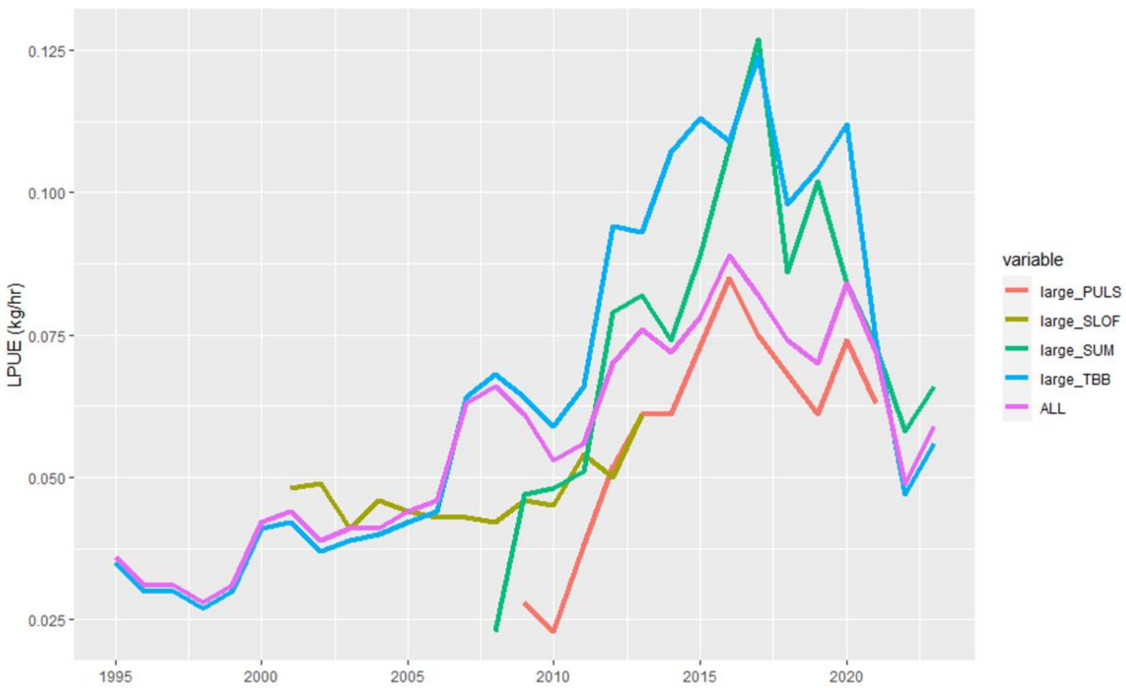

Figure 2.10. Turbot LPUE by fleet segment over time (1995 – 2023).

2.5.2 Benchmark

2.5.2.1 Scientific survey indices

After trialling and presenting model runs with several survey configurations (Table 2.3), the benchmark group decided that keeping the index developed for the commercial BSAS survey worked best in the assessment model when used separately from the scientific surveys. This survey configuration combined the coastal SNS and DYFS scientific survey with the offshore BTS survey via a Delta-GAM index model while running BSAS as a separate commercial tweedie modelled index. This dynamic assumes that surveys conducted on research vessels share more similar qualities compared to BSAS which was designed by scientific researchers but is carried out by commercial trawlers with observers collecting the samples.

All survey configurations were trialled with and without the commercial LPUE index. Upon analysis of assessment model diagnostic plots, it was decided to remove the LPUE index for the updated assessment (see section 2.6 for details)

The modelled BTS+COAST index shows improved cohort tracking compared to the previous CPUE-based indices used in the previous assessment derived from the BTS and SNS surveys (details in WD - Survey indices developed for turbot - tur.27.4; Figure 2.11; Table 2.5). However, due to low catchabilities in older ages, this new index still provides poor cohort tracking for ages 6 and 7+.

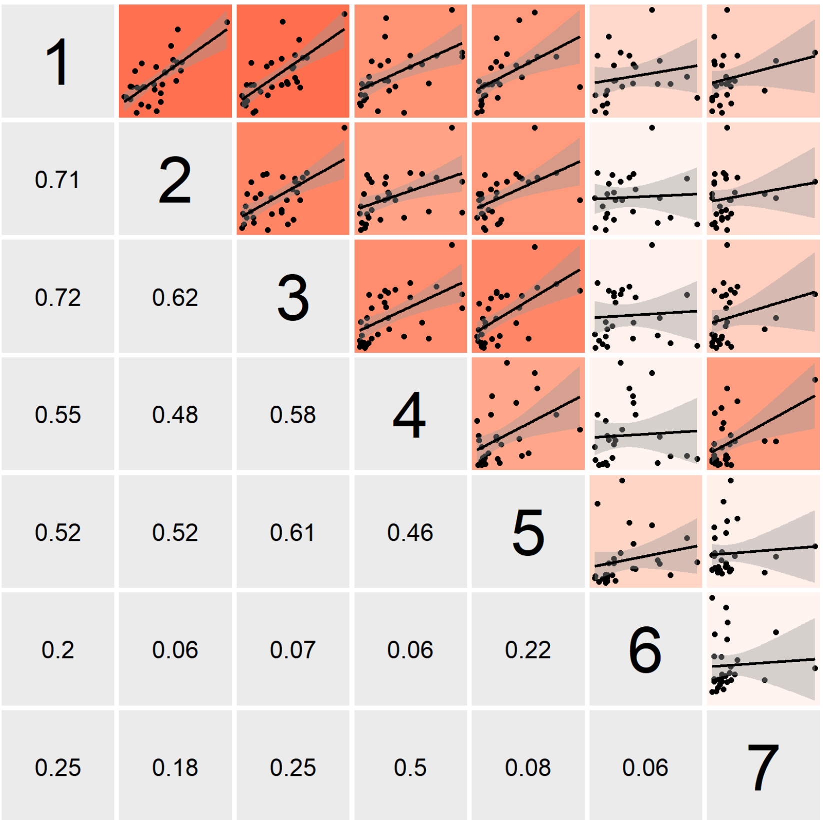

Figure 2.11. Turbot in Subarea 4. Cohort correlation on the index of abundance based on the combined BTS+COAST quarter 3 surveys (1991-2023)

Table 2.5. Age-structured index for BTS+COAST used in the turbot assessment

Year	1	2	3	4	5	6	7
1991	36.348	163.608	15.906	1.919	2.845	1.993	7.167
1992	41.784	100.958	35.104	0.572	2.412	1.782	2.879
1993	51.585	86.412	11.625	4.491	0.888	1.562	2.112
1994	66.365	125.642	8.078	1.007	2.837	0.824	1.260
1995	79.676	56.739	13.210	0.315	1.782	2.226	2.030
1996	19.590	125.950	6.577	2.665	1.888	1.215	3.881
1997	15.622	117.733	31.070	3.362	1.742	1.715	2.521
1998	109.251	77.706	24.507	17.195	2.485	0.000	5.253
1999	98.732	112.747	21.681	10.793	1.023	0.446	0.737
2000	166.114	78.053	66.735	25.715	1.968	1.723	1.702
2001	59.209	149.405	12.859	14.546	0.587	0.384	13.068
2002	166.865	64.476	19.054	5.492	1.227	1.540	0.757
2003	153.484	116.978	9.242	7.258	2.777	2.558	3.058
2004	155.784	74.000	46.083	4.061	15.520	8.370	4.832
2005	91.923	166.025	75.627	16.781	6.636	0.000	4.361
2006	190.733	113.284	39.867	12.370	6.142	11.233	1.134
2007	121.080	150.943	84.035	36.016	7.596	7.246	0.750
2008	99.706	156.465	77.817	20.818	12.019	2.415	15.759
2009	100.105	67.568	77.329	59.135	30.511	4.458	3.015
2010	108.705	90.629	22.738	5.836	9.316	3.260	1.256

2011	182.154	128.743	18.575	1.650	13.683	3.112	5.131
2012	99.920	158.671	80.478	39.839	7.168	10.130	24.946
2013	67.955	93.617	88.069	16.702	4.852	7.028	3.977
2014	181.845	52.807	59.713	44.303	6.305	4.421	1.280
2015	315.226	168.401	40.997	7.132	18.189	2.418	2.917
2016	92.871	259.397	93.559	1.096	3.892	4.029	6.066
2017	237.156	84.731	143.895	29.424	2.975	0.000	6.628
2018	149.362	146.268	46.669	53.326	23.637	1.514	3.973
2019	291.895	134.459	82.780	4.464	17.425	0.652	4.279
2020	179.469	159.569	73.909	15.002	2.255	6.450	3.360
2021	101.951	88.044	60.871	29.387	6.256	0.000	4.188
2022	148.910	64.531	59.365	15.507	4.663	1.868	1.673
2023	152.087	135.010	67.533	58.986	12.938	4.680	1.180

Figure 2.12 shows that the catch per unit of effort (CPUE) for BTS+COAST is highest for ages 1-4. BTS+COAST covers a large part of the North Sea with most turbot being caught in the southern and eastern regions. The estimated abundance at age for BTS+COAST is shown in Figure 2.13.

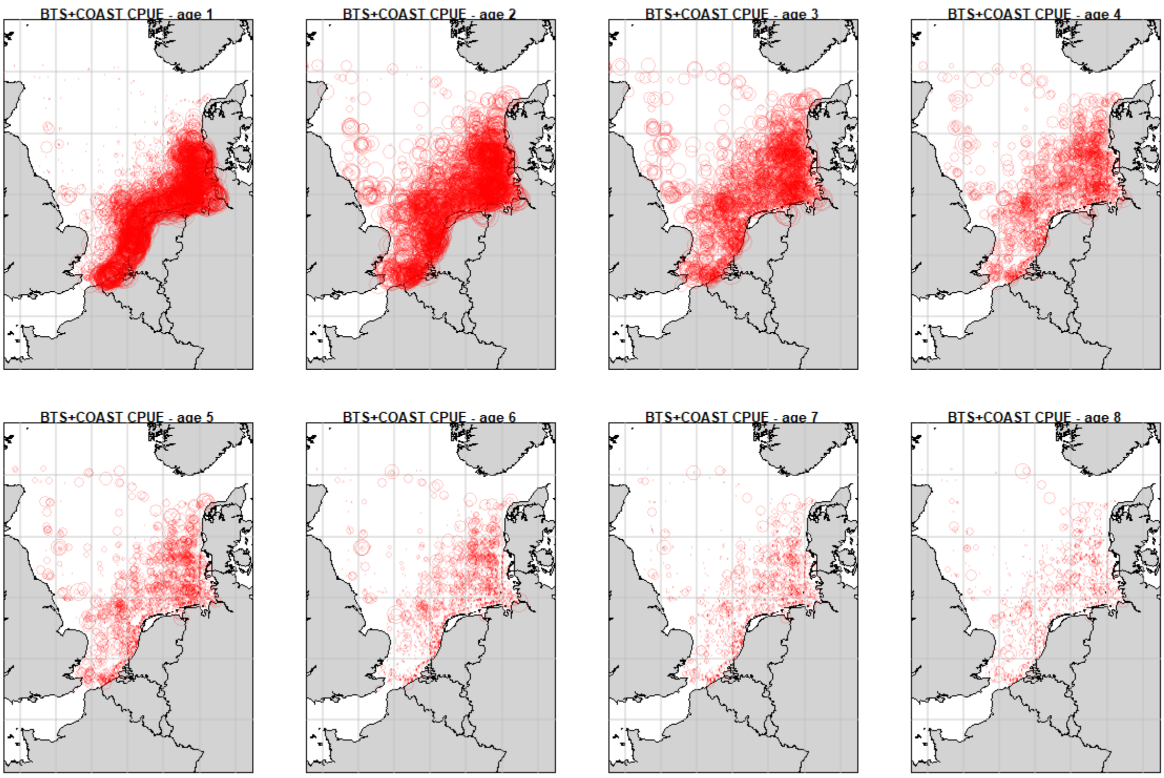

Figure 2.12. Catch per unit effort in the BTS+COAST index from 1991-2023.

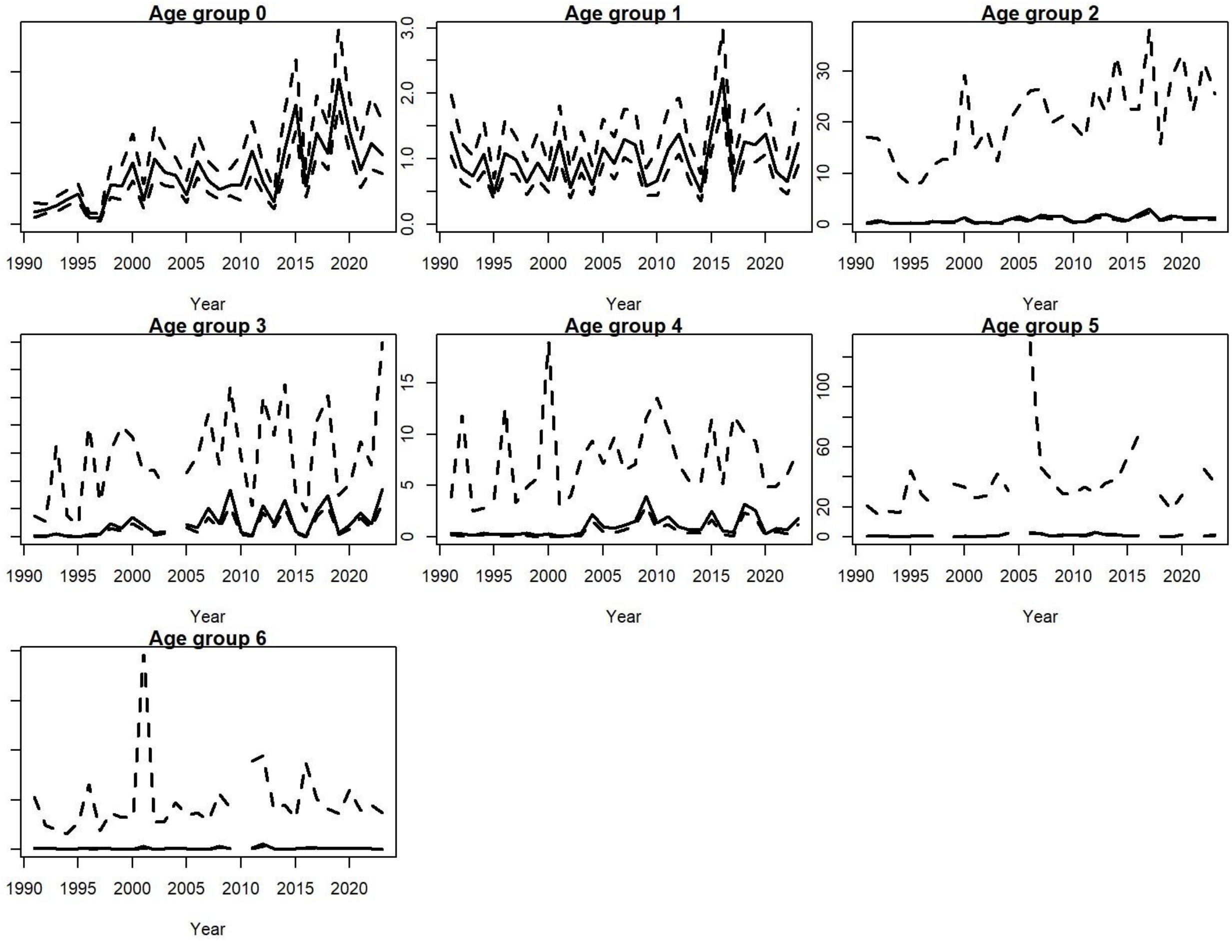

Figure 2.13. Relative abundances at age from the index of abundance based on the BTS survey, showing the estimated value and credibility intervals. Note here age group 0 corresponds to age 1 and so on. The final age is a plus group.

2.5.2.2 Commercial survey index: Industry survey for turbot and brill (BSAS)

The benchmark group eventually decided that with the inclusion of BSAS, the assessment no longer had the need for the commercial LPUE index. Concerns for double counting of abundance information and overweighting of the LPUE index have been a concern since the previous inter-benchmark for North Sea turbot in 2018. In its place, the BSAS index which is derived from a survey conducted by commercial beam trawlers, has been a significant upgrade with its ability to provide age-disaggregated information on turbot and brill in the North Sea. Additionally, the higher catchability for older aged turbot in the BSAS survey compared to the BTS and SNS scientific surveys (previously the only surveys used in the turbot assessment) provides more confidence in evaluating population dynamics of intermediate to older aged fish (Figure 2.14).

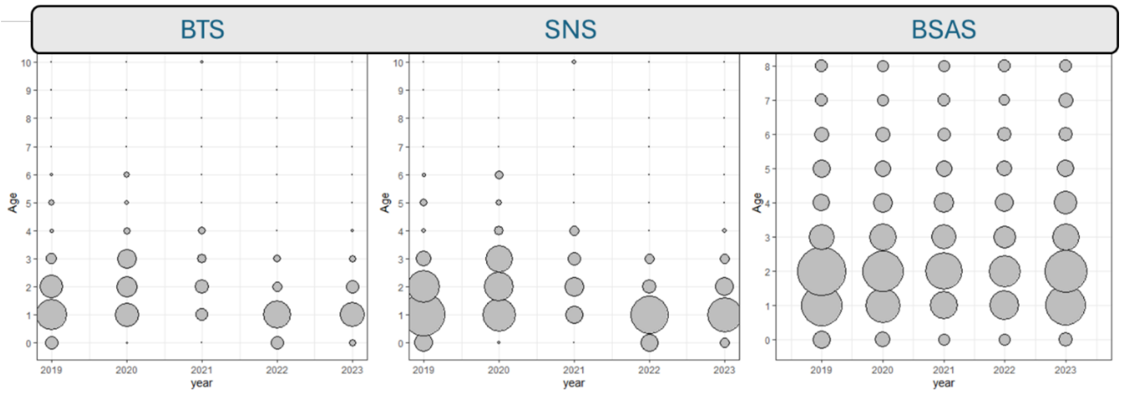

Figure 2.14. Catch per unit effort (CPUE) at-age comparison between the BTS, SNS, and BSAS surveys from 2019 – 2023.

Due to the short timeframe, we cannot yet provide a full age correlation diagram for all ages used in BSAS (age 1 to the plus group at age 8). However, other age correlations linking to ages 3-4, the cohort tracking for older ages in particular appears to be significantly improved (Figure 2.15) compared to the indices derived from the scientific surveys (Figure 2.11; Table 2.6). Ages 3-4 in the current BSAS index are linked with exceptionally low recruitment years, potentially disrupting the correlations linking with these age classes.

Figure 2.15. Age correlation plots for the new Tweedie BSAS index showing correlations between ages 1-4 (left), 3-7 (middle), and 5-8 (right).

Table 2.6. Age-structured index for BSAS used in the turbot assessment

Year	1	2	3	4	5	6	7	8
2019	24865.374	14640.708	4869.150	858.393	2387.064	626.381	253.884	177.809
2020	9689.555	12531.767	5301.699	1392.035	461.626	996.085	79.564	46.599
2021	8284.124	8912.598	4471.756	1919.434	673.079	100.458	289.901	103.646
2022	7047.044	5139.984	3420.717	985.046	625.940	160.435	13.560	341.134
2023	14619.362	9260.831	2384.728	1928.701	639.174	320.705	60.386	26.950

Figure 2.16 shows that the catch per unit effort (CPUE) for BSAS is highest for ages 1-4. BSAS covers an important area for turbot in the south and central North Sea, but its areas is more limited compared to the BTS+COAST index. The index model fit to observations shows much tighter confidence bounds compared to BTS+COAST, particularly at older age groups (Figure 2.17).

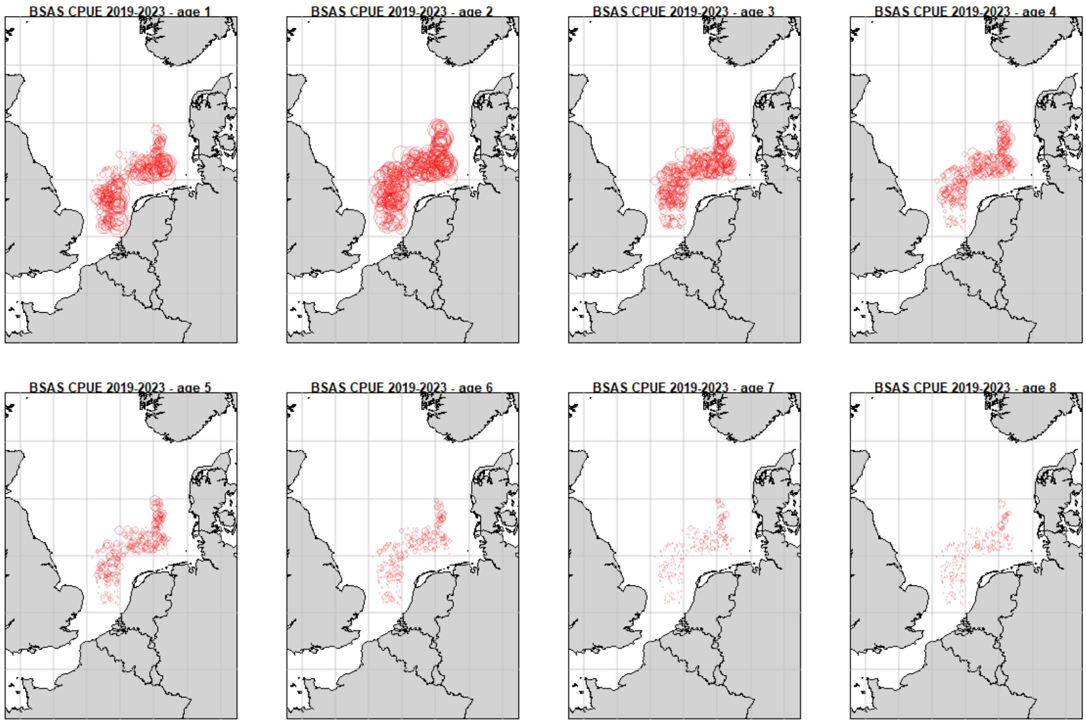

Figure 2.16. Catch per unit effort in the BSAS index from 2019-2023.

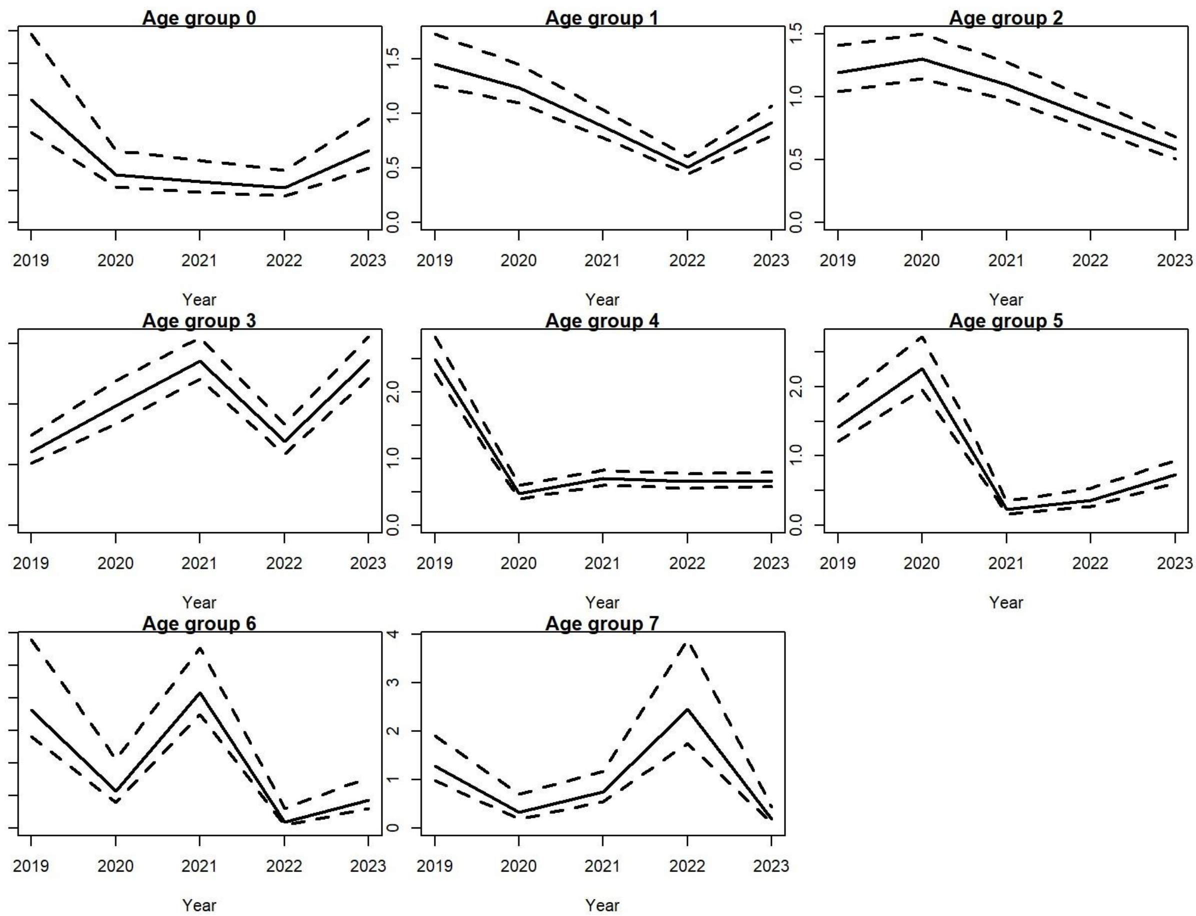

Figure 2.17. Relative abundances at age from the index of abundance based on the BSAS survey, showing the estimated value and credibility intervals. Note, here age group 0 corresponds to age 1 and so on. The final age is a plus group.

Both BTS+COAST and BSAS are generally in agreement when comparing trends between age groups (Figure 2.18). The largest disparity between surveys appears to occur in age 7, for which the confidence in the BTS+COAST index is quite low, and age 3 in 2013 where BSAS suggests a much lower relative abundance than BTS+COAST.

Figure 2.18. Turbot in Subarea 4. Standardized relative biomass from the two indices of abundance.

2.6 Assessment method

2.6.1 Benchmark model runs

During the 2025 ICES benchmark for the turbot 27.4 assessment, 20 model configurations were tested (Table 2.7). The base case model was the SAM assessment model used in WGNSSK 2024. A revised maturity ogive was evaluated, showing minimal differences from the base case. However, since it was derived from a larger and more recent dataset (quarter 2), the updated ogive was selected for further assessment runs.

Multiple assessment runs explored different methods for estimating weights-at-age for catch and stock weights. For the Gausian Markov Random Field (GMRF) based internal SAM weight-at-age estimation, concerns arose regarding certain years where newly added weight-at-age data led to inconsistencies, particularly in the plus group. This issue was less pronounced in models using time-varying von Bertalanffy growth curves, which provided a smoother trend across years, mitigating abrupt deviations in the dataset. After further evaluation, the newly added weight-at-age data for 2003 for ages 8 and up (derived from Dutch beam trawlers) was excluded due to unrealistically low weight-at-age estimates.

Due to some issues arising from the implementation of the GMRF-based weight at age estimation, testing of different survey configurations proceeded using the time-varying von Bertalanffy methods using 15 knots (the previous assessment used 5 knots). Upon reviewing model diagnostic plots and (potential) residual patterns, it was decided to use the combined coastal (COAST = SNS+DYFS) and offshore (BTS) scientific surveys, creating the BTS+COAST index, and to keep the BSAS survey index as a separate index. All potential index combinations were run with and with and without the Dutch LPUE index.

Table 2.7. Description of model runs trialed for North Sea turbot.

No	Name	Change from base case
0	Base case (old assessment)	-
1	Maturity	New maturity ogive
2a	Stock weights knots	New maturity ogive + new stock weights with 10 knots
2b	Stock weights rolling	New maturity ogive + new stock weights with rolling average
2c	Stock weights model	New maturity ogive + new stock weights (GMRF method)
2d	Stock weights model 2	New maturity ogive + new stock weights (GMRF; one point removed, 2003 age 8)
2e	Stock weights model 3	New maturity ogive + new stock weights (GMRF, remove year 2003)
3a	Separate surveys no LPUE	New maturity ogive + new stock weights (15 knot spline) + BTS + BSAS + COAST
3b	Separate surveys LPUE	New maturity ogive + new stock weights (15 knot spline) + BTS + BSAS + COAST + LPUE
3c	Separate surveys-spline no LPUE	New maturity ogive + new stock weights (15 knot spline) + BTS + BSAS+ COAST
3d	Separate surveys-spline LPUE	New maturity ogive + new stock weights (15 knot spline) + BTS + BSAS+ COAST + LPUE
4a	BTS + BSAS combined no LPUE	New maturity ogive + new stock weights (15 knot spline) + (BTS + BSAS) + COAST
4b	BTS + BSAS combined LPUE	New maturity ogive + new stock weights (15 knot spline) + (BTS + BSAS) + COAST + LPUE
5	All surveys combined	New maturity ogive + new stock weights (15 knot spline) + (BTS + BSAS + COAST)
6a	BSAS separate-spline no LPUE	New maturity ogive + new stock weights (15 knot spline) + (BTS + COAST) + BSAS
6b	BSAS separate-spline LPUE	New maturity ogive + new stock weights (15 knot spline) + (BTS + COAST) + BSAS + LPUE
7a	BSAS separate-no LPUE-GMRF	New maturity ogive + modelled weights (GMRF method) + (BTS + COAST) + BSAS
7b	BSAS separate-no LPUE-GMRF_new pars	New maturity ogive + modelled weights (GMRF method) + (BTS + COAST) + BSAS, updated parameters (coupled more ages)
8	Lorenzen's M	New maturity ogive + modelled weights (GMRF method) +(BTS + COAST) + BSAS + Lorenzen's M (age varying natural mortality)
9*	**Fixed Lorenzen's M**	**New maturity ogive + modelled weights (GMRF method) + (BTS + COAST) + BSAS + Fixed Lorenzen's M**

*Final benchmark model

After deciding to use an index configuration that combined scientific surveys (BTS+COAST) with BSAS as a separate commercial index, model diagnostic plots were examined to determine whether LPUE should be included or excluded. One-step-ahead residual plots revealed distinct observation residual patterns at older ages in recent years when LPUE was included in the assessment runs (Figure 2.19). In particular, catch residuals and BTS+COAST observation errors overestimate much of the observations for older ages in the most recent years (Figure 2.19). Although less obvious, the process errors for the model with the LPUE index also shows patterns with larger negative residuals for older ages in recent years (Figure 2.20). Omitting the LPUE index seems to mitigate these issues providing more balanced process and observation errors (Figures 2.21 and 2.22). These patterns, along with concerns about potential double-counting of abundance information, led to the decision to exclude LPUE from further assessment runs and retain BSAS as a separate index.

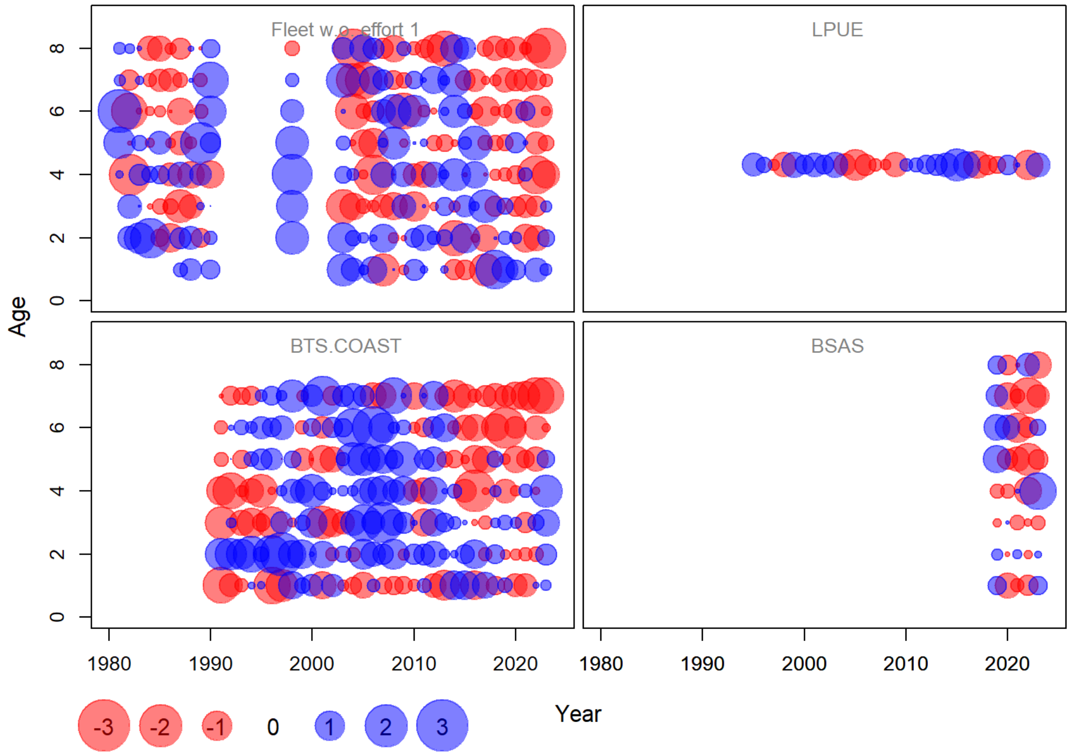

Figure 2.19. Observation errors from model 6b (last model with LPUE).

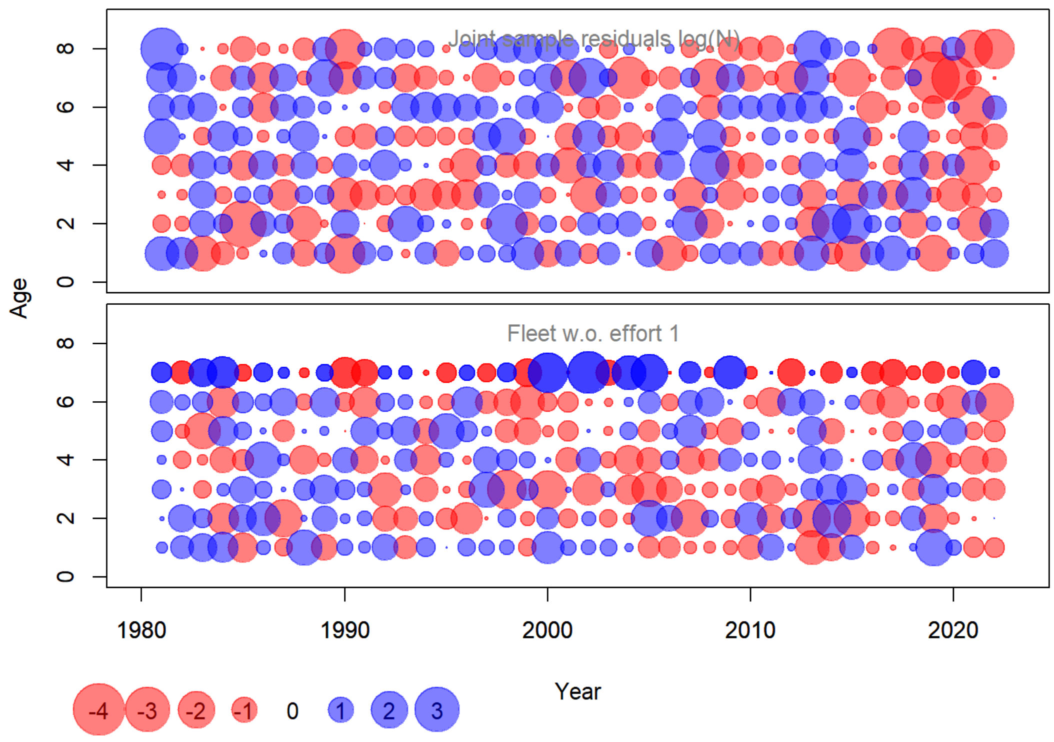

Figure 2.20. Process errors from model 6b (last model with LPUE).

Figure 2.21. Observation errors from model 6a (no LPUE) to compare with model 6b.

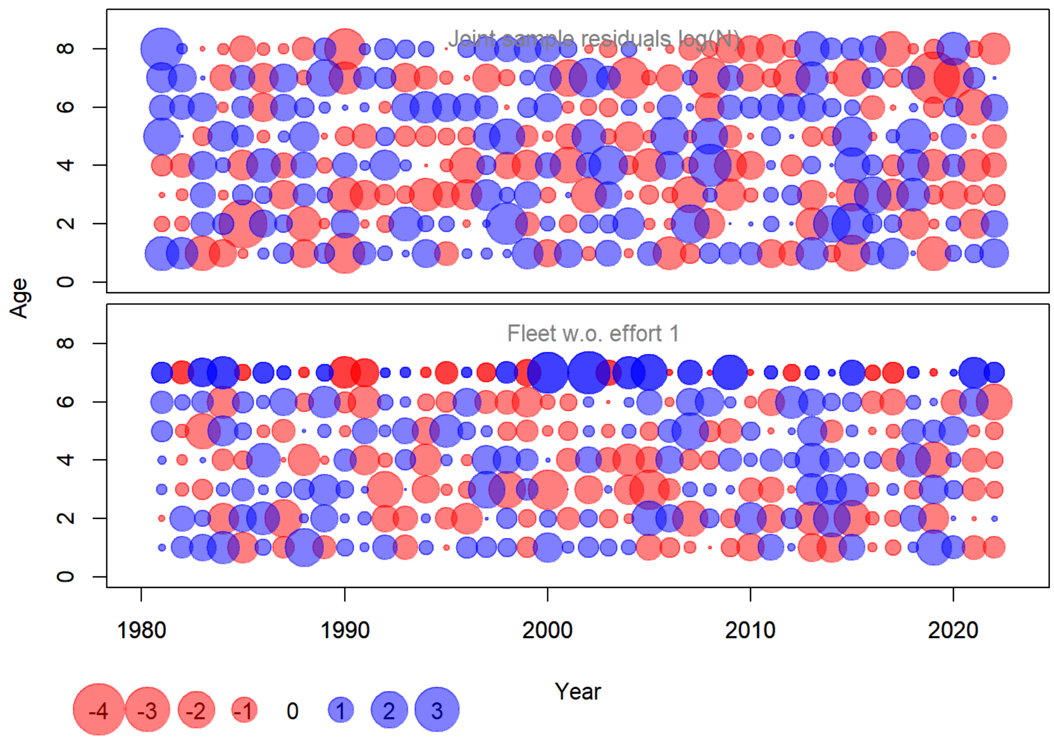

Figure 2.22. Process errors from model 6a (no LPUE) to compare with model 6b.

Upon dropping the commercial LPUE index, we were able to successfully implement the Gaussian Markov Random Field (GMRF) approach for calculating stock and catch weights-at-age internally in SAM and proceeded to use this method (model 7a). Parameters were then adjusted and additional ages were coupled to reduce the number of parameters in the model which were deemed excessive (model 7b).

Until this point, the previous natural mortality vector had been used which featured a constant 0.2 value for all ages. For model 8, this was replaced with an age varying natural mortality vector derived from a weight-based approach similar to the methods seen in Lorenzen (1996; Figure 2.9). Initially, weights-at-age were determined using von Bertanlanffy modelled weights per age group. However, this resulted in convergence issues, and it was decided that taking the mean weights for each age provided a more realistic natural mortality at age estimate, with lower natural mortality at ages 1 and 2. This new natural mortality estimate was included in the final benchmark model (9 “Fixed Lorenzen's M”; Table 2.7).

Figure 2.23 provides a comparison of fishing pressure recruitment and SSB from 1) the latest model trialed that featured the LPUE index (6b); 2) the corresponding model with dropping the LPUE (6a); and the final assessment model (9) which features updated, parameters, age varying natural mortality, and weights at age estimated though the GMRF approach (Figure 2.23). Dropping the LPUE index resulted in a considerable increase of Fbar in the most recent decade (Figure 2.23).

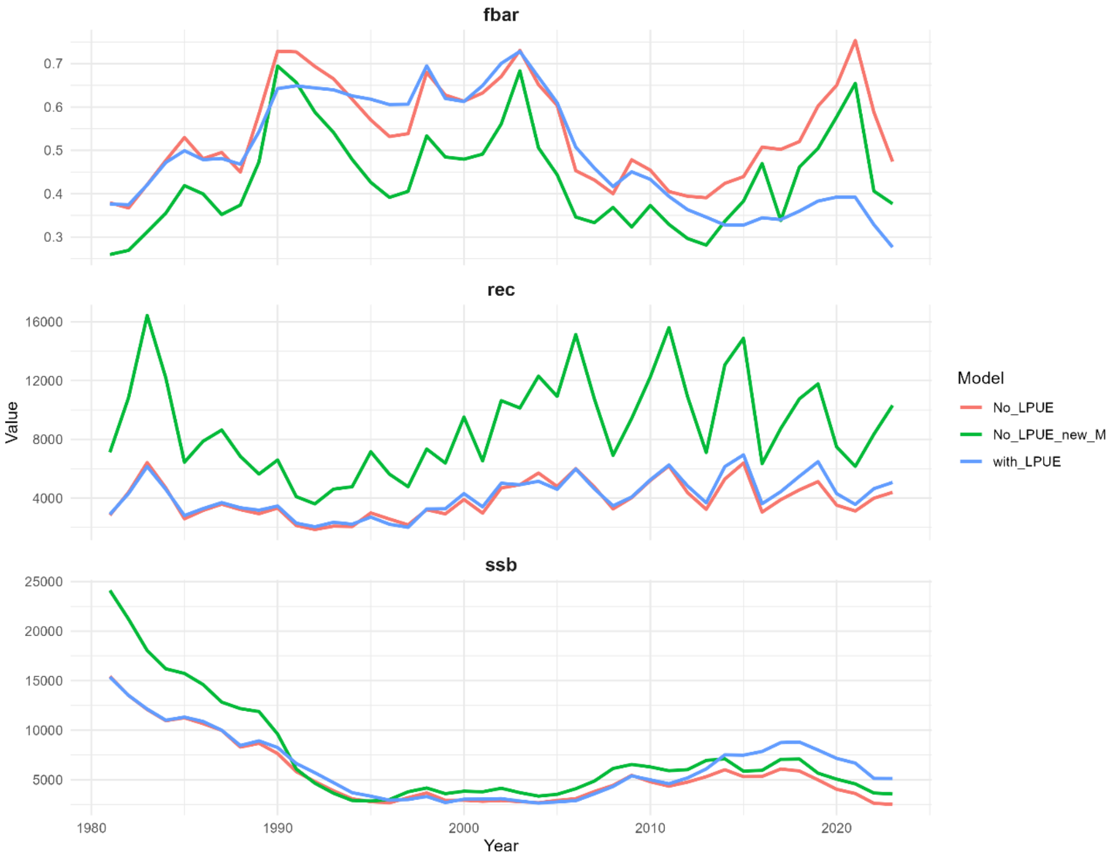

Figure 2.23. Comparison of fishing pressure (fbar), spawning stock biomass (ssb) and recruitment (rec) between models 6b (latest model with the LPUE index; “with_LPUE”), the corresponding model the LPUE removed (model 6a; “No_LPUE”), and the final benchmark model used which features age-varying natural mortality and also omits the LPUE index (model 9; “No_LPUE_new_M”).

2.6.2 Final model run

The benchmark model continues to use the same state-space stock assessment model (SAM) as in the previous assessment. However, the new model configuration incorporates updated vectors for maturity, natural mortality, and revised survey indices. A key change is the transition from separate CPUE indices for BTS-ISIS and SNS to a Delta-GAM index that combines all North Sea BTS surveys with the SNS and DYFS coastal surveys (BTS+COAST). The updated stock assessment remains a landings only assessment due to low discard rates and insufficient discard sampling information.

One of the most significant changes in the new assessment is the exclusion of the LPUE index. While this index was necessary in the previous assessment due to the low quality of available survey indices, its continued use posed issues related to double-counting. Additionally, LPUE was believed to have an unrealistically high influence on the assessment due to its low observation variances (a byproduct of double counting; Figure 2.24) and contributed to residual patterns seen in the observation errors (Figure 2.19).

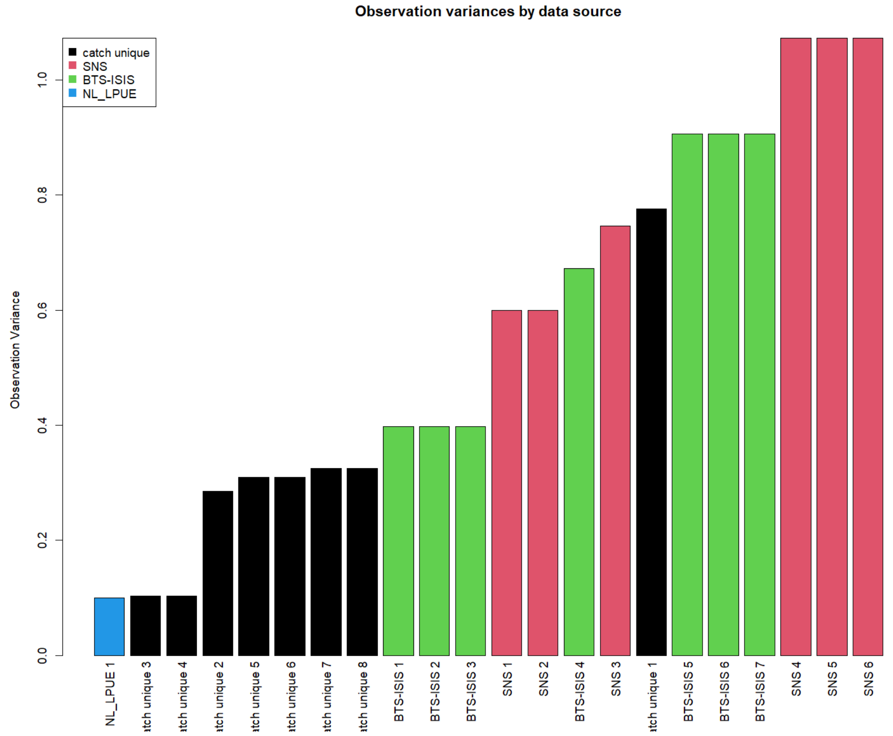

Figure 2.24. Observation variances by data sources in the previous North Sea turbot stock assessment model (WGNSSK 2024). The lower the variance, the higher its weight in the assessment.

The updated assessment benefits from improved model-derived indices and the inclusion of the Dutch commercial industry survey (BSAS), which was specifically designed to address the catchability challenges that have historically complicated the turbot stock assessment (Figure 2.25).

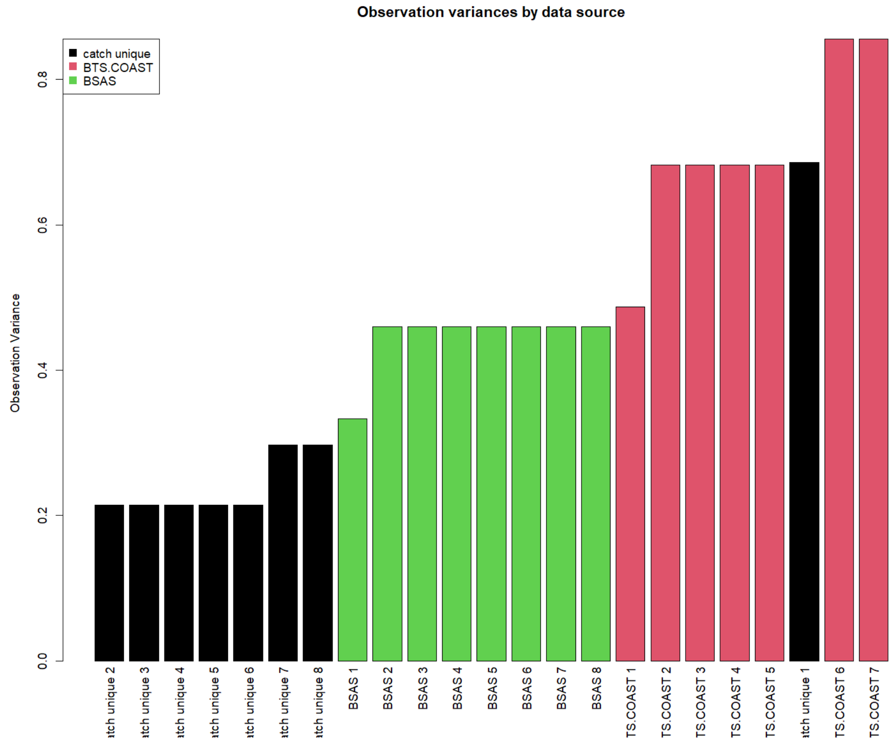

Figure 2.25. Observation variances by data sources in the new North Sea turbot stock assessment model (WKBNSCS 2025). The lower the variance, the higher its weight in the assessment.

Recruitment in the new assessment is notably higher compared to the previous assessment model, driven by the updated age-varying natural mortality (M) vector, which assumes a more realistic, higher M for younger individuals. To compensate for the elevated mortality in early life stages, the model increases total recruitment so that abundance estimates remain consistent with observed data (Figure 2.26 and 2.23).

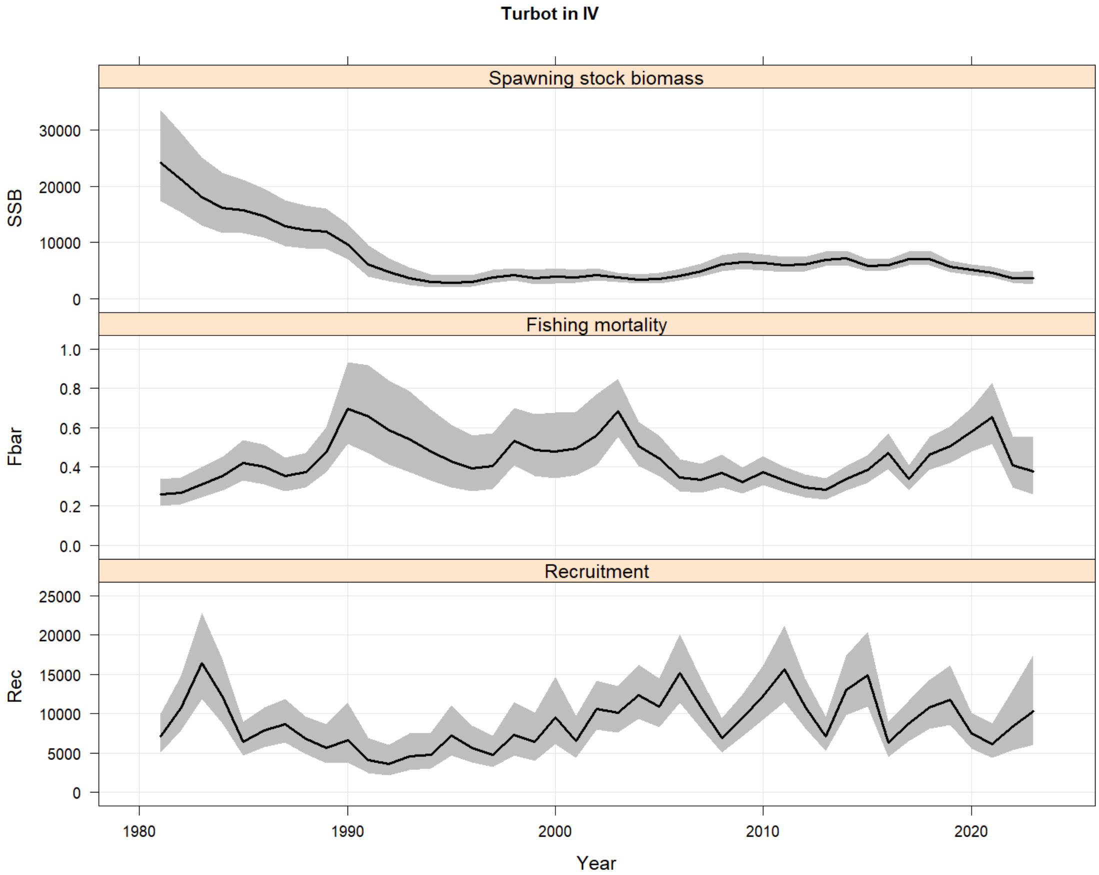

Figure 2.26. Summary of the North Sea turbot stock assessment.

The updated assessment indicates a higher perception of fishing pressure compared to the previous assessment, with a notable spike in 2021 before declining (Figure 2.27). Concurrently, the new model estimates a lower SSB, primarily due to reduced estimates of older individuals. In the previous model, low catchability for older fish in both surveys and catches—combined with a constant natural mortality vector—suggested that many older turbot avoided capture and thus survived in greater numbers, despite these individuals not being observed in surveys and commercial catches (Figure 2.28).

In contrast, the new assessment incorporates updated survey indices, the removal of the LPUE index, and an age-varying natural mortality vector. Together, these factors lead to a revised perception of the stock, particularly regarding older fish. Data from the BSAS survey, which exhibits higher catchability for older turbot, indicates that older fish may not have been as abundant as previously assumed under the old assessment (Figure 2.28).

Due to the higher natural mortality estimate, SSB at the start of the time series is estimated to be higher than in the previous model as the new model has to compensate to fit observations from catches (Figure 2.27 and 2.23). The period from 1981 – 1990 is characterized by an absence of survey data when the only information available is from commercial catch data.

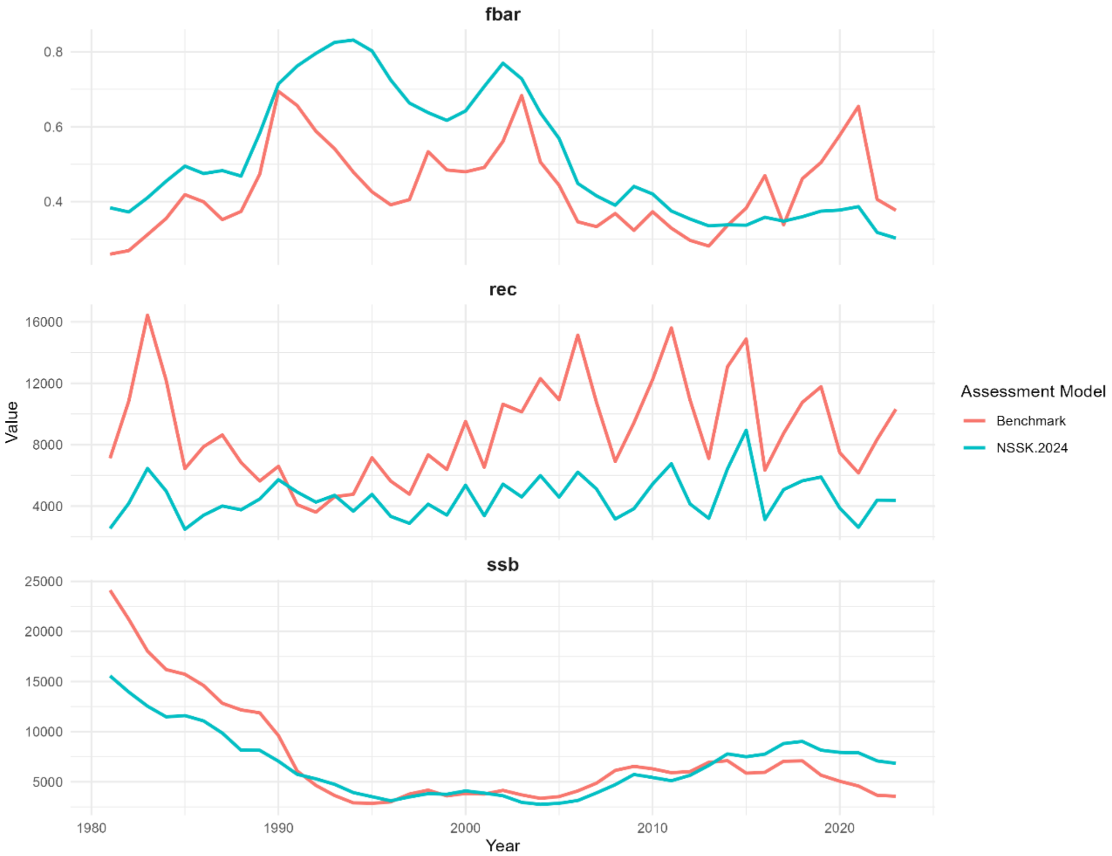

Figure 2.27. Comparison of F between the previous assessment (WGNSSK 2024) and the updated benchmark assessment for the North Sea turbot.

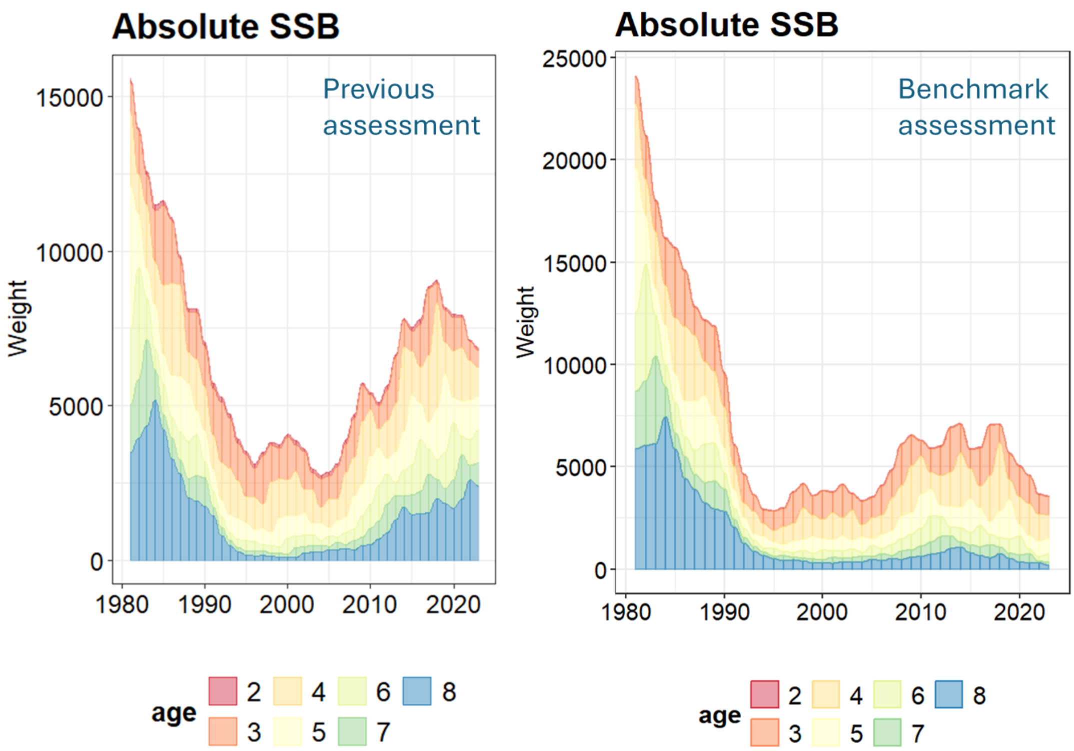

Figure 2.28. Distribution of biomass-at-age in the previous assessment (left) and updated turbot assessment (right).

2.6.2.1 Data input

While information on catch numbers and weights at age for North Sea turbot is available from 1975 onwards, data before 1981 is derived from only German sampling data which only reflected a minor proportion of total catches (ICES, 2017). The assessment begins in 1981 where fleet-based catch-at-age information is available from Dutch fisheries which is thought to be more representative of the North Sea turbot stock (Boon and Delbare, 2000; Figure 2.29). Stock weights-at-age are derived from quarter 2 catch data during the peak spawning period.

The BTS survey contains reliable age-based information from 1991 onwards when size based ALKs became standard. The SNS and DYFS coastal surveys contribute information from 2004 and 2003 onwards when yearly ALKs became available. The aforementioned surveys are not combined via Delta-GAM into a comprehensive index (BTS+COAST) of turbot in Subarea 4 derived from scientific beam trawl surveys. The Dutch industry survey for turbot and brill in the North Sea (BSAS) is a relatively new scientifically designed survey carried out by commercial trawlers which after its pilot year in 2018, now officially contributes data for the North Sea turbot from 2019 onwards. At the moment, the 5 years of data contributed from BSAS limits its influence on the stock assessment model. However, in the coming years, BSAS is believed to provide some of the most relevant data informing the turbot stock assessment due to its high catchability of turbot and brill. Data from BSAS is standardized via a Tweedie GAM model.

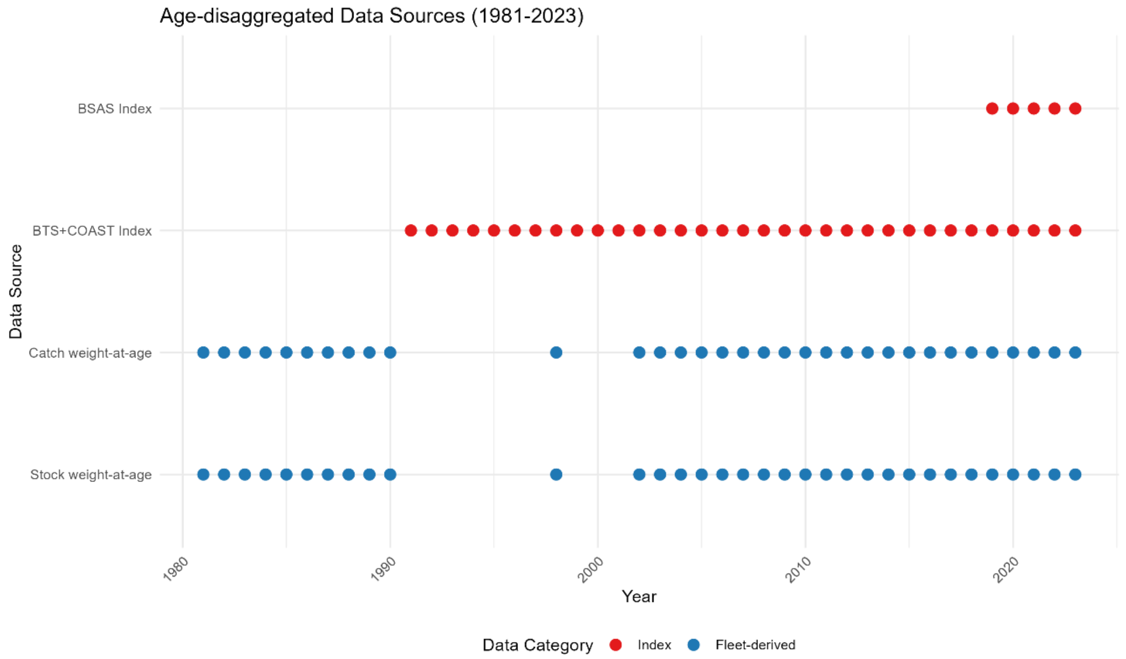

Figure 2.29. Data sources in the turbot assessment where age information is available. Weight-at-age data is modelled internally in SAM to smooth over the years with missing data.

2.6.2.2 Model diagnostics

One-step ahead residuals

Residual plots show generally balanced error distributions for both observation and process errors (Figures 2.30 and 2.31). While in some periods, such as the 1998 catch residuals still show a tendency towards underestimation of abundance for several age groups, the observation residual patterns are much improved compared to model runs including the commercial LPUE (Figure 2.29). The BSAS index currently shows more negative residuals for the five years of data it contribute to the assessment, however, it is difficult to draw strong conclusions with the limited time-series of that index.

Compared to the observation errors, the process errors appear more randomly distributed across years and ages. The one-step-ahead residuals for process errors show no pronounced clustering or trends suggesting that with that the model’s process component adequately represents real population changes (e.g., recruitment, growth, and mortality). Overall, both sets of residuals—process and observation—were reviewed and accepted by the benchmark group.

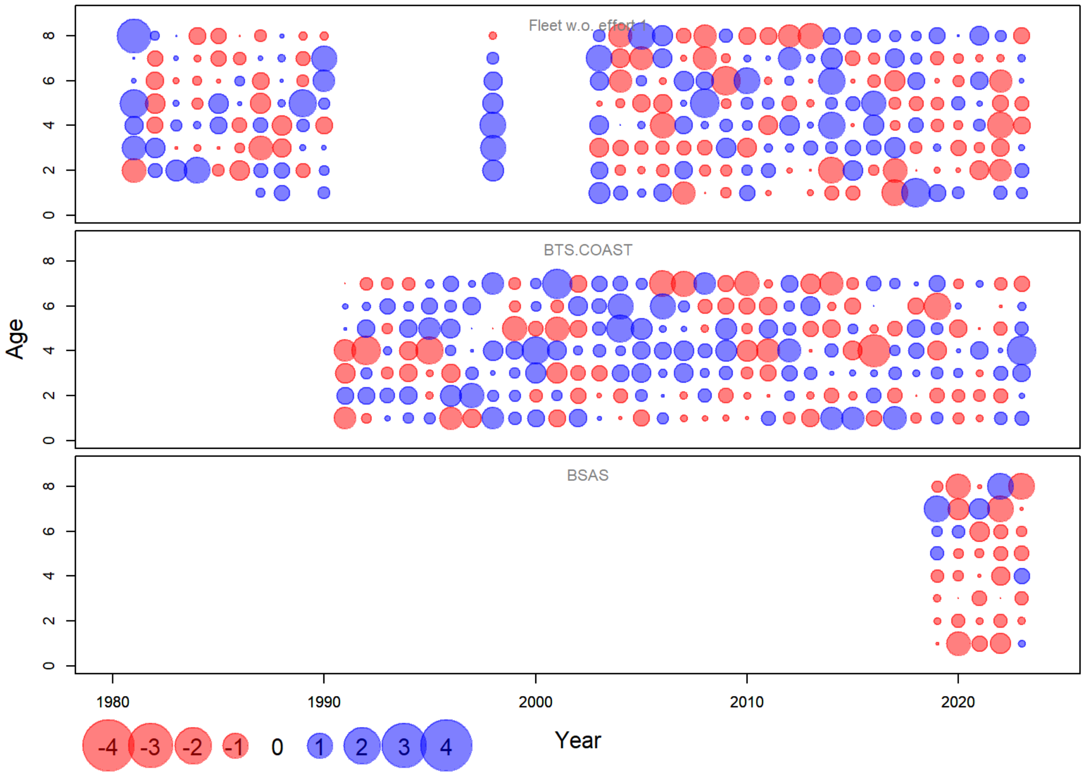

Figure 2.30. Observation errors from the final benchmark model.

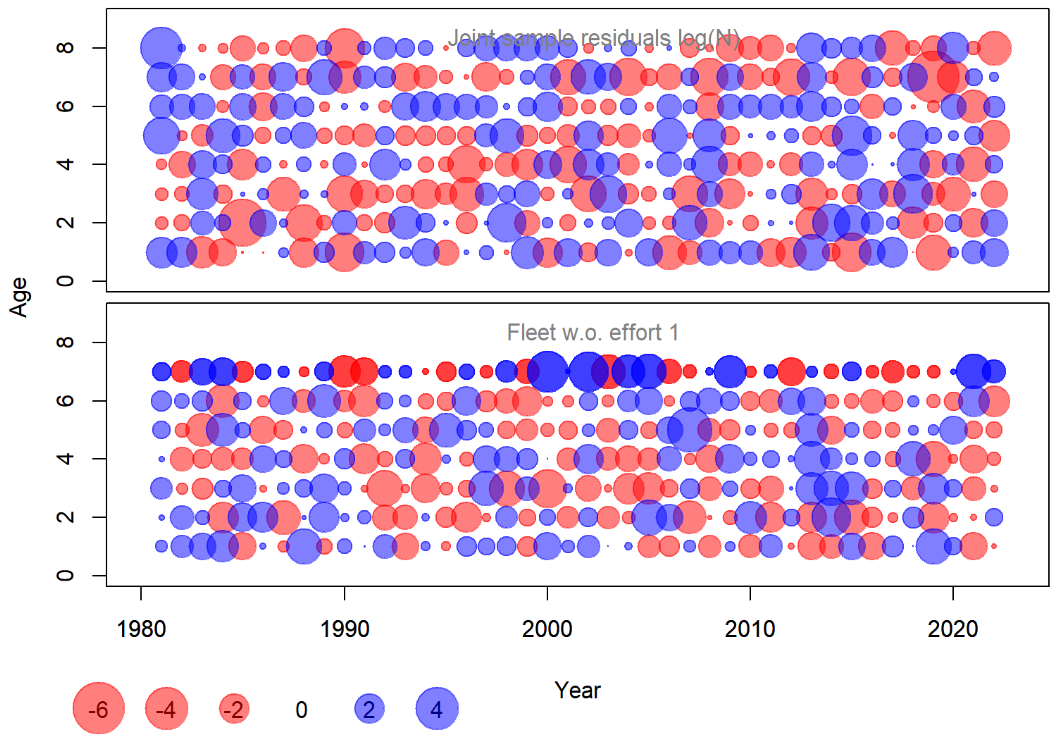

Figure 2.31. Process errors from the final benchmark model.

Model Fit

The updated stock assessment model features better fits the catch data compared to the survey indices (Figures 2.32 – 2.34 and 2.25). This was also apparent in the previous stock assessment model with the exception to the fit to the LPUE index which was believed to be high due to double counting (Figure 2.24). With the exclusion of the LPUE index, the updated stock assessment has commercial catches as the highest weighted data source.

Figures 2.25 and 2.32 show that the observation variances are highest with age 1 catches followed by the plus group (8+). This likely represents the lower commercial fleet catchability for age classes representing younger or older aged turbot. It is believed that older and larger turbot, which are generally caught as bycatch, are fast enough to outswim beam trawlers targeting plaice or sole while younger turbot are generally allocated in shallow areas and are also not desirable for fishers.

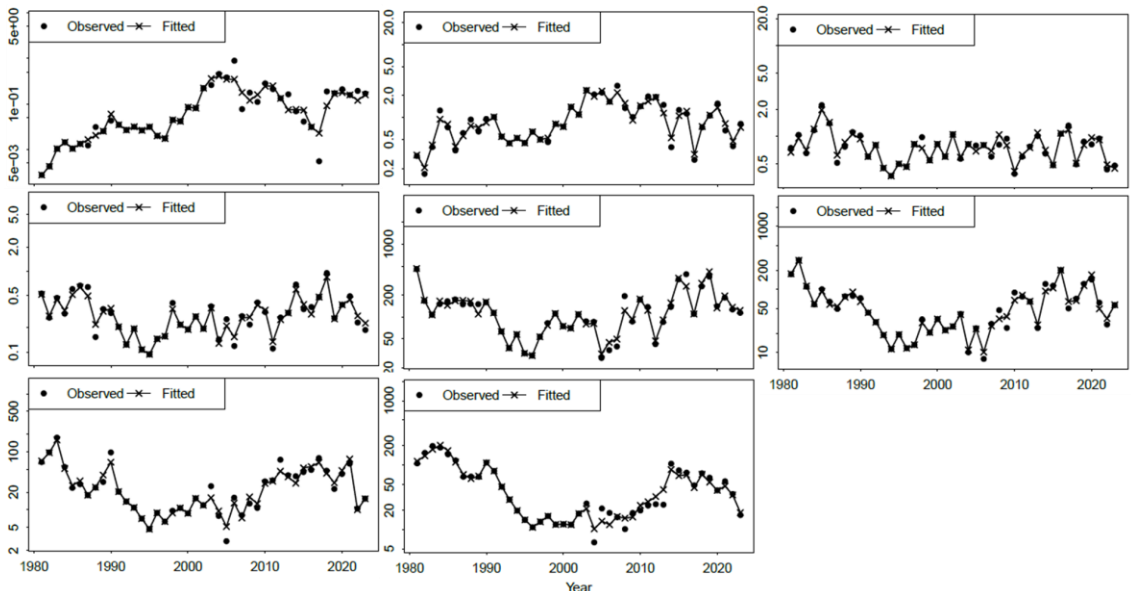

Figure 2.32. Model fit to catches for the North Sea turbot assessment.

While cohort tracking is improved in new combined BTS+COAST index compared to the BTS-ISIS and SNS indices featured in the previous stock assessment, BTS+COAST remains (with the exception of age 1 catches) the lowest weighted data source in the updated assessment due to its generally high observation variances (Figures 2.33 and 2.25). Similar to the fits to the catch and BSAS data sources, the BTS+COAST features increasing observation variances with age. This dynamic reflects the lower catchabilities for both survey and fleet for the oldest age classes. However, the fit to age 1 individuals is improved compared to age 1 in the commercial catches (Figures 2.32, 2.33 and 2.25).

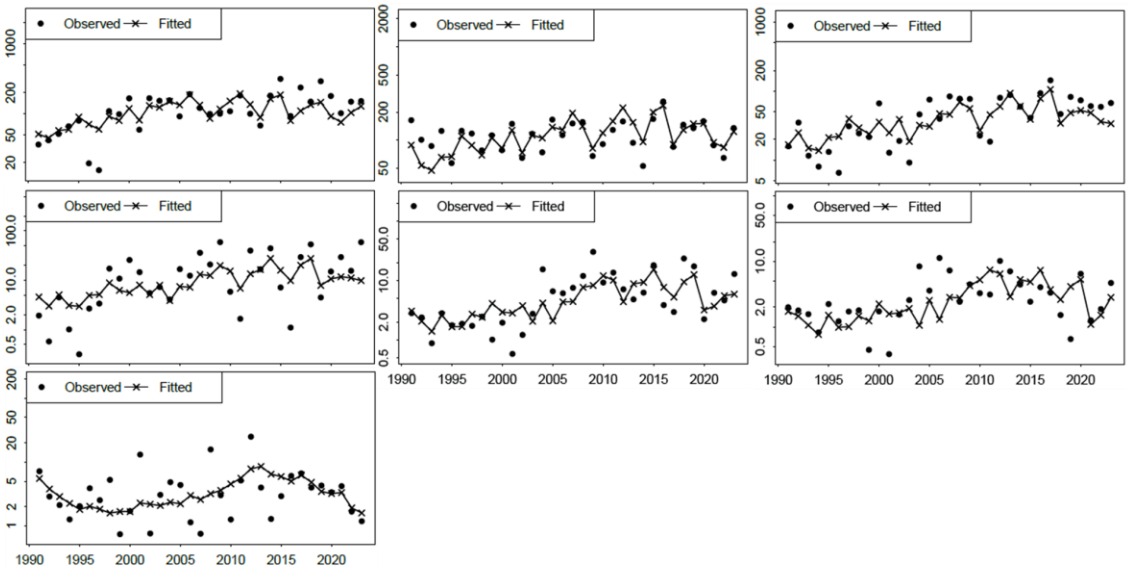

Figure 2.33. Model fit to the BTS+COAST index for the North Sea turbot assessment.

Although the BSAS index covers a limited time frame (5 years), all its age classes receive greater weight in the assessment compared to BTS+COAST due to their lower observation variances (Figures 2.34 and 2.25). The decoupling of age 1 from the other age classes is evident, as it exhibits comparatively low observation variance (Figure 2.25). The plus group (8+) remains the poorest-fitting age class, with the model underestimating observations in 2022 and overestimating those in 2023 (Figure 2.34).

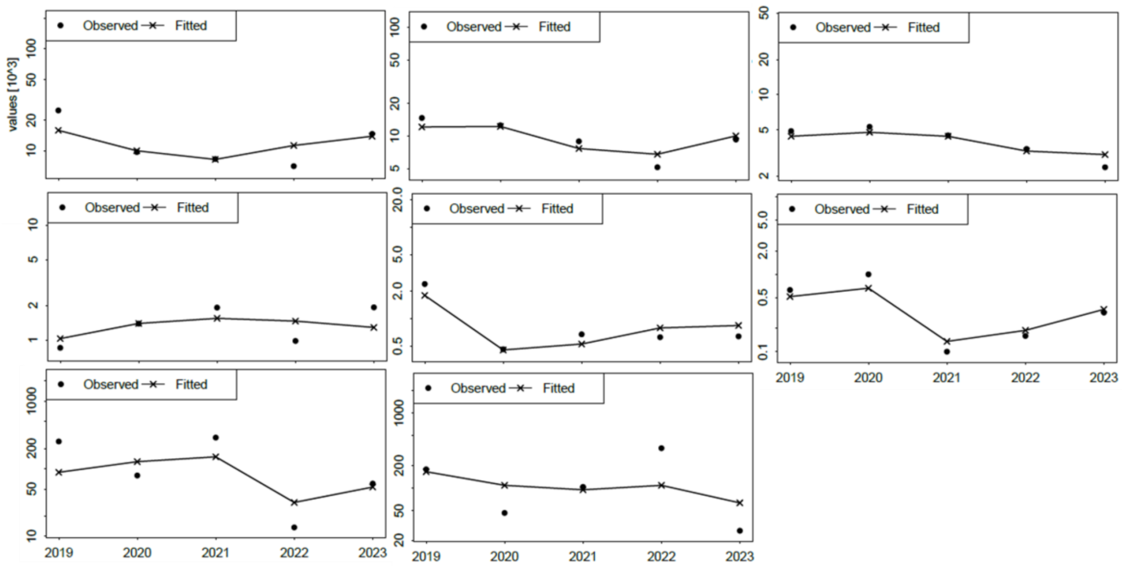

Figure 2.34. Model fit to the BSAS index for the North Sea turbot assessment.

2.6.2.3 Retrospective analysis

The retrospective analysis for the North Sea turbot assessment faced some challenges due to the limited five-year time series of the BSAS survey index. To address this, the benchmark group agreed to use a three-year retrospective analysis and Mohn's Rho calculation, ensuring a more appropriate evaluation given the restricted data availability from BSAS. The resulting Mohn's Rho values fall within ICES acceptable ranges for SSB (0.16) and Fbar (-0.12). As the BSAS index continues to accumulate data, these retrospective issues are expected to resolve naturally (Figure 2.35). At the moment, given its short time series of BSAS, a five year retrospective analysis and

Mohn's Rho values are not considered the most reliable metric for evaluating the turbot assessment.

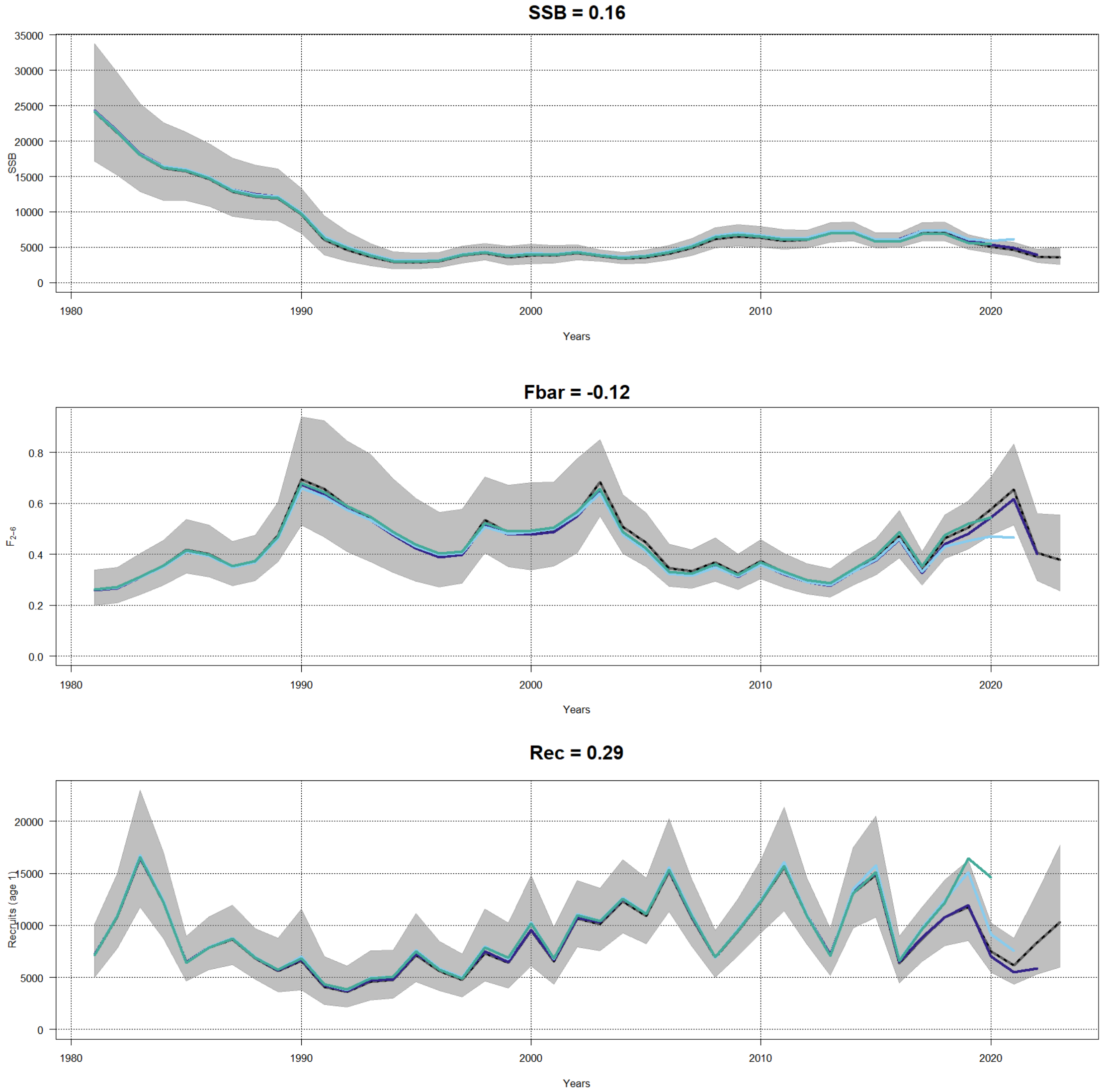

Figure 2.35. Retrospective analysis for North Sea turbot.

2.6.2.4 Model parameters

Table 2.8 is from the model.cfg file from SAM which details the final parameters set in the updated stock assessment model for North Sea turbot.

Table 2.8. The SAM configuration file for the North Sea turbot stock assessment.

$minAge
The minimium age class in the assessment
1
$maxAge
The maximum age class in the assessment
8
$maxAgePlusGroup
Is last age group considered a plus group for each fleet (1 yes, or 0 no).
1 1 1
$keyLogFsta

```
# Coupling of the fishing mortality states processes for each age (normally only
# the first row (= fleet) is used).
# Sequential numbers indicate that the fishing mortality is estimated individually
# for those ages; if the same number is used for two or more ages, F is bound for
# those ages (assumed to be the same). Binding fully selected ages will result in a
# flat selection pattern for those ages.
  0  1  2  3  4  5  6  6
 -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: AR(1) first order autoregressive - similar ages are more highly correlated than
# ages that are further apart, so similar ages have similar F patterns over time.
# if the estimated correlation is high, then the F pattern over time for each age
# varies in a similar way. E.g if almost one, then they are parallel (like a
# separable model) and if almost zero then they are independent.
2
```

$keyLogFpar

```
# Coupling of the survey catchability parameters (normally first row is
# not used, as that is covered by fishing mortality).
 -1 -1 -1 -1 -1 -1 -1 -1
  0  1  2  3  4  5  5 -1
  6  7  8  9 10 11 12 12
```

$keyVarF

```
# Coupling of process variance parameters for log(F)-process (Fishing mortality
# normally applies to the first (fishing) fleet; therefore only first row is used)
  0  1  2  2  3  3  3  3
 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarLogN

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

$keyVarObs

```
# Coupling of the variance parameters for the observations.
# First row refers to the coupling of the variance parameters for the catch data
# Second and further rows refers to coupling of the variance parameters for the
  0  1  1  1  1  1  2  2
  3  4  4  4  4  5  5 -1
  6  7  7  7  7  7  7  7
```

$obsCorStruct

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

$keyCorObs

```
# Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#1-2 2-3 3-4 4-5 5-6 6-7 7-8
  NA  NA  NA  NA  NA  NA  NA
  0  0  0  0  0  0  0
```

```
 NA  NA  NA  NA  NA  NA  NA
$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk).
 0
$fbarRange
# lowest and higest age included in Fbar
 2 6
$fixVarToWeight
# If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight). Can be specified fleetwise.
 0 0 0
$fracMixF
# The fraction of t(3) distribution used in logF increment distribution
 0
$fracMixN
# The fraction of t(3) distribution used in logN increment distribution (for each age group)
 0 0 0 0 0 0 0 0
$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
$stockWeightModel
# Integer code describing the treatment of stock weights in the model (0 use as known, 1 use as observations to inform stock weight process (GMRF with cohort and within year correlations)), 2 to add extra correlation to plusgroup
 1
$keyStockWeightMean
# Coupling of stock-weight process mean parameters (not used if stockWeightModel==0)
 0 1 2 3 4 5 6 7
$keyStockWeightObsVar
# Coupling of stock-weight observation variance parameters (not used if stockWeightModel==0)
 0 0 0 0 0 0 0 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)), 2 to add extra correlation to plusgroup
 1
$keyCatchWeightMean
# Coupling of catch-weight process mean parameters (not used if catchWeightModel==0)
  0  1  2  3  4  5  6  7
$keyCatchWeightObsVar
# Coupling of catch-weight observation variance parameters (not used if catchWeightModel==0)
  0  0  0  0  0  0  0  0
```

2.7 Biological reference points

Upon reviewing the stock-recruitment relationship for North Sea turbot, the benchmark group agreed on a type 5 stock-recruitment dynamic (Figure 2.36). This relationship is characterized by no clear link between spawning stock biomass (SSB) and recruitment, with no evidence of impaired recruitment. Type 5 utilizes the $B_{empirical}$, where B_{lim} is calculated as the average of the three lowest SSB values that correspond to above-median recruitment.

There was some debate about whether a Type 2 relationship might be more appropriate, as a few data points in the stock-recruitment plot suggested lower recruitment at low SSB, potentially indicating impaired recruitment. However, these points originate from the early part of the time series when stock estimates were informed solely by catch data, making them less reliable indicators of true recruitment dynamics (Figure 2.36).

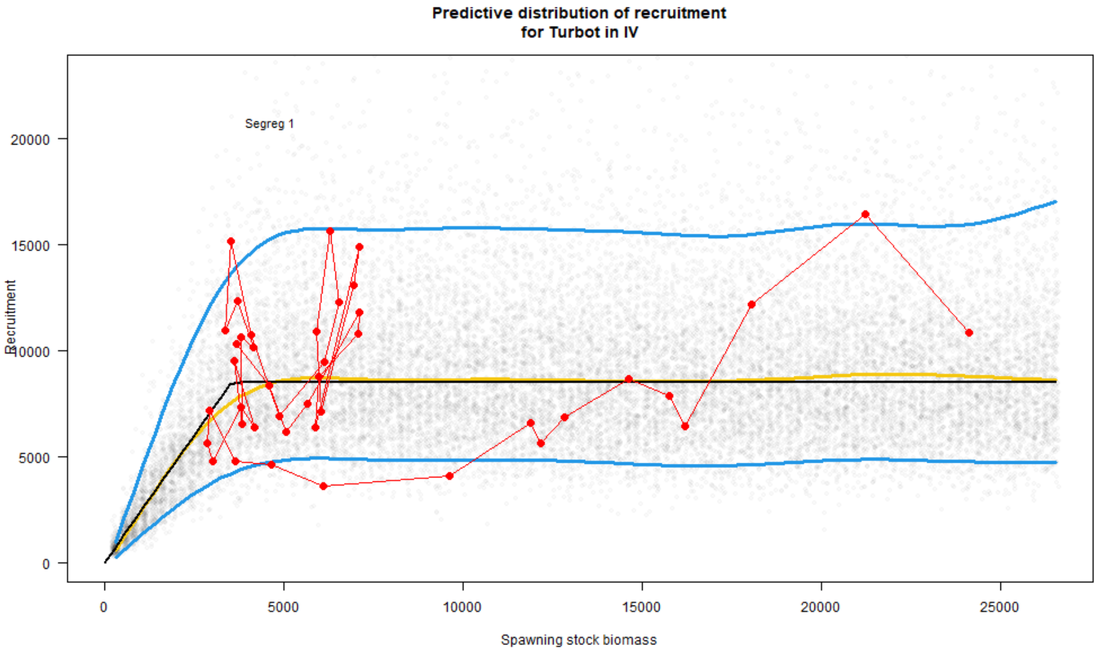

Figure 2.36. Stock recruitment relationship estimated by the SR models using a segmented regression.

Reference points were estimated using an R script developed by Iago Mosqueria and Ghassen Halouani which applies the Eqsim software following ICES guidelines for Category 1 stocks. Compared to the set of biological reference points for North Sea turbot established at the last inter-benchmark for turbot in 2018 (ICES, 2018; Table 2.9), the estimate for MSY $B_{trigger}$ is now been adjusted to align with B_{pa} reducing the previous value to 4837 t (Table 2.10). This change follows the ICES reference points decision tree, which specifies that MSY $B_{trigger}$ should be set to B_{pa} if the stock has been fished at above F_{MSY} in the 5 years prior. The revised B_{pa} and B_{lim} values are higher than previously established while F_{pa} and F_{lim} are lower. The updated reference point for F_{MSY} is slightly higher than the previous estimate at 0.39, while F_{MSY} upper is now set as equal to F_{pa} in accordance to ICES guidelines.

Table 2.9. Previous set of biological reference points for North Sea turbot

Reference point	Estimate
MSY $B_{trigger}$	6353
B_{pa}	4163
B_{lim}	2974
F_{pa}	0.43
F_{lim}	0.61
$F_{P.05}$	0.86
F_{MSY}	0.36

$F_{MSY\ lower}$	0.25
$F_{MSY\ upper}$	0.48

Table 2.10. Updated biological reference points for North Sea turbot.

Reference point	Estimate
MSY $B_{trigger}$	4837
B_{pa}	4837
B_{lim}	3481
F_{pa}	0.40
F_{lim}	0.48
$F_{P.05}$	0.40
F_{MSY}	0.39
$F_{MSY\ lower}$	0.27
$F_{MSY\ upper}$	0.40

2.8 Forecast settings

One of the, advantages for using the Gaussian Markov Random Field (GMRF) method for calculating weight-at-age data in stock assessments is its ability use projected data for forecasting. While in previous forecast methodology used stock and catch weights at age equal to those in the final assessment year, the updated assessment uses projected weights estimated through the GMRF approach where stock and catch weights drift towards the long-term mean in future projections (Figures 2.37 and 2.38).

The projected fishing pressure-at-age uses the average fishing pressure over the previous 5 years (Figure 2.39). Since there is no clear relationship between SSB and Rec, it was decided to assume recruitment to follow a geometric mean for the entire time-series, including the latest estimate (Figure 2.26). A hypothetical forecast table, illustrating the application of the benchmark model in the 2024 stock assessment, is provided in Table 2.11.

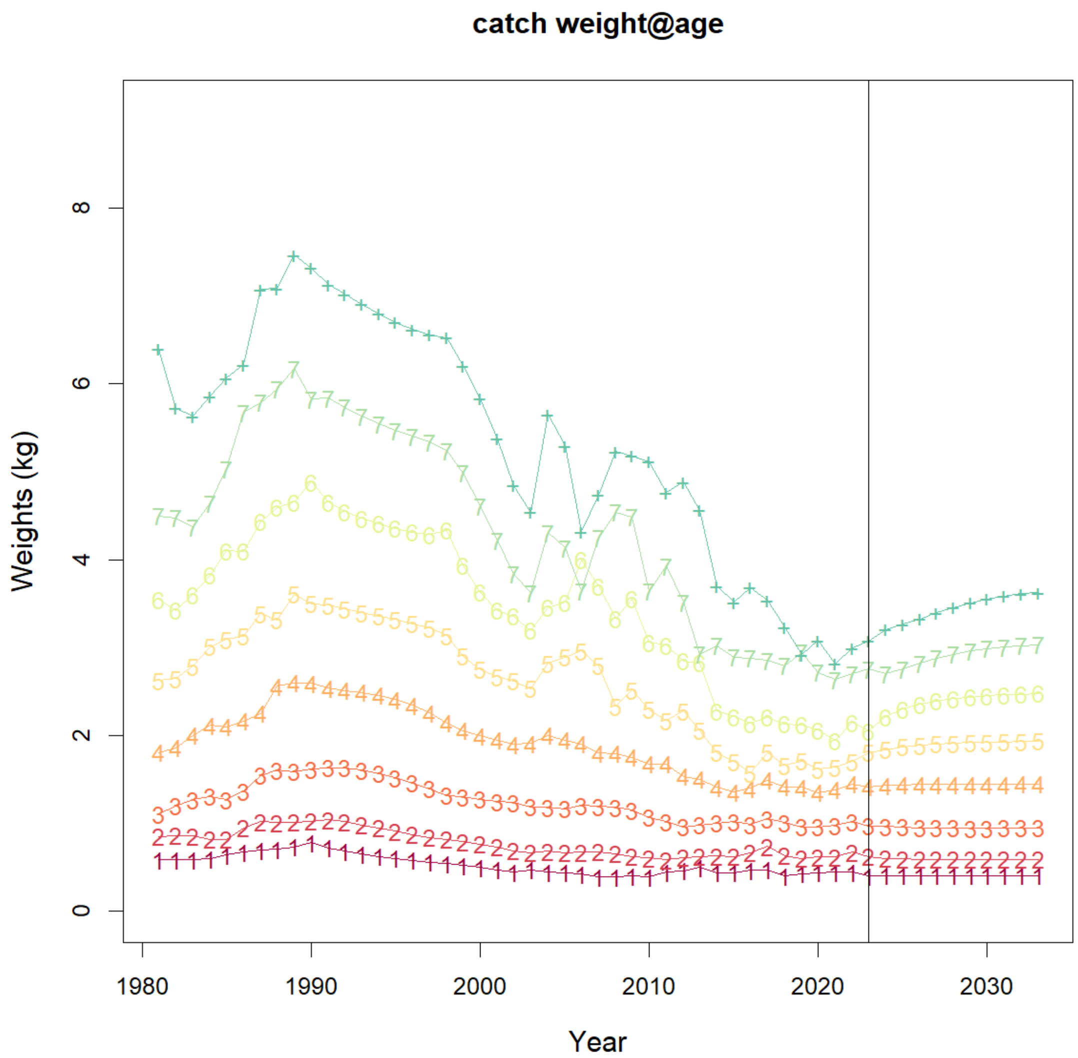

Figure 2.37. Modelled catch weights at age using the Gaussian Markov Random Field method of estimating biological data. The weights used in forecasting are indicated to the right of the vertical line.

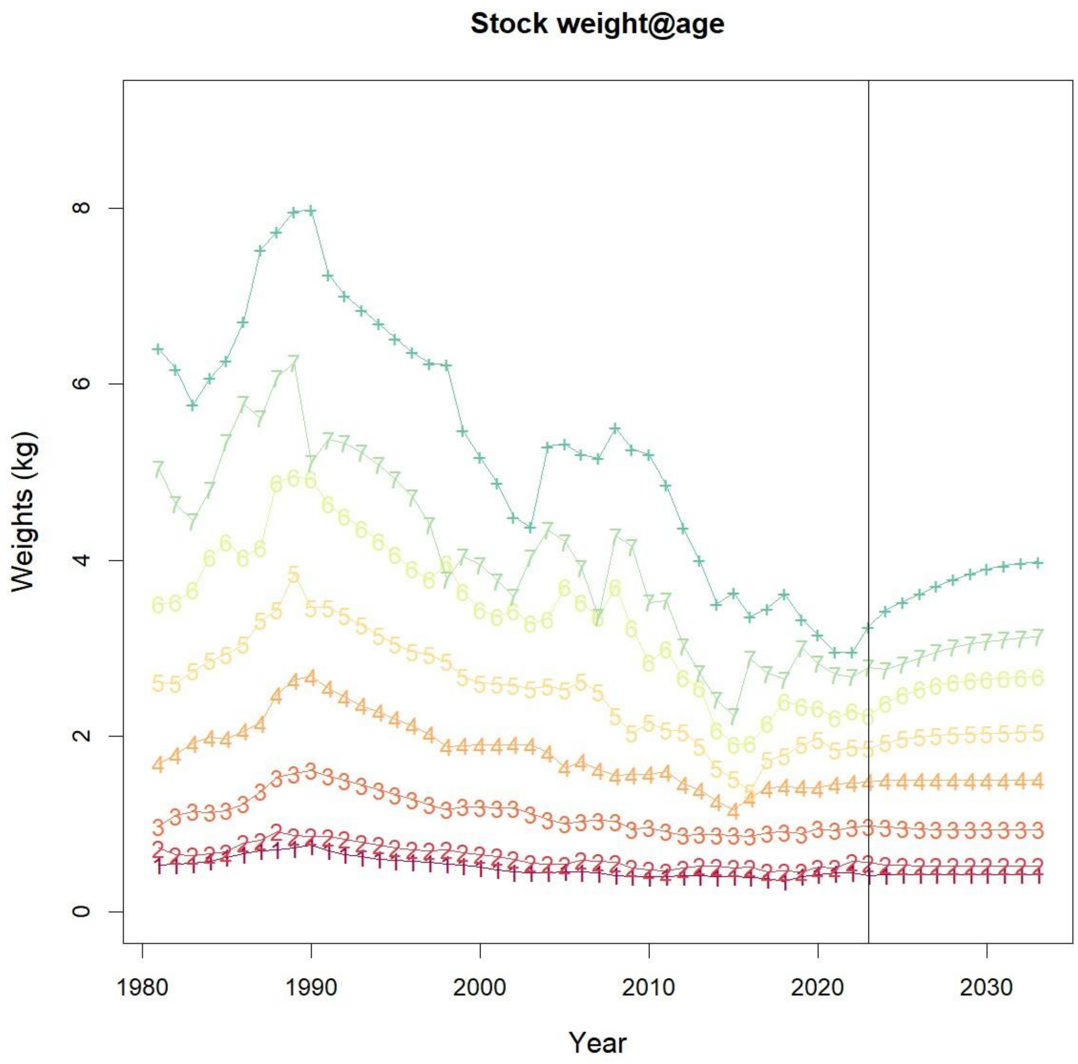

Figure 2.38. Modelled stock weights at age using the Gaussian Markov Random Field method of estimating biological data. The weights used in forecasting are indicated to the right of the vertical line.

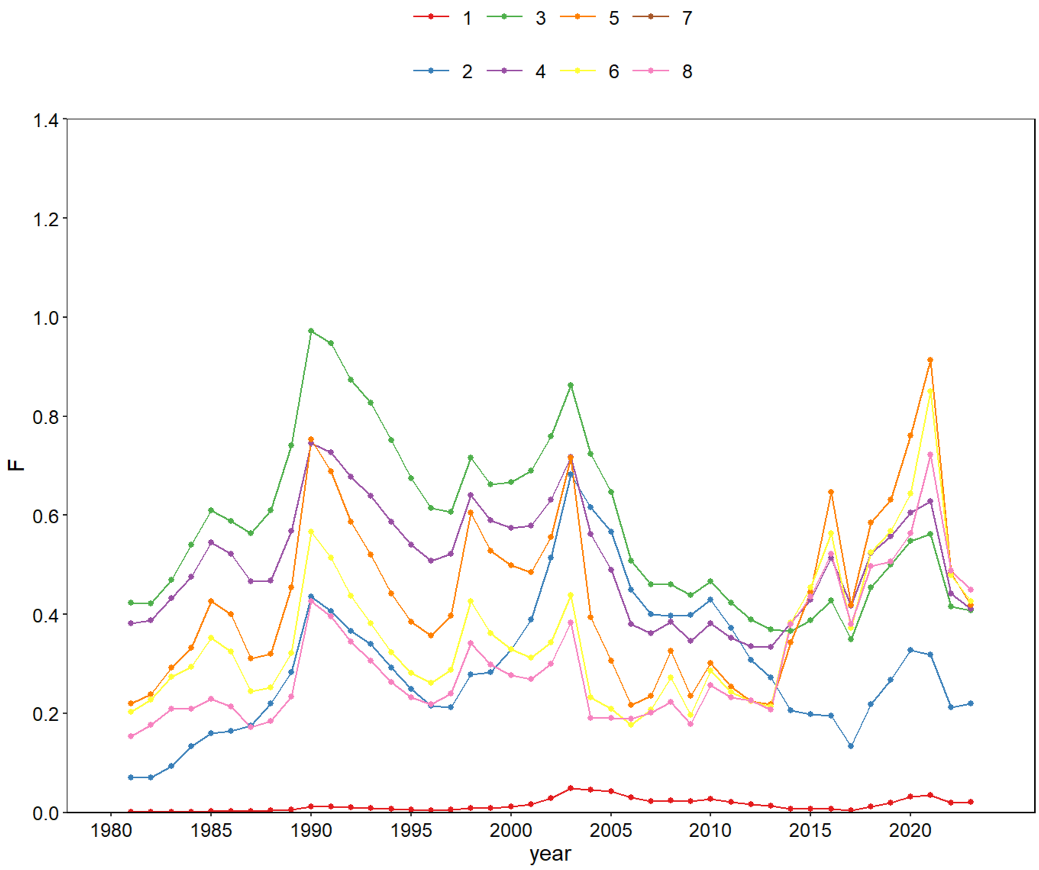

Figure 2.39. F-at-age in the North Sea turbot benchmark assessment.

Table 2.11. Turbot in Subarea 4. Annual catch scenarios. All weights are in tonnes.

Rationale	Total Catch (2025)	Projected Landings (2025)	Projected Discards (2025)	Projected Fbar (2025)	SSB (2026)	% SSB change	% Advice change
MSY approach: FMSY	**2244**	**2113**	**132**	**0.38**	**5238**	**8.2**	**9.4**
FMSY upper = 0.40	2332	2195	137	0.40	5153	6.4	13.6
FMSY lower = 0.27	1674	1576	98	0.28	5800	19.7	-18.4
F = 0	0	0	0	0.00	7486	55	-100
Flim	2701	2542	158	0.48	4796	-1	32
Fsq	2199	2070	129	0.38	5283	9.1	7.2
ssb(2025) = Blim	4097	3856	240	0.84	3481	-28	100
ssb(2025) = Bpa	2658	2502	156	0.47	4837	-0.1	30
ssb(2025) = Btrig	2658	2502	156	0.47	4837	-0.1	30
Roll-over advice	2052	1932	120	0.35	5427	12	0

2.9 Recommendations for the future

A major improvement to the turbot stock assessment model is the removal of the commercial LPUE index. Beyond double-counting and problematic residual patterns, this index likely contributed to an overly optimistic view of spawning stock biomass and overall stock status. In its place, and alongside slightly improved scientific surveys, the relatively new BSAS survey, conducted by commercial vessels, has been incorporated. While promising due to its high catchability of turbot and brill, the future success of the North Sea turbot stock assessment depends on the continued reliability of BSAS. Although the scientific surveys (now combined as BTS+COAST) show improvements in cohort tracking and recruitment estimates due to the inclusion of the DYFS survey, they remain characterized by low catchabilities for older individuals. Therefore, a survey like BSAS is crucial for providing higher-quality information on turbot stock dynamics. Any disruption to the annual implementation of BSAS could negatively impact the turbot stock assessment, highlighting the need to prioritize its effectiveness.

Since its inception, discussions have focused on the potential international expansion of BSAS, currently limited by funding to three Dutch vessels. Expanding this survey in collaboration with other North Sea countries (e.g., Belgium, Germany, Denmark, and the UK) would benefit the turbot stock assessment by extending its coverage to other important areas for the stock.

The updated turbot stock assessment continues to function as a landings only assessment. Although discards for turbot are generally low (<10%) the inclusion of discards in the North Sea assessment would provide a more realistic picture of stock dynamics. This, however, has proved to be challenging due to the lack of biological information for turbot discards. Although there has been an increase in Danish biological samples for discards in recent years, the availability and quality of annual discard sampling has not yet improved sufficiently to properly incorporate discards into the turbot assessment. Furthermore, while discards are generally low in North Sea fisheries for turbot, there are isolated circumstances in which much higher discards discard ratios have been observed demonstrating that they are a non-negligible factor for accurately assessing turbot stock dynamics.

During the benchmark assessment, it was originally planned to extract survey model CV's to incorporate directly into SAM. This was previously recommended to better control the weighting of indices into SAM. This was conducted during the benchmark for several model runs, however, the method used seemed to worsen the model fit. Due to this aspect and time constraints, the decision was made to move forward with the model development without directly implementing the index CV's for weighting. It could be beneficial to revisit this issue to explore the potential improvements from its proper implementation in to SAM

2.10 References

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2.11 Reviewers report

Turbot in Subarea 4 is an ICES category 1 stock that was last inter-benchmarked in 2018 (ICES, 2018) and currently uses an age-based state-space assessment model (SAM) with two survey indices (SNS and BTS) and a commercial LPUE index. A thorough model selection was conducted given the update data, and the main discussions and decisions to determine the final model are presented here.

An age-varying natural mortality calculated with Lorenzen's method was found to be the most appropriate and realistic for the stock, rather than the current constant natural mortality rate or any other of the varying natural mortality methods explored during the benchmark.

Stock weights were modelled with a Gaussian Markov random field internal to SAM. This model was correlated over both time and cohort and produced weight-at-age estimates that had several advantages over the externally estimated GAM model used previously. In particular, any uncertainty in the internally estimated weights carried through to the assessment model estimates. The previous weights from the GAM were assumed without error, meaning that the uncertainty around model estimates and/or derived values may be underestimated. In addition, using the GAM weights in retrospective analysis is problematic because the retro peels use information that the assessment wouldn't have in the previous year (data from all years were used to generate the GAM fit, but the retro peels should not include data from all years). The decision to use internally modelled stock weights at age is therefore considered more objective than the alternative and more robust in case of potential future gaps in the data.

WKBNSCS explored the addition of two new survey indices (DYFS and BSAS) and discussed the exclusion of the LPUE index. SNS and DYFS were combined to get an index for ages 0-3 turbot that live close to the shore (COAST index). Afterwards, COAST was combined with BTS, which catches the larger turbot that move offshore, providing the index with more area- and age-coverage. The inclusion of the BSAS index was considered sufficient to replace and improve the information previously coming from the LPUE index, especially for older ages. The exclusion of the LPUE index results in a better fit to the model, prevents double counting and avoids the uncertainty around recent changes on the Dutch fleet.

Significant retrospective patterns in SSB and F were detected when using five peels to calculate Mohn's rho values, but this is a minor concern, as it is explained by the current short time series of the BSAS survey (5 years). The Mohn's rho estimates are expected to improve during the next assessment years as the BSAS time series gets longer. The reviewers advise using three peels to carry out this analysis in the coming assessment years.

There is not a clear relationship between stock and recruitment, and consequently the stock is considered to be type 5 following ICES guidelines (ICES, 2025). For the reference point estimates, the WG decided to use five years for the biological and selectivity parameters, due to changes in trends before that timeframe. For the recruitment, a longer time series was selected (1981 – 2022), but the 2023 year was not included due to the higher uncertainty in this last year. Following the latest ICES guidelines (ICES, 2025), B_{lim} was set at *Empirical* B_{lim} (the average of the lowest three SSB estimates that resulted in above median recruitment).

The age-based SAM model developed by WKBNSCS provides a better quantification of uncertainties through the new modelled stock weights at age. Additionally, the updated natural mortality rates and new BSAS index are thought to better capture our current understanding of the stock. The new model is therefore a good representation of the stock and appropriate to use in ICES advice together with the new reference points estimated during the benchmark.

The stock assessment for turbot in Subarea 4 met the terms of reference and can be used to provide management advice. The assessment methods workshop went smoothly and finished on time, largely due to the preparation and diligence of the assessment teams. The external reviewers would like to thank Anders Nielsen for attending the workshop and providing invaluable advice on SAM configuration and analysis and Dorleta Garcia for providing advice on ICES reference point guidelines during the meeting.

3 Whiting (*Merlangius merlangus*) in Division 7.a

3.1 Summary

Whiting in Division 7.a is a category 1 stock where a full analytical assessment and forecast has been carried out since 2017 following WKIrish3. The model previously used to assess the stock was the single fleet Age-Structured Assessment Program (ASAP). There were a number of limitations with this model notwithstanding the use of a single fleet and fixed selectivity blocks without allowing for gradual changes in selectivity that occurred as the fishery exploiting the stock changed from a gadoid directed one to one where whiting is mainly bycatch in the *Nephrops* fishery.

The benchmark meeting aimed to address several issues identified for this stock. New natural mortality, maturity and mean stock weights were derived. The survey index was changed from a design-based index to a model-based index using VAST. A State -Space stock assessment model (SAM) was used to assess the stock. This model has several advantages over the ASAP model in that in can account for both process and observation errors and the selectivity pattern can vary over time. Ecosystem information was presented following on from the WKIrish processes and was used as a basis to outline the regime shift that is thought to have occurred in the Irish sea since the early 1990's. Genetic information was presented whereby there is no evidence of a genetic bottleneck for this stock or that there is no genetic difference between the once considered separate east and west components of the stock. Recreational catch estimates were also available for the first-time and these were included in the assessment for the first time.

More detailed information can be found in the following working documents.

1. Moore S-J. and Gerritsen H. 2024. WD 3.1 Whiting in Division 7.a Catch Data. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024;10 pp.
2. Gerritsen H. and Moore S-J. 2024. WD 3.2 Whiting in Division 7.a life-history parameters. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024;12 pp.
3. Gerritsen H. and Moore S-J. 2024. WD 3.3 Whiting in Division 7.a VAST index for NIGFS. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024;15 pp.
4. Beggs S. and Kelly R. 2024. WD 3.4 Whiting in Division 7.a Environmental and ecosystem considerations. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024;19 pp.
5. Beggs S. and Kelly R. 2024. WD 3.5 Whiting in Division 7.a History of fishery and spatial considerations. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024; 23 pp.
6. Fallon N. WD 3.6 Whiting in Division 7.a SAM Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), February 3–7, 2025; 18 pp.
7. Gerritsen H 2024 WD 3.7 Whiting in Division 7.a Reference points. Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), February 3–7, 2025;15 pp.
8. Radford Z., Ryan D., Moore S-J and Gerritsen H. 2024 WD 3.8 Whiting in Division 7.a Reconstruction of Recreational Catches Working Document for the Benchmark Workshop on selected North Sea and Celtic Sea Stocks (WKBNSCS 2024), November 19–21, 2024;13 pp.

Issue List

- **Improve the quality of the analyses to provide advice or new recurrent advice**
  - A single fleet ASAP with fixed selection assumption is used. Exploring alternative modelling frameworks which allow for changes in selection should be investigated - SAM model was used
  - Alternative model types and selectivity assumptions may be more appropriate to estimate stock biomass trends - SAM model was used and survey-based design index changed to modelled VAST index
- **Discards**

    - Discards data remain highly uncertain for this stock. Partitioning catch data into landings and discards or by fleet with different CVs may help smooth out some of this variability - SAM allows for F partitioning in forecast
- **Life History parameters**
    - **natural mortality:** updated Lorenzen M
    - **maturity estimates** were knife-edge at age 2 for all years now time-varying maturity estimated from NIGFS-WIBTS-Q1
    - **mean stock weights:** change from using Q1 catch weights to weights at age from NIGFS-WIBTS-Q1
- **Tuning Indices**
    - Change from design-based survey index to one modelled with VAST.
- **Dietary and Genetic Analysis**
    - New analysis presented
- **Ecosystem Aspects**
    - Evidence of regime shift and informed decision making in reference point analysis.
- **Discard Sampling**
    - Not addressed. Recommendation to improve discard sampling for this stock

3.2 Stock identity

3.2.1 Data evaluation meeting

Stock identity is outlined in detail in WKIrish2. Whiting spawn in spring in eastern Irish Sea and in the coastal waters of the western Irish Sea, recruitment grounds are in the same general area as the spawning grounds. Historical tagging studies in the 1950s showed some seasonal dispersal of larger whiting into the Clyde, eastern Irish Sea and Celtic Sea with evidence of return migrations. The age structure in the eastern Irish Sea is normally broader than in the west.

Recent genetic analysis has examined evidence of biological and genetic bottlenecks of Irish sea whiting (Prodöhl, 2023). Contemporary genomic DNA was extracted from whiting samples collected in the early 2000's and 2022 and historical samples were extracted from whiting from the late 50's and early 60's. High levels of genetic variation was observed in both the contemporary (2004-2022) and the historical (1957-1962) samples. Results indicated that there was no evidence of genetic sub structuring and that there was no evidence of a genetic bottleneck.

Feeding and food web dynamics were also investigated and detailed information can be found in WD 3.4. It showed that juvenile whiting (<23cm) primarily fed on prawns and shrimps, small pelagic fish and epifauna. There was evidence indicating an increased occurrence of cannibalism among whiting within this specific size class. Adult whiting (>23cm) were found to have a diet onsisting of higher proportions of fish. There was a higher incidence of cannibalism detected in the more recent years, typically from 1990's onwards during the period of decline in SSB. This increased incidence of cannibalism maybe evidence of a decline in alternative prey, or an increase in spatial overlap between adult and juvenile whiting.

Overall there was no strong evidence to support a change in the assessment boundaries.

3.3 Catch data

3.3.1 Data evaluation meeting

3.3.1.1 Commercial data

Catch numbers (both landings and discards) at age data were revised for 2003 to 2023 using updated information received in the data call. New or updated catch information was submitted to Intercatch by the UK (England, Wales, Scotland and the Isle of Man), Belgium, France and the Netherlands. There were no updates to data from Ireland and Northern Ireland as the data submitted previously was considered to be the best estimates from both countries. A summary overview of the fishery dependent data available and used by WKBNSCS for whiting 27.7.a is provided in Table 3.3.1.

For 2003-2015, the catch numbers were aggregated using already combined Ireland and Northern Ireland raised to the new or revised international catch data. This was partly due to incomplete data for Ireland and Northern Ireland in Intercatch for those years. Since 2016, there has been more complete national data submitted to Intercatch however raising the international data was continued using spreadsheets.

There was marginal difference in the catch estimates with the addition of new information for the data call (Figure 3.3.1).

Catch weights were also updated with the new information supplied following the data call.

Sampling levels were also explored during WKBNSCS. Sampling of landings in recent years has been sparse as landings have been low. Furthermore, discard sampling levels in recent years has also reduced with low numbers of trips sampled and patchy coverage. In 2020, 2022 and 2023 discards were derived for Ireland as actual sampling data was insufficient to provide reliable estimates. Discard sampling needs to improve for this stock since discards account for the vast majority of the catch in weight and number.

A more detailed description can be found in WD 3.1.

3.3.1.2 Recreational data

Recreational data was made available for the first time for Whiting 27.7a following the data call. Both retained and released catch estimates were provided. For released catch the WGRFS experts recommended that a 35.1% mortality rate should be applied to released catches based on the upper limit of the boat-based mortality for cod (Capizzano *et al*. 2016). Recreational catch data from the UK (England, Wales, Scotland, Isle of Man) was available for 2016-2023. For the years that data was provided, recreational catches accounted for on average 11% of the total international trawl catch. Given the significant proportion of recreational catch and the associated mortality, the benchmark concluded that it was appropriate to include recreational catches in the assessment model.

Historic sampling and estimation of recreational catch for Ireland was preliminary and only available for 2022. Recreational catches from Ireland are considered negligible for this stock (4t in 2022). A description of how the recreational estimates were derived is provided in WD 3.8.

The selection ogives of the combined UK(NI) and IRE catch data and recreational data were examined. Although the sampling of the recreational catch is variable the selection ogive of the commercial catch and recreational catch showed similar patterns (Figure 3.3.2). The assumption is that the size and age structure of the recreational and commercial catch is similar back in time and therefore in order to include the recreational catch in the assessment model the catch data was scaled according to four scenarios as below:

- **S1** – Recreational removals are proportional to the SSB with no limits on catches.
- **S2** – Removals are proportional to the SSB until 1995, then become constant.
- **S3** – Catches are proportional to the SSB, but recreational anglers have an upper limit on whiting catches (based on the average diarist who caught whiting in 7.a).

- **S4** – Recreational removals have been consistent over time (based on the average removals from 2016-2023).

Given the significant proportion of recreational catch and the associated mortality, the benchmark concluded that it was appropriate to include recreational catches in the assessment model. The scenarios were evaluated during the benchmark meeting (see section 3.3.2.2).

Table 3.3.1. Time series of fishery dependent data types by country available and used to construct the whiting 27.7.a assessment inputs. New or updated data shown in red.

	Northern Ireland				Ireland				
Year	Landings (t)	Discards (t)	LNAA	DNAA	Landings (t)	Discards (t)	LNAA	DNAA	Recreational
1980	yes but no info		Market	SS	yes but no info				
1981	yes but no info		Market	SS	yes but no info				
1982	yes but no info		Market	SS	yes but no info				
1983	yes but no info		Market	SS	yes but no info				
1984	yes but no info		Market	SS	yes but no info				
1985	yes but no info		Market	SS	yes but no info				
1986	yes but no info		Market	SS	yes but no info				
1987	yes but no info		Market	SS	yes but no info				
1988	Yes	Yes	Market	SS					
1989	Yes	Yes	Market	SS	Yes				
1990	Yes	Yes	Market	SS	Yes				
1991	Yes	Yes	Market	SS	Yes				
1992	Yes	Yes	Market	SS	Yes		Market		
1993	Yes	Yes	Market	SS	Yes		Market		
1994	Yes	Yes	Market	SS	Yes		Market		
1995	Yes	Yes	Market	SS	Yes		Market		
1996	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1997	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1998	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1999	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
2000	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
2001	Yes	Yes	Market	SS	Yes	Yes	Market	Not used	
2002	Yes	Yes	Market	SS	Yes	Yes	Market	Not used	
2003	Yes	Yes	Insufficent data	Insufficent data	Yes	Yes	Market	Obs	
2004	Yes	Yes	Insufficent data	Insufficent data		Yes	Market	Obs	
2005	Yes	Yes	Insufficent data	Insufficent data	Yes	Yes	Market	Obs	
2006	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2007	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2008	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2009	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2010	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2011	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2012	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2013	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2014	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2015	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2016	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2017	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2018	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2019	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2020	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	
2021	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2022	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	Yes
2023	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	

Table 3.3.1 continued. Time series of fishery dependent data types by country available and used to construct the whiting 27.7.a assessment inputs. New or updated data shown in red.

	England, Wales, Scotland, Isle of Man					Belgium			
Year	Landings (t)	Discards (t)	LNAA	DNAA	Recreational	Landings (t)	Discards (t)	LNAA	DNAA
1980	yes but no info					yes but no info			
1981	yes but no info					yes but no info			
1982	yes but no info					yes but no info			
1983	yes but no info					yes but no info			
1984	yes but no info					yes but no info			
1985	yes but no info					yes but no info			
1986	yes but no info					yes but no info			
1987	yes but no info					yes but no info			
1988	Yes					Yes			
1989	Yes					Yes			
1990	Yes					Yes			
1991	Yes					Yes			
1992	Yes					Yes			
1993	Yes					Yes			
1994	Yes					Yes			
1995	Yes					Yes			
1996	Yes		Provided but not used			Yes			
1997	Yes		Provided but not used			Yes			
1998	Yes		Used			Yes			
1999	Yes		Used			Yes			
2000	Yes		Used			Yes			
2001	Yes		Used	Provided but not used		Yes			
2002	Yes		Used	Provided but not used		Yes			
2003	Yes	Yes	Used	Used		Yes	Yes		
2004	Yes	Yes	Used	Used		Yes	Yes		Used
2005	Yes	Yes	Used	Used		Yes	Yes		Used
2006	Yes	Yes				Yes	Yes		Used
2007	Yes	Yes		Used		Yes	Yes		Used
2008	Yes	Yes		Used		Yes	Yes		Used
2009	Yes	Yes		Used		Yes			
2010	Yes	Yes		Used		Yes	Yes		
2011	Yes	Yes		Used		Yes	Yes		Used
2012	Yes	Yes				Yes	Yes		Used
2013	Yes	Yes				Yes	Yes		
2014	Yes	Yes		Used		Yes	Yes		
2015	Yes	Yes		Used		Yes	Yes		
2016	Yes	Yes		Used	Yes	Yes	Yes		
2017	Yes	Yes		Used	Yes	Yes	Yes		
2018	Yes	Yes		Used	Yes	Yes	Yes		
2019	Yes	Yes		Used	Yes	Yes	Yes		
2020	Yes	Yes		Used	Yes	Yes	Yes		
2021	Yes	Yes		Used	Yes	Yes	Yes		
2022	Yes	Yes	Used	Used	Yes	Yes	Yes		
2023	Yes	Yes		Used	Yes	Yes	Yes		

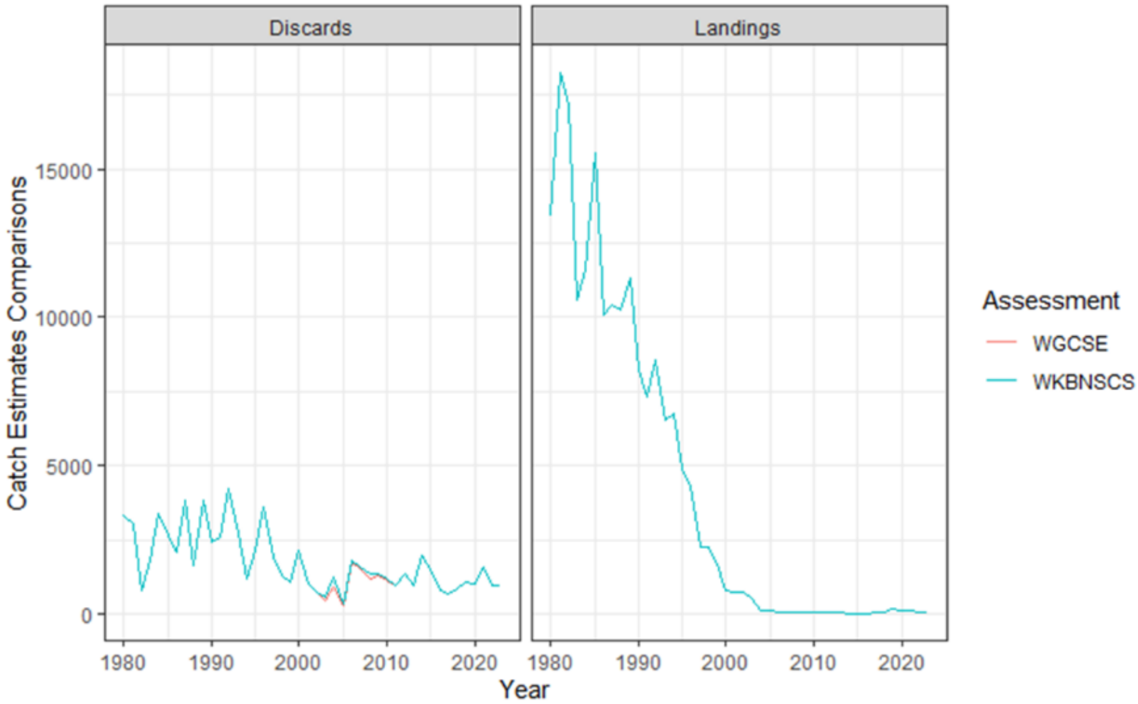

Figure 3.3.1. Comparison between discards and landings estimates for WGCSE and WKBNSCS.

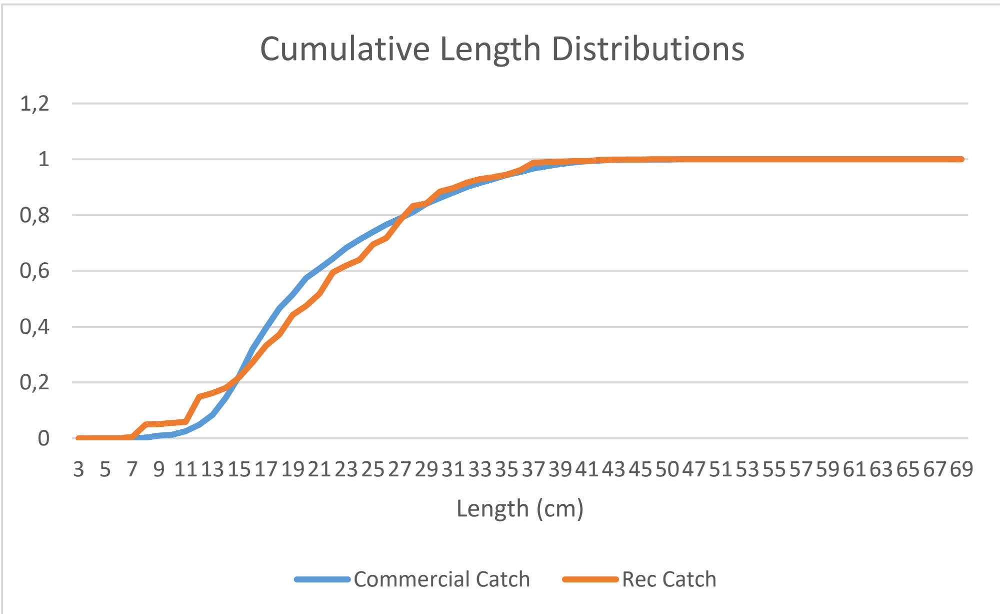

Figure 3.3.2 Cumulative length distribution (Selection Ogive) of Commercial catch data and recreational data for 2016-2023 for Whiting in Division 7.a.

3.3.2 Benchmark

3.3.2.1 Commercial data

As above.

3.3.2.2 Recreational data

Sensitivity runs were carried out with the four scenarios for the recreational data included in the model.

Each of the four scenarios were run as sensitivities in the final model configuration. They exhibited minimal differences from one another, aside from their influence on Spawning Stock Biomass (SSB). The scenarios in which recreational catches were proportional to SSB were excluded, as including a model output as a proxy for an input variable was considered circular.

Further information is detailed below in section 3.6.

3.4 Biological parameters

3.4.1 Data evaluation meeting

3.4.1.1 Maturity

Previously, maturity ogives were knife-edge at age 2 for all years. In the data evaluation meeting maturity estimates for NIGFS-WIBTS-Q1 were analysed and deemed sufficient to support time-varying maturity. Female maturity was used and a running average smoother was applied to reduce noise while still accounting for the trends over time that were observed. Estimates from the start of the survey time-series were used to extrapolate to the start of the assessment time series (close to zero for age 1 and close to 1 for age 2 and 1 for age 3+). More details on this process is available in WD 3.3.

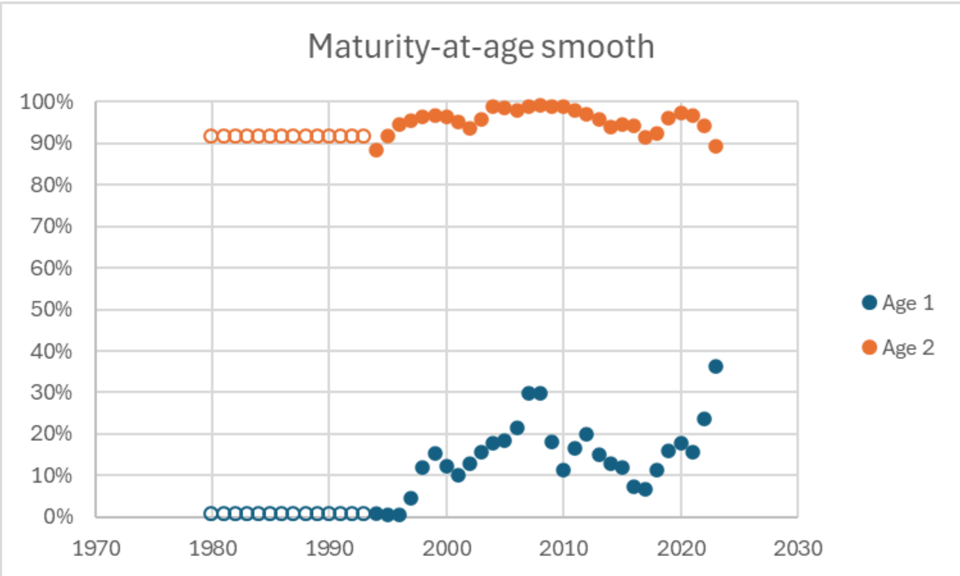

Figure 3.4.1. Proportion mature at ages 1 and 2 over time. Ago 0 are 100% immature and ages 3+ are considered 100% mature. Solid points are observed values; open circles are extrapolated from the three earliest observed values.

3.4.1.2 Natural mortality

Previously the Lorenzen method was used to estimate natural mortality. During the data evaluation workshop various empirical methods were explored. Most of these resulted in estimates of at least 0.6 for mature fish and considerably higher for juveniles. It is likely that small individuals will be more susceptible to predation and various size-based methods resulted in similar estimates, therefore there is no reason to deviate from the current Lorenzen method. The method was updated with recent estimates of size-at-age from survey data resulting in higher estimates of M (Table 3.4.1). Time-varying M (based on time-varying stock weights) was explored as a sensitivity run using the ASAP model but because this does not account for other changes in the ecosystem, this was not considered a realistic option. Details are expanded on in WD3.3.

Table 3.4.1. Updated Natural Mortality (M) estimates using the Lorenzen method on growth parameters from NIGFS-WIBTS-Q1 survey

Age	0	1	2	3	4	5	6
Previous	1.08	0.80	0.72	0.61	0.55	0.52	0.52
Updated	2.20	0.98	0.75	0.67	0.63	0.62	0.61

3.4.1.3 Stock weights

Stock weights were previously derived from catch weights and smoothed using a running average over a 3 year period. The benchmark considered that the survey data are more appropriate to use due to its wide spatial coverage of the stock and small mesh size. In the earlier part of the time series when the survey had not yet begun, the catch weights are still used. A running average smoother was applied to reduce noise while still accounting for the trends over time that are observed. Details are expanded on in WD3.3.

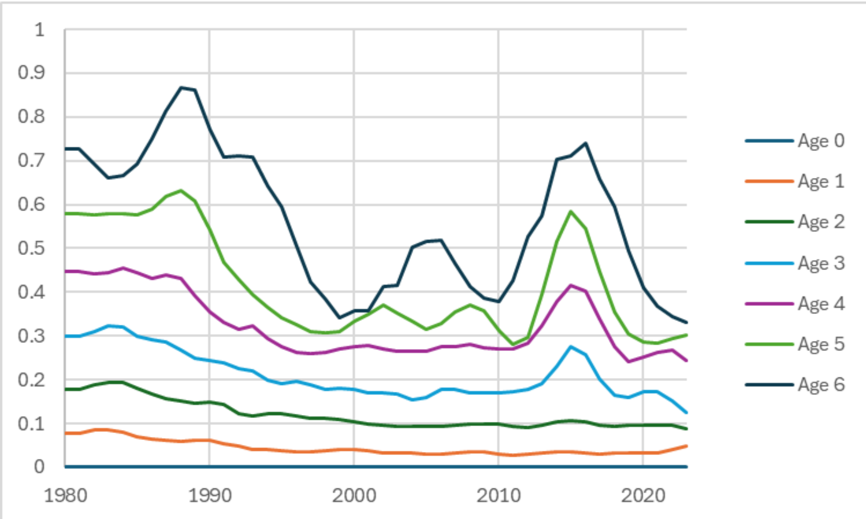

Figure 3.4.2. Final stock weights-at-age.

3.5 Indices of abundance

A detailed description of survey indices can be found in working document 3.3. No changes were made to the MIK survey index.

The Vector Autoregressive Spatio-Temporal package was used to model the Q1 and Q4 Northern Irish Groundfish Survey index for Irish Sea whiting. By accounting for spatio-temporal processes, it was possible to extend the survey area to the full stock area despite incomplete sampling in the southern part of the Irish Sea. It is also expected that a modelled survey index is more robust to gaps in data collection.

The annual age data collected on the surveys appeared to be insufficient to construct a reliable age-length-key (ALK) for each year and quarter; therefore, all age data for each survey period were combined to create time-invariant ALKs.

The final modelled indices performed better in terms of internal consistency for most age classes than the current design-based indices and the consistency between the two survey periods (Q1 and Q4) was considerably better. It appears that this is in a large part due to the application of the time-invariant ALK and only partly due to the spatial model. Figure 3.51 shows a comparison between the 'old' design-based index and the proposed VAST modelled index.

The estimated distribution of whiting in the Irish sea (Figures 3.5.2a and 3.5.2b, Table 3.5.1) indicates that while the distribution of young fish overlaps considerably with the main fishery in the area (trawl fishery targeting *Nephrops*), older fish have limited overlap with the fishery. This seems to be in conflict with the high total mortality signal (Z) in the catch and survey numbers-at-age. This indicates that there may be other sources of removals (higher M than currently estimated; migration out of 7a; and/or significant unaccounted mortality due to recreational or commercial catches).

Table 3.5.1. Overlap of the estimated spatial distribution of whiting with the *Nephrops* fishing grounds.

	Overlap with *Nephrops* fishery	
Age	Q1	Q4
0	-	58%
1	45%	41%
2	34%	34%
3	31%	30%
4	31%	28%
5	32%	29%
6	34%	27%
7	32%	21%

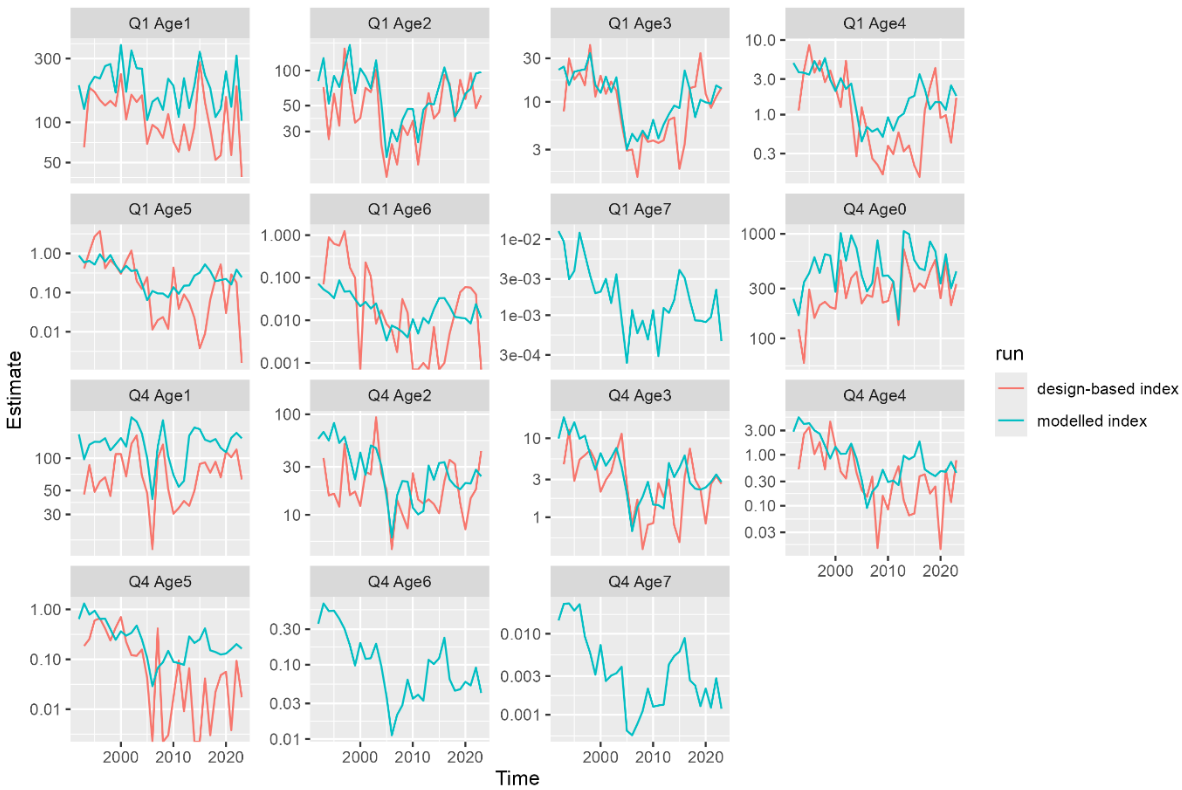

Figure 3.5.1. Comparison between the design-based index (which was used in the previous assessment) and the VAST modelled index.

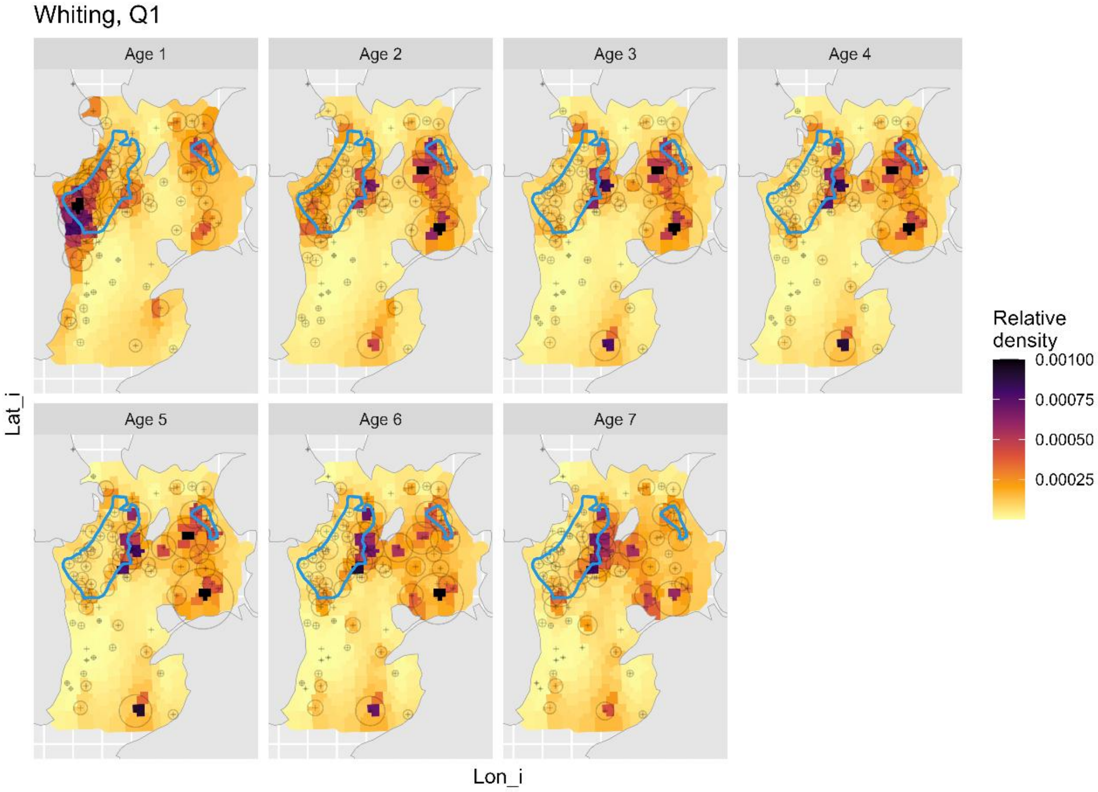

Figure 3.5.2a. Spatial distribution of whiting in Q1 estimated by the final model (average over all years). The crosses indicate the sampling locations, the circles indicate the average catch numbers per swept area; the areas outlined in blue are the main fishing grounds (*Nephrops*).

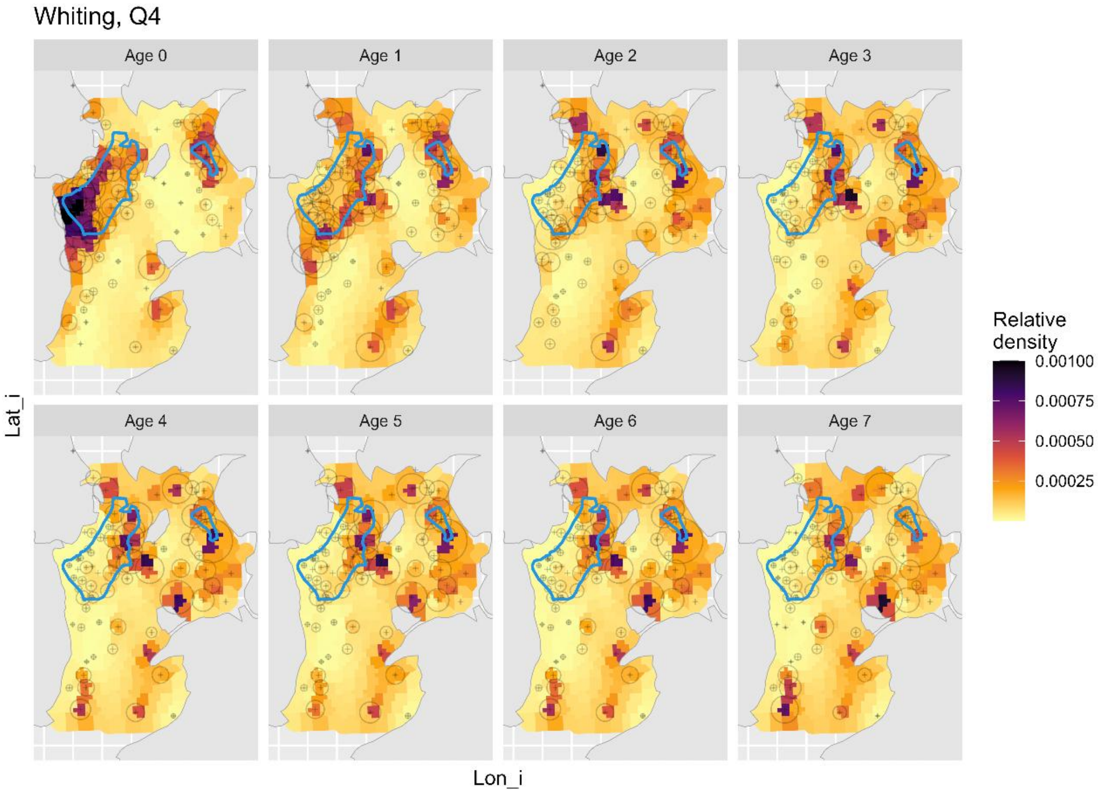

Figure 3.5.2b. Spatial distribution of whiting in Q4 estimated by the final model (average over all years). The crosses indicate the sampling locations, the circles indicate the average catch numbers per swept area; the areas outlined in blue are the main fishing grounds (*Nephrops*).

3.6 Assessment method

3.6.1 Sensitivity analyses and final SAM settings

Configuration settings for the SAM assessment were explored through sensitivity analyses (full details in WD 3.6) that were carried out on a base model configuration which was generated using the "defcon" function in the "stockassessment" R package (Nielsen and Berg, 2014 & 2016). To summarise, sensitivity analyses were carried out on settings for: each of the recreational data scenarios, catch data uncertainty, fleet covariance configuration, survey catchability coupling, and fishing mortality states process coupling. In the cases of fleet covariance structure, and survey catchability plausible combinations of coupling vectors for each fleet were implemented as potential configuration matrices, and the best fit for each was identified by AIC, as well as examination of residuals, retrospective patterns, leave-one-out analyses, and conditional simulation runs. During the benchmark workshop, two configurations of fishing mortality states coupling were compared: all ages decoupled (requested by workshop participants), and ages zero to three decoupled, with ages four to six+ coupled (best fit model from pre-workshop explorations). The model with all ages decoupled provided what was considered a more realistic selectivity-at-age profile to the alternate configuration.

Settings for the final SAM run were chosen through the consideration of AIC, and the examination of model residuals, leave-one-out analyses, conditional simulation runs, and retrospective patterns. The full configuration of the final model is given in Table 3.6.1. The following list summarises the main features of the final model configuration which were informed by sensitivity analyses and discussions at the benchmark:

- Fishing mortality states process uncoupled for all ages.
- Catchabilities for each modelled survey index are coupled as follows: NIGFS Q1 age one uncoupled, ages two to five coupled, age six+ uncoupled; NIGFS Q4 age zero uncoupled, ages one to three coupled, and ages four and upwards uncoupled.
- The catch and NIMIK fleets are modelled with independent covariance structures, whereas the NIGFS survey fleets are modelled with a first order autoregressive variance structure (AR1).
- $\bar{F}$ was set at ages one to three to reflect fishery selectivity, which moved from a target fishery in the 1980s and 1990s to a bycatch & discard component of the *Nephrops norvegicus* trawl fishery from the early 2000s onwards.
- Recreational catches were included as a constant scalar to the catch numbers-at-age input data, based on average recreational removals from 2016-2023 (All data inputs are described in Tables 3.6.2 & 3.6.3).
- Coefficients of variation from VAST were used as relative interannual weights within each of the modelled survey indices (NIGFS Q1 & Q4).

Table 3.6.1. Final SAM configuration settings for assessment of 7.a whiting agreed at WKBNSCS 2025

Model Setting	Setting name	Agreed configuration & details
Minimum age in model	$minAge	0
Maximum age in model	$maxAge	6
Maximum age plus group	$maxAgePlusGroup	Maximum age as plus group applies to the commercial catch data, and the modelled Q1 & Q4 survey indices
Coupling of the fishing mortality state processes	$keyLogFsta	Uncoupled across all age classes
Correlation of fishing mortality across ages	$corFlag	AR1 (first order autoregressive)
Coupling of the survey catchability parameters	$keyLogFpar	NIGFS-Q1: age 1 uncoupled; ages 2 to 5 uncoupled; age 6+ uncoupled NIGFS-Q4: age 0 uncoupled; ages 1 to 3 uncoupled; ages 4 to 6+ uncoupled NIMIK: n/a as this is a single age class recruitment index
Density dependent catchability power parameters	$keyQpow	n/a
Coupling of process variance parameters for *log*(F) process	$keyVarF	Coupled across all age classes
Coupling of the recruitment and survival process variance parameters	$keyVarLogN	Age 0 uncoupled; ages 1 to 6+ coupled
Coupling of the variance parameters for the observations	$keyVarObs	Catch: all ages coupled NIGFS-Q1: all ages coupled NIGFS-Q4: all ages coupled NIMIK: n/a
Covariance structure for each fleet	$obsCorStruct	Catch: Independent (”ID”) NIGFS-Q1: ”AR1” NIGFS-Q4: ”AR1” NIMIK: “ID”
Coupling of correlation parameters for fleet covariance	$keyCorObs	NIGFS-Q1: age 1 uncoupled; ages 2-3 and 3-4 coupled; ages 4-5 and 5-6+ coupled NIGFS-Q4: age 0; ages 1-2, 2-3, 3-4, 4-5, and 5-6+ coupled
Stock recruitment code	$stockRecruitmentModelCode	0; Plain random walk
Number of years where catch scaling is applied	$noScaledYears	0
Years where catch is scaled	$keyScaledYears	n/a

Table 3.6.1. Final SAM configuration settings for assessment of 7.a whiting agreed at WKBNSCS 2025

Model Setting	Setting name	Agreed configuration & details
Matrix specifying the couplings of scale parameters	$keyParScaledYA	n/a
Lowest and highest ages included in $\bar{F}$	$fbarRange	1, 3
Biomass survey configuration	$keyBiomassTreat	n/a
Observational likelihood	$obsLikelihoodFlag	Catch: ″LN″ NIGFS-Q1: ″LN″ NIGFS-Q4: ″LN″ NIMIK: ″LN″
Observation weighting configuration	$fixVarToWeight	0
Fraction of t(3) distribution used in logF increment distribution	$fracMixF	0
Fraction of t(3) distribution used in logN increment distribution	$fracMixN	0
Fraction of t(3) distribution used in distribution of fleets	$fracMixObs	Catch: 0 NIGFS-Q1: 0 NIGFS-Q4: 0 NIMIK: 0
Break years between which recruitment is constant	$constRecBreaks	n/a
Coupling of parameters used in a prediction-variance link for observations	$predVarObsLink	n/a

Table 3.6.2. SAM input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Canum*	Catch numbers-at-age	1980 onward	0 to 6+	Yes
Weca	Weight-at-age in the commercial catch	1980 onward	0 to 6+	Yes
Weca discards†	Weight-at-age in the commercial discards	1980 onward	0 to 6+	Yes
Weca landings†	Weight-at-age in the commercial landings	1980 onward	0 to 6+	Yes
West=Weca	Weight-at-age of the spawning stock at spawning time	1980 onward	0 to 6+	Yes
Mprop	Proportion of natural mortality before spawning	1980 onward	0 to 6+	No
Fprop	Proportion of fishing mortality before spawning	1980 onward	0 to 6+	No
Matprop	Proportion mature at age	1980 onward	0 to 6+	No
Natmor	Natural mortality	1980 onward	0 to 6+	No

* Including recreational catch scenario S4; † The assessment does not model landings and discards separately

Table 3.6.3. Survey indices used in final SAM model.

Type	Name	SAM acronym	Year range	Age range
Tuning fleet 1	NIGFS-WIBTS-Q1 [G7144]*	NIGFS-Q1	1992–onward	1 to 6+
Tuning fleet 2	NIGFS-WIBTS-Q4 [G7655]*	NIGFS-Q4	1992–onward	0 to 6+
Tuning fleet 3	NI MIK [I9826]	NIMIK	1994–onward	0

* Coefficient of variance estimates were included as weightings in SAM for these indices

3.6.2 Assessment results

A summary of estimates from the final SAM run is shown in Figure 3.6.1, and the associated parameter estimates are presented in Table 3.6.4. The estimated $\bar{F}_{1\text{-}3}$ increases in the early part of the time series until the late its peak in 2006, after which there is a decrease until the mid-2010s after which $\bar{F}_{1\text{-}3}$ has remained relatively stable but high. Estimated SSB follows a steep decline for the early part of the modelled period and remained consistent from the early 2000s until 2010. From 2010 until the end of the modelled period, estimates SSB has followed a steady increasing trend, albeit at a relatively very low level.

The standardised one-observation-ahead residuals, and process residuals are shown in Figures 3.6.2 and 3.6.3, respectively. The model fits the catch-at-age data reasonably well for much of the modelled period. A distinct pattern in the catch residuals can be seen across ages two to six+, between the early 1990s and the early-to-mid 2000s, where a switch between predominantly positive values to negative values can be observed. This is reflective of the changes in fishery selectivity known to have happened during that period. This was examined at length during the benchmark meeting (see also. WD 3.6 - SAM) and was deemed to be far enough back in the time series as to be inconsequential in terms of understanding recent stock development, and for the provision of advice. Implementation of a first order autoregressive covariance structure for the modelled NIGFS Q1 and Q4 indices substantially reduced the tendency of their six+ residuals towards negative and positive biases, respectively.

The retrospective analysis peels are shown in Figure 3.6.4. Trends in SSB and $\bar{F}_{1\text{-}3}$, and recruitment are stable to the sequential annual removal of data working backwards from the terminal year. All retrospective peels remained within the 95% confidence bounds, only diverging slightly from the final model estimates with no obvious directional trends over time. The Mohn's ρ values for all three quantities were relatively low: $\rho_{SSB} = 0.003$, $\rho_F = -0.01$, $\rho_{rec} = 0.01$.

The leave-one-out runs for the final model are presented in Figure 3.6.4. Estimates of SSB appear reasonably robust to the sequential exclusion of different survey indices, following very similar trends across the time series around a relatively tight confidence interval. Estimates of $\bar{F}_{1\text{-}3}$ are perhaps the most indicative of conflicts between datasets, with removal of the NIGFS Q4 and NIMIK indices having a similar effect on the model, generally lowering the overall range of variability in $\bar{F}_{1\text{-}3}$, particularly noticeable between 2000-2010. Estimates of recruitment again follow similar trends, straying outside the 95% confidence bounds to a substantial degree, particularly in the early-to-mid 1990s, with the removal of the NIGFS Q4 and NIMIK indices.

The conditional simulations from the final assessment reproduced the model estimates well (Figure 3.6.5), for the most part falling within the 95% confidence bounds.

Table 3.6.4. Parameter estimates from final SAM run for 7.a whiting

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-4.975	0.114	0.007	0.005	0.009
logFpar_1	-4.226	0.131	0.015	0.011	0.019
logFpar_2	-5.352	0.259	0.005	0.003	0.008
logFpar_3	-4.941	0.131	0.007	0.005	0.009
logFpar_4	-4.335	0.124	0.013	0.010	0.017
logFpar_5	-4.078	0.141	0.017	0.013	0.022
logFpar_6	-3.491	0.151	0.030	0.023	0.041
logFpar_7	-2.856	0.430	0.057	0.024	0.136
logFpar_8	-7.164	0.177	0.001	0.001	0.001
logSdLogFsta_0	-1.971	0.188	0.139	0.096	0.203
logSdLogN_0	-2.022	0.181	0.132	0.092	0.190
logSdLogObs_0	-0.269	0.057	0.764	0.683	0.856
logSdLogObs_1	-1.355	0.137	3.876	2.947	5.097
logSdLogObs_2	-1.160	0.128	3.189	2.470	4.118
logSdLogObs_3	-0.169	0.137	0.844	0.643	1.109
transfIRARdist_0	-1.238	0.420	0.290	0.125	0.671
transfIRARdist_1	-3.178	0.367	0.042	0.020	0.087
transfIRARdist_2	-4.066	0.403	0.017	0.008	0.038
transfIRARdist_3	-1.154	0.382	0.315	0.147	0.677

transfIRARdist_4	-2.808	0.294	0.060	0.034	0.109
itrans_rho_0	1.459	0.220	4.303	2.772	6.678

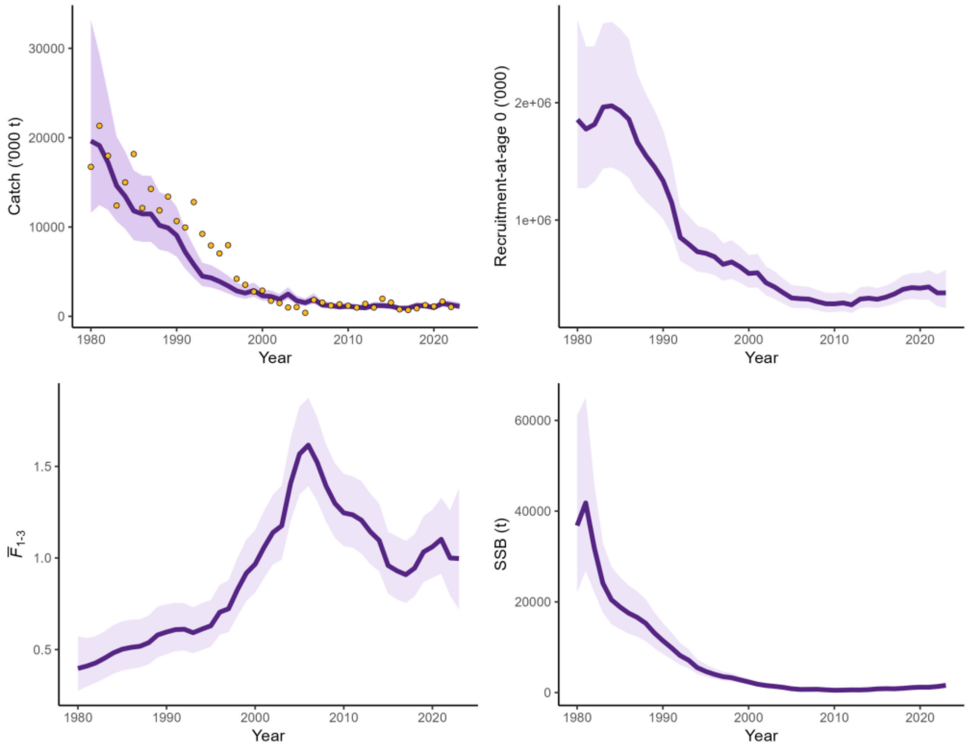

Figure 3.6.1. Stock development of final whg.27.7a SAM run, with 95% confidence intervals. The *yellow* dots show ICES catch estimates.

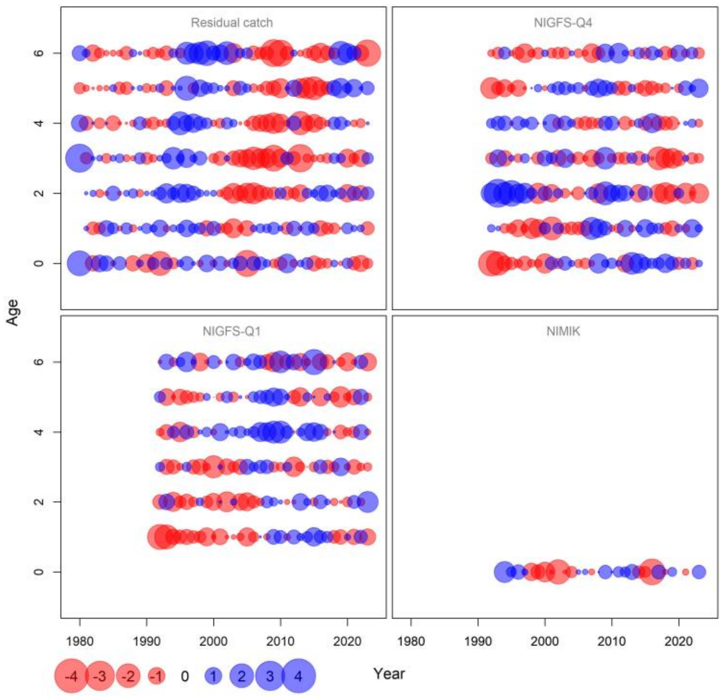

Figure 3.6.2. Standardized one-observation-ahead residuals from the final whg.27.7a SAM run for the catch (*top left*), NIGFS-WIBTS-Q1 (*bottom left*), NIGFS-WIBTS-Q4 (*top right*), and NI MIK (*bottom right*) fleets.

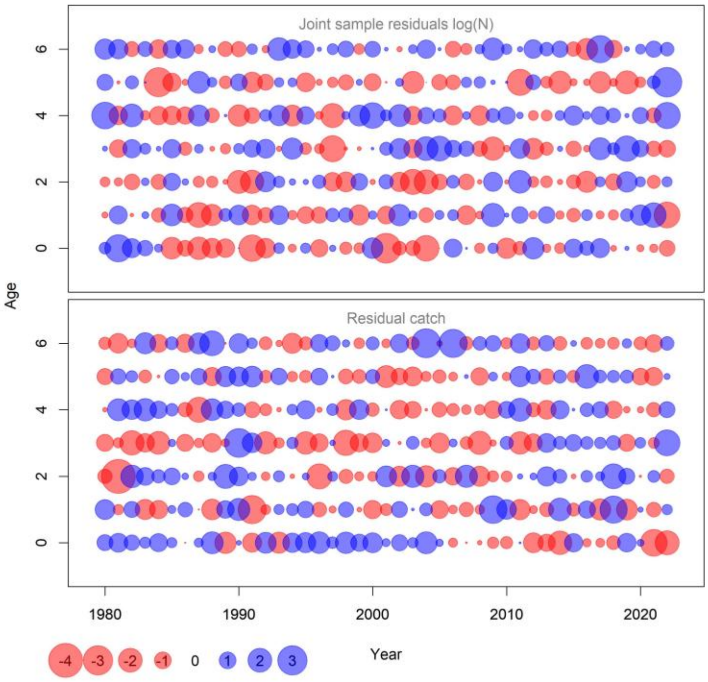

Figure 3.6.3. Process residuals from the final whg.27.7a SAM run for the stock numbers-at-age (*top*), and $\overline{F}$-at-age (*bottom*).

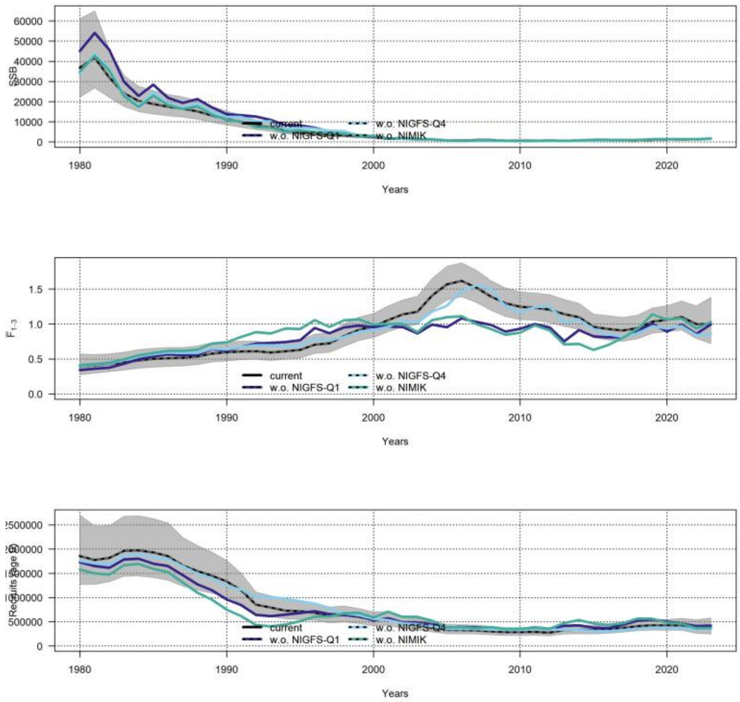

Figure 3.6.4. Leave-one-out runs based on the final whg.27.7a SAM configuration.

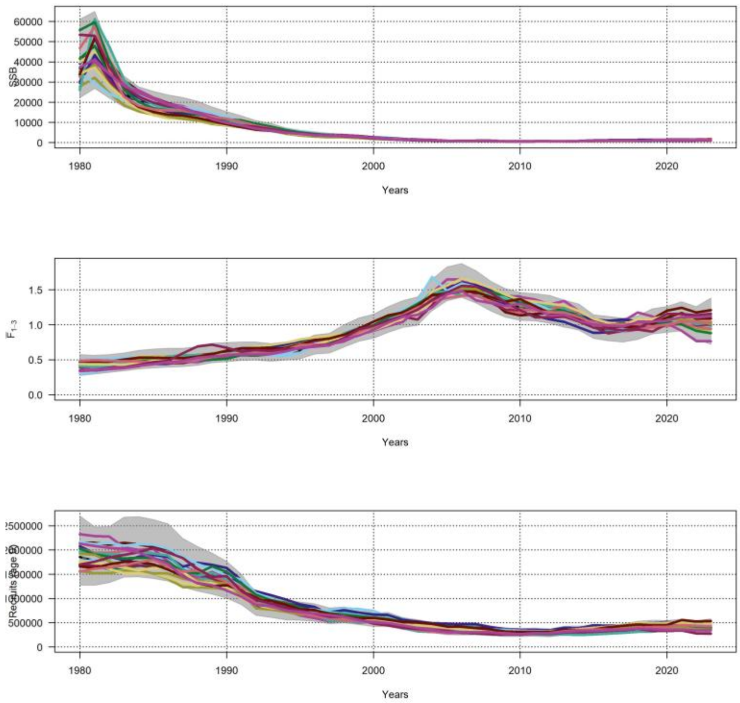

Figure 3.6.5. Conditional simulation runs based on the final whg.27.7a SAM configuration.

3.7 Biological reference points

3.7.1 Regime shift

The Irish Sea ecosystem has undergone major changes in recent decades, with evidence of large changes in the abundance and composition of species communities, including phytoplankton, zooplankton and fish species. The majority of these changes began in the early 1990's and are coincident with rising sea temperatures. This is referred to by some authors as a 'regime shift' in the Irish Sea ecosystem (e.g. ICES 2016, Bentley et al. 2020, Mitchell, 2021, Tironen, 2023).

An overview of ecological changes was presented during the WKNSCS data benchmark and summarised in working document 3.4. The ecosystem changes presented include:

- Broadscale changes in the Irish Sea ecosystem including climate, phytoplankton, zooplankton and fish species.
- Environmental correlates of biological parameters: changes in weights-at-age; total mortality rates; and recruitment.
- Stock-recruitment change-point detection.
- Diet analysis: evidence of an increase in the incidence of cannibalism.
- Modelling whiting Irish sea Ecopath with Ecosim (EwE).
- Genetic analysis

The WKBNSCS experts concluded that there was sufficiently evidence of a 'regime shift' to consider the use of a shortened time-series for reference point setting (following ICES, technical guidelines for setting reference points for cat 1 and 2 stocks and WKNEWREF recommendations).

3.7.2 Identifying the appropriate period of stock-recruit pairs

The review of ecosystem changes in the Irish Sea indicated that many of these changes occurred around the 1990s. The stock-recruitment data for the full time series (Figure 3.7.1) indicate that the both the stock size recruitment levels were very high during the 1980s. During this period the stock size decreased, initially maintaining high recruitment but since the mid-1980s, recruitment decreased. After an apparent changepoint in 1992 the stock appeared to decline along an almost perfect Beverton-Holt curve before settling at a low but relatively stable SSB and recruitment. It should be noted that the SAM model was fit without a stock-recruit model (i.e. recruitment was estimated independently of stock size).

The year 1992 was chosen as the start of the new stock-recruit regime. This allowed the inclusion of the maximum number of SR pairs in the recent period (further shortening of the time series would have little impact on the SR parameters because the observations fit very closely to the BH curve). Figure 3.7.2 shows the recent SR pairs with the fit to the BH curve.

3.7.3 Stock type and B_{lim} and B_{pa}

The SR relationship does not fall into any of the SR types described in the ICES technical guidelines for setting reference points. The group considered the following:

- Bloss was not considered to be a precautionary candidate for Blim.
- There is no clear breakpoint for a segmented regression.
- A Blim value based on median recruitment (B empirical) would be highly dependent on the choice of time period to include in the analysis.
- Basing Blim on a proportion of R0 may be a reasonable approach but not one that is routinely used in ICES.
- WKNEWREF (2024) collated information on Blim as a proportion of B0 for stocks where B0 was well defined. For gadoids, the mean Blim/B0 ratio is 15%. This is at the higher end of the recent levels of SSB and is therefore considered to be conservative.

WKNSCS decided that Blim = 15% B0 is the most appropriate basis for Blim in this case. However, considering the uncertainty around the potential reproductive capacity of the stock; this decision needs to be reviewed on a regular basis: if there is evidence that recruitment is further impaired at this level of SSB, a more precautionary Blim reference point may need to be set.

Decision: B_{lim} = 15% B0 = 1,670 t

B_{pa} is defined as B_{lim} plus assessment error: The model estimates assessment error to be 0.16. This may be an under estimate so it was decided to use the default error value of 0.2 resulting in a $B_{pa} = B_{lim} * \exp(1.645 * 0.2) =$ 2,322

Decision: B_{pa} = 1.39 * B_{lim} = 2,322 t

3.7.4 F_{MSY} and $B_{trigger}$

The eqsim approach was used to estimate F reference points (https://github.com/ices-tools-prod/msy). F_{MSY} is initially calculated based on an evaluation with the inclusion of stochasticity in a population (i.e. recruitment, M, maturity, growth) and fishery (e.g. selectivity) as well as assessment error. This is a constant F, which should provide maximum yield without biomass constraints (without MSY $B_{trigger}$). F_{MSY} without $B_{trigger}$ is estimated as 0.21.

MSY $B_{trigger}$ should be selected to safeguard against an undesirable or unexpected low SSB when fishing at F_{MSY}. For most stocks that lack data on fishing at F_{MSY}, MSY $B_{trigger}$ is set at B_{pa}. However, as a stock starts to be fished consistently with F_{MSY}, it is possible to move towards implementation of a value for MSY $B_{trigger}$ that reflects the 5th percentile definition of MSY $B_{trigger}$. In this case the stock has not been fished near F_{MSY} so Bmsy5pc is not appropriate here and MSY $B_{trigger}$ is set at B_{pa}

Decision: $B_{trigger} = B_{pa}$

Note that in order to ensure consistency between the precautionary and the MSY frameworks, F_{MSY} is not allowed to be above Fp05 (F_{pa}). The ICES MSY AR should therefore be evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfills the precautionary criterion of having less than 5% annual probability of SSB < Blim in the long term. The evaluation must include realistic assessment/advice error and stochasticity in population biology and fishery selectivity.

F_{MSY} with the AR is unchanged at 0.21 with a range of 0.16-0.314 and F_{pa} is estimated to be well above that at 0.78 so there is no need to cap F_{MSY} or $F_{MSYUpper}$ (Figure 3.7.3).

The estimated reference points are shown below and the recent stock development in relation to the reference points is shown in Figure 3.7.4.

Reference Point	Value	Rationale
B_{lim}	1,670	0.15*B0; average B_{lim}/B0 for gadoids (WKMSYREF)
B_{pa}	2,322	B_{lim} with assessment error
MSY $B_{trigger}$	2,322	B_{pa}
F_{pa}	0.78	F with 95% probability of SSB>B_{lim} (BH with $B_{trigger}$)
F_{MSY}	0.21	Stochastic simulations
$F_{MSYLower}$	0.16	Stochastic simulations
$F_{MSYUpper}$	0.314	Stochastic simulations

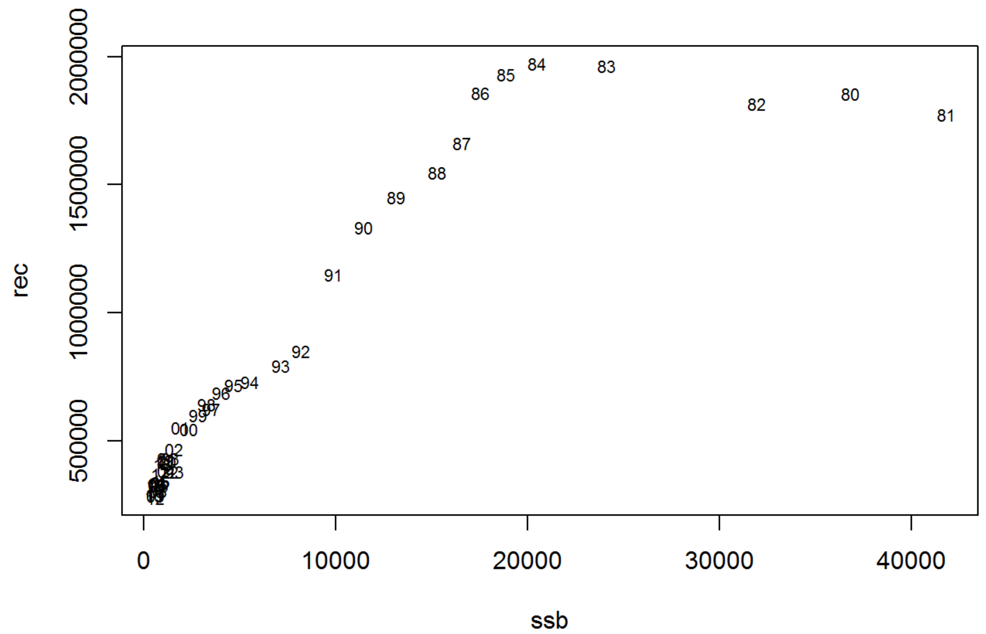

Figure 3.7.1. Stock-recruit pairs for the full time series.

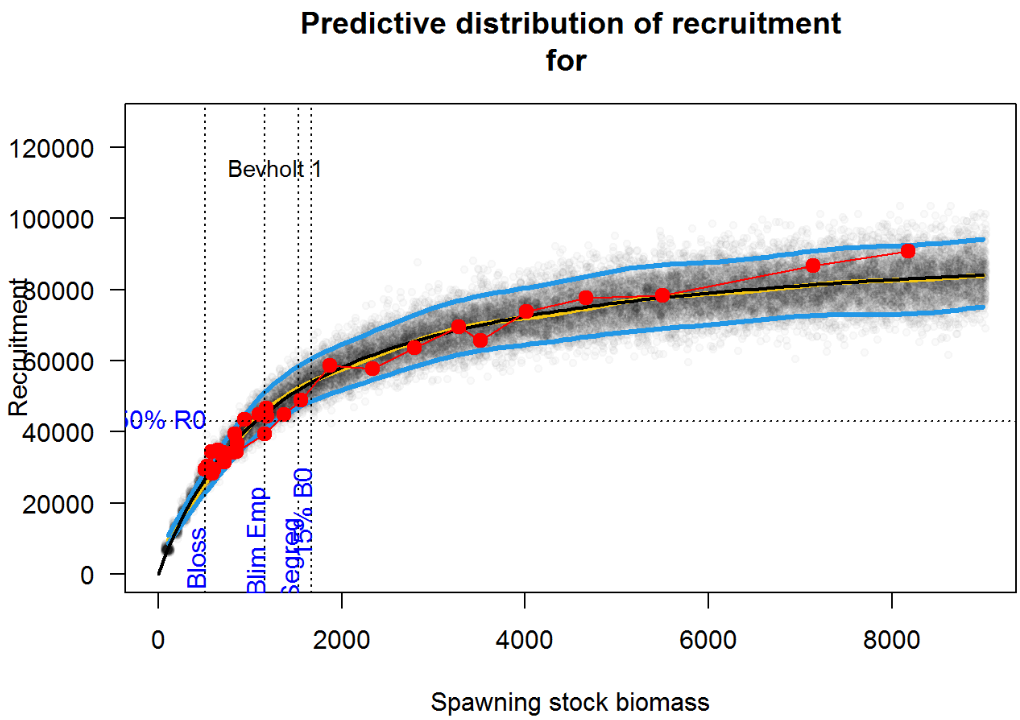

Figure 3.7.2. Stock-recruit pairs of the recent time period with the fitted BH curve. The vertical lines indicate some biomass points that can inform B_{lim}: B_{loss}; Empirical B_{lim}; segreg breakpoint and 15% B0. The horizontal line indicates the point where recruitment is 50% of R0.

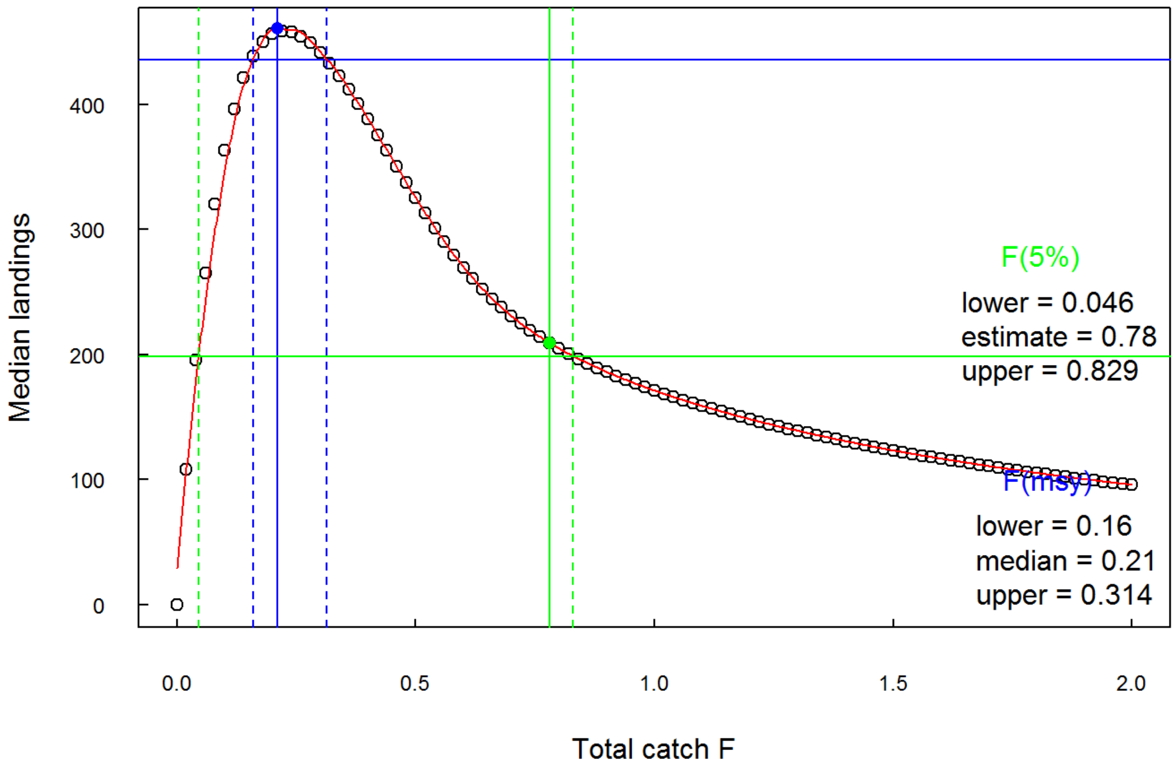

Figure 3.7.3. Eqsim run with the ICES advice rule, assessment error and stochasticity in population biology and fishery selectivity.

Figure 3.7.3. Recent stock development with the main reference points. For F, the dotted line corresponds to F_{MSY}, for SSB the dotted line is B_{lim} and the dashed line is $B_{trigger}$.

3.8 Forecast settings

The WK agreed that the short-term forecast functionality of the "stockassessment" R package was a suitable method for performing stochastic short-term projections from the assessment, for the provision of catch advice. It was agreed that recruitment should be resampled from the most recent 19-year period. Since the early 2000s, recruitment has remained at a consistent, relatively low level (Figure 3.8.1). Over that period, the values are evenly distributed around their median and geometric mean, suggesting some stability in levels of recruitment rates, supporting the choice of that period for forecast resampling.

Catch weights at age have generally followed a declining trend across ages over the modelled period (Figure 3.8.2). In recent years (i.e. since 2000), mean weights-at-age have been quite variable, particularly for ages three and upwards where sample sizes are often quite small. It was agreed that five-year averages should be used for the input weights-at-age in the forecast to smooth through some of that sample variability (this also applies to stock weight, maturity, and natural mortality profiles).

Fishery selectivity (i.e. proportion landed by age, Figure 3.8.3) had some definite trends in ages one-four, particularly in the early part of the modelled period, and then fluctuated substantially over time for different age classes since around 2000. Due to the noisy nature of these estimates in most recent years, a five-year average was recommended for the forecast selection pattern. The assumption of *F* in the intermediate year is a decision that should be reviewed at the assessment WG meeting based on the best knowledge of the fishery from year-to-year.

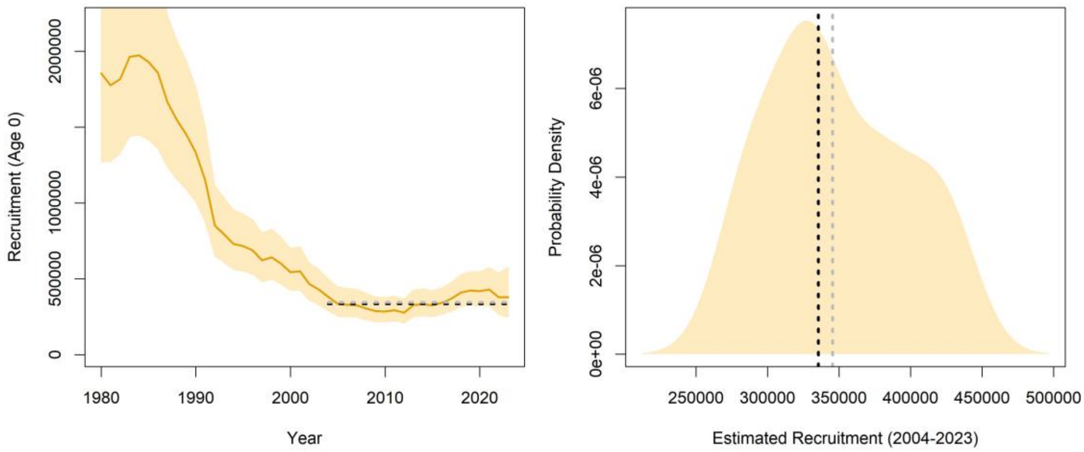

Figure 3.8.1. Recruitment estimates over the modelled period with 95% confidence intervals (left), and probability density of recruitment estimates from 2004-2023 (right). In both panels, the black and grey dotted lines show the median and geometric mean values of recruitment, respectively, between 2004-2023.

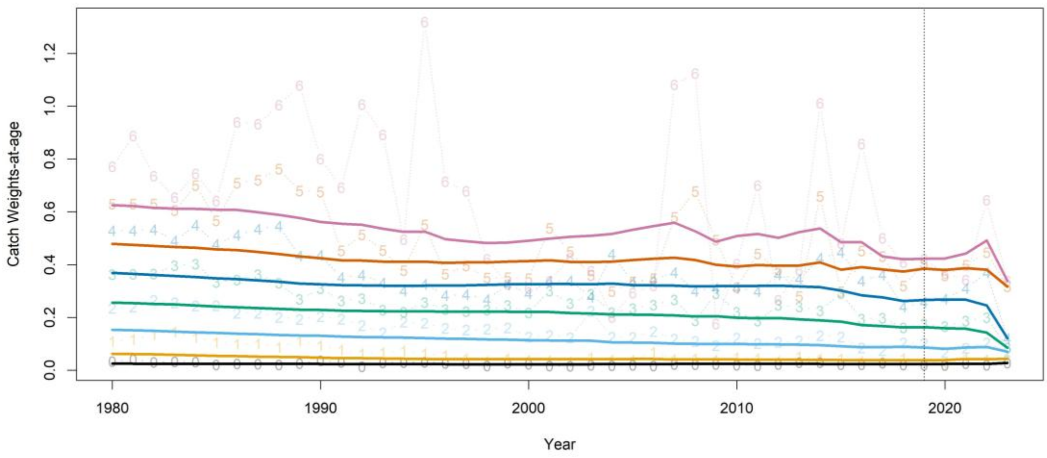

Figure 3.8.2. Catch weights-at-age for 7.a whiting are shown in the feint-coloured lines and numbers, with retrospective cumulative averages shown with heavier lines. The vertical dotted black line shows the five-year average used in the forecast.

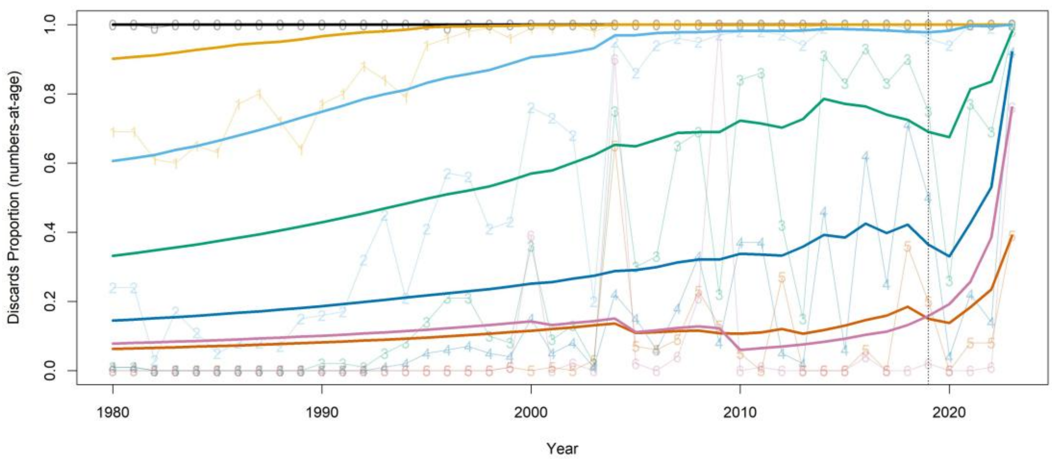

Figure 3.8.3. Discard proportions-at-age for 7.a whiting are shown in the feint-coloured lines and numbers, with retrospective cumulative averages shown with heavier lines. The vertical dotted black line shows the five-year average used in the forecast.

3.9 Recommendations for the future

The following recommendations are put forward for future work for this stock.

- Recreational data should be requested in future data calls.
- Improved sampling of discards is needed. Any further decline in sampling, as indicated by recent reductions, will compromise the accuracy and reliability of future stock assessments.

- To WGBIOP: Following a mini age calibration exchange between Ireland and Northern Ireland, coupled with recent changes in primary age readers, there is a recommendation for a more formal age reading workshop to be conducted via SMARTDOTS.
- To WGCSE: WGCSE should annually review whether the reference points are still appropriate. Considering the uncertainty around the potential reproductive capacity of the stock; the reference points (in particular the decision around B_{lim}) needs to be reviewed on a regular basis: if there is evidence that recruitment is further impaired, a more precautionary B_{lim} reference point may need to be set.

3.10 References

Capizzano, C. W., Mandelman, J. W., Hoffman, W. S., Dean, M. J., Zemeckis, D. R., Benoît, H. P., Kneebone, J., Jones, E., Stettner, M. J., Buchan, N. J., Langan, J. A., & Sulikowski, J. A. (2016). Estimating and mitigating the discard mortality of Atlantic cod (*Gadus morhua*) in the Gulf of Maine recreational rod-and-reel fishery. *ICES Journal of Marine Science*, *73*(9), 2342–2355.

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ICES (2021). ICES fisheries management reference points for category 1 and 2 stocks (2021). ICES Technical Guidelines. Report. https://doi.org/10.17895/ices.advice.7891

ICES (2024). Workshop on the calculation and evaluation of new reference points for category 1–2 stocks (WKNEWREF). ICES Scientific Reports. Report. https://doi.org/10.17895/ices.pub.27905664.v1

Nielsen, A., and Berg, C. W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research, 158: 96–101.

Nielsen, A., and Berg, C. W. 2016. Accounting for correlated observations in an age-based state-space stock assessment model. ICES Journal of Marine Science 73, 1788-1797.

Prodöhl, P.A. (2023). *Evidence of Biological and Genetic Bottlenecks of Irish Sea Whiting (Merlangius merlangus)*. Unpublished manuscript, School of Biological Sciences, Queen's University Belfast. Prepared for AFBI

3.11 Reviewers report

The previous assessment for whiting in Division 7.a was based on an ASAP model that combined landings and discards as one series and three indices from RV surveys. Issues flagged with this previous assessment model included 1) fixed selectivity blocks, when the composition of the fishing fleet is known to have changed over time, 2) poor fit to survey observations in the 90's, and 3) lack of inclusion of fishery discards. The state-space assessment model (SAM) is a flexible framework that was used as the assessment model for the benchmark with the hopes of addressing issues with the previous model.

Changes to model inputs were discussed and accepted at the data review meeting. Knife-edge maturity was updated to a time-varying ogive by running a smoother through the raw data. This was considered a better approach as the Q1 NIBTS survey has good sampling for maturity, and the previous approach did not capture changes in maturity over time. Stock weights were previously based on catch weights. These were updated to smoothed survey weights which had better resolution and availability. Survey indices from the previous assessment were design-based estimates from the fixed-station surveys. Model-based indices were developed and showed better internal consistency than the design-based indices. Additionally, consistency between the two survey periods was also improved.

Major topics of discussion at this benchmark included 1) strange patterns in the catch at age residual plots, 2) how/if to incorporate recreational catch estimates in the assessment, and 3) truncating of the recruitment time series when estimating reference points.

1) Initial model runs from the pre-benchmark meeting showed strange patterns in the catch at age residuals, which were amplified in the plots of aggregated observed vs predicted catches. The model showed consistent under estimation of aggregated catch from approximately 1990-2009, and under estimation for the subsequent few years. The issue was flagged at the pre-meeting, however it was suggested that these issues could most likely be resolved through exploration of various model formulations. At the benchmark, a wide range of model formulations were explored, including accounting for recent recreational catch estimates, coupling of the fishing mortality processes, changing the fleet covariance structure, and coupling of the survey catchability estimates. No model formulation appeared to address the misfit in the catch at age data. It was noted that there was a known change in the fishery selectivity (from a midwater gadoid fishery to bycatch in the *Nephrops* fishery) during that time period, and it appeared that the model simply could not account for this abrupt change. Sensitivity runs that attempted to fit closely to the catch at age data did not converge and a run that removed the problematic years produced results similar to the model that included the data in those years. Since the problematic years fell in the middle of the time series, did not appear to drive any of the model estimates, and there was a known change in fishery selectivity during that time period, the benchmark group decided to accept the model for the assessment.
2) Recreational catch data were available for the first time for this benchmark. At the data review meeting, four approaches were considered for how to incorporate recreational catches in the stock assessment models, with the assumption that recreational removals have been constant over time (based on the mean removals 2016-2023) selected as most reasonable. SAM models were fit with and without the inclusion of the recreational data and had little impact on final model output (other than expected changes, i.e. slight rescaling of population processes). There were lengthy discussions on whether or not to include the recreational data in the final assessment model since recreational estimates were based on only eight years of data. It was noted that the assumption that catches were constant in time inherently assumes that the selectivity has changed in line with the commercial catches, which is very unlikely. However, due to a lack of information on the historical recreational catches, it was considered a better approach than ignoring the recreational catches altogether. An alternative suggestion, to only include the years where recreational estimates were available, was rejected since this made the assumption of no recreational catches for years where the data did not exist. The final model selected included the recreational catches since this was considered more representative of total stock removals.
3) Detailed discussions were had about whether there was sufficient evidence to truncate the recruitment time series under the assumption that a regime shift had occurred. The assessment team presented a range of evidence to support a regime shift, including stock-recruit change-point detection, increased evidence of cannibalism based on diet composition analysis, changes in species composition/abundance and rising sea temperatures. The group agreed that there was strong evidence of a change in regime and there was general consensus to truncate the time series. The majority of the work flagged these

changes as occurring around the 1990's, and it was agreed to truncate the recruitment time series from 1992 onward. The eqsim approach was used to estimate reference points based on the truncated time series.

The assessment teams were well prepared for both the data and benchmark meetings and were open and willing to address additional requests and sensitivity runs from the reviewers. Very much appreciated the collaborative and welcoming environment!

The meeting greatly benefited from having Anders Nielsen available to assist with final model selection/debugging and understand that this is the standard ICES approach for Benchmarks. However, running through final model selection during the meeting can become a bit confusing and rushed. Might be useful to reach out to Anders before the meeting (know this was done in some cases) and run the suite of candidate models before the meeting so that reviewers can easily run through the model formulations and to help expedite the Benchmark process.

The stock assessment for whiting in Division 7.a met the terms of reference and can be used to provide management advice. The external reviewers would like to thank Anders Nielsen for attending the workshop and providing invaluable advice on SAM configuration and analysis and Dorleta Garcia for providing advice on ICES reference point guidelines during the meeting.

Annex 1: List of participants

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Annex 2: Resolutions

WKBNSCS – Benchmark workshop on North Sea and Celtic Sea stocks

2024/WK/FRSG A **Benchmark workshop on North Sea and Celtic Sea stocks (**WKBNSCS**),** chaired by Lies Vansteenbrugge, Belgium, and Daniel Hennan, US, and attended by reviewers Andrea Perreault, Canada, and Mikel Aristegui-Ezquibela, Ireland, will be established and meet online on 19-21 November 2024 for a data evaluation workshop, and on 3-7 February 20245 at ICES Headquarters, Copenhagen, for an assessment methods workshop. WKBNSCS will:

a) As part of the data workshop:
    1. Consider the quality of data proposed for use in the assessment;
    2. Consider stock identity and migration issues, if appropriate;
    3. Make a proposal to the benchmark on the use and treatment of data for each assessment, including discards, surveys, life history, etc.
        i. Note: stakeholders are also invited to contribute data in advance of the data evaluation workshop (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality.

b) In preparation for the assessment methods workshop:
    1. Produce working documents to be reviewed during the assessment methods workshop at least 14 days prior to the meeting.

c) As part of the assessment methods workshop, agree to and thoroughly document the most appropriate, data, methods, and assumptions for:
    1. Obtaining population abundance and exploitation level estimates (conducting the stock assessment);
    2. Estimating fisheries and biomass reference points that are in line with ICES guidelines (see latest technical guidelines on reference points);
        i. Note: If additional time is needed to conduct the work and agree to reference points, an additional reference point workshop could be scheduled.
    3. Conducting the short-term forecast.

d) As part of the assessment methods workshop, a full suite of diagnostics (regarding e.g. data, retrospective behaviour, model fit, predictive power etc.) should be examined to evaluate the appropriateness of any model developed and proposed for use in generating advice.

e) If no analytical assessment method can be agreed upon, then an alternative method (the former method, or following the ICES data-limited stock approach see WKLIFE X[1],

[1] ICES. 2020. Tenth Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE XI). ICES Scientific Reports. 2:98. 72 pp. http://doi.org/10.17895/ices.pub.5985

including considerations of stock-specific tuning with a management strategy evaluation, if possible) should be put forward by the benchmark;

f) Update the stock annex;

g) With support from the ICES Secretariat, document the stock assessments in the Transparent Assessment Framework (TAF)[2]; and

h) Develop recommendations for future improvements in the assessment methodology and data collection.

WKBNSCS will report by 01 March 2025 for the attention of ACOM.

Recurrent advice subject to benchmark				
Stock name	**Stock code**	**Current assessment**	**Aims at the benchmark**	**Link to latest ICES advice**
Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	Tur.27.4	SAM		HERE
Plaice (*Pleuronectes platessa*) in Division 7.d (eastern English Channel)	Ple.27.7d	Aarts and Poos		HERE
Whiting (*Merlangius merlangus*) in Division 7.a (Irish Sea)	Whg.27.7a			HERE

[2] https://taf.ices.dk/app/procedure

Annex 3: Working Documents

Update of biological data of plaice (*Pleuronectes platessa*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025)

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1. Maturity

The plaice maturity was updated based on the study of Sauger et al., (2023) in the English Channel. The new maturity ogive was estimated using a quantitative histological analysis considered as more accurate than the visual determination of the sexual maturity (Figure 18). The comparison of the two methods showed that the macroscopic visual method misclassified some individuals that had spawned but were considered as immature (Sauger et al., 2023). Due the change of the method of the estimation of the maturity ogive, it was decided during the benchmark meeting (WKBNSCS 2024) to use the new maturity ogive estimation based on histological method as a constant maturity for the entire time series. This choice was also justified by the fact there are no trends in the proportions of matures from UK and French data (Figures 19 and 20).

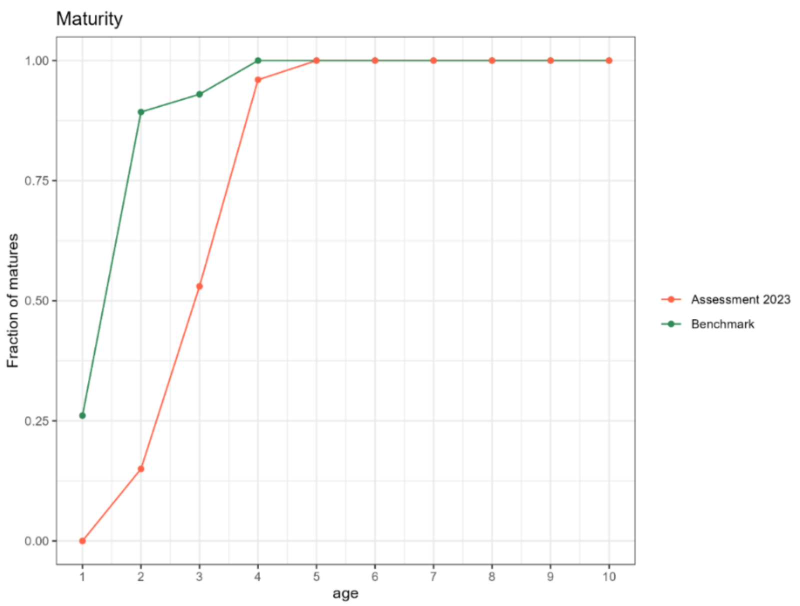

Figure 18 : The fraction of matures used in WGNSSK 2024 estimated using a visual method (red) and the fraction of matures estimated using a histological method (green)

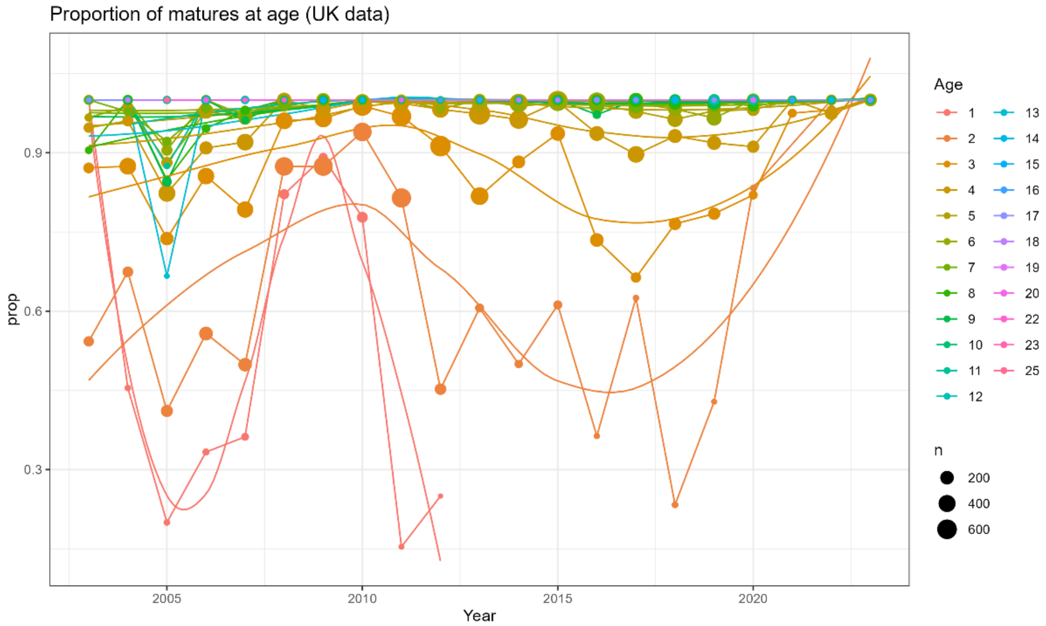

Figure 19: The proportion of matures over the period 2003 – 2023 from UK data

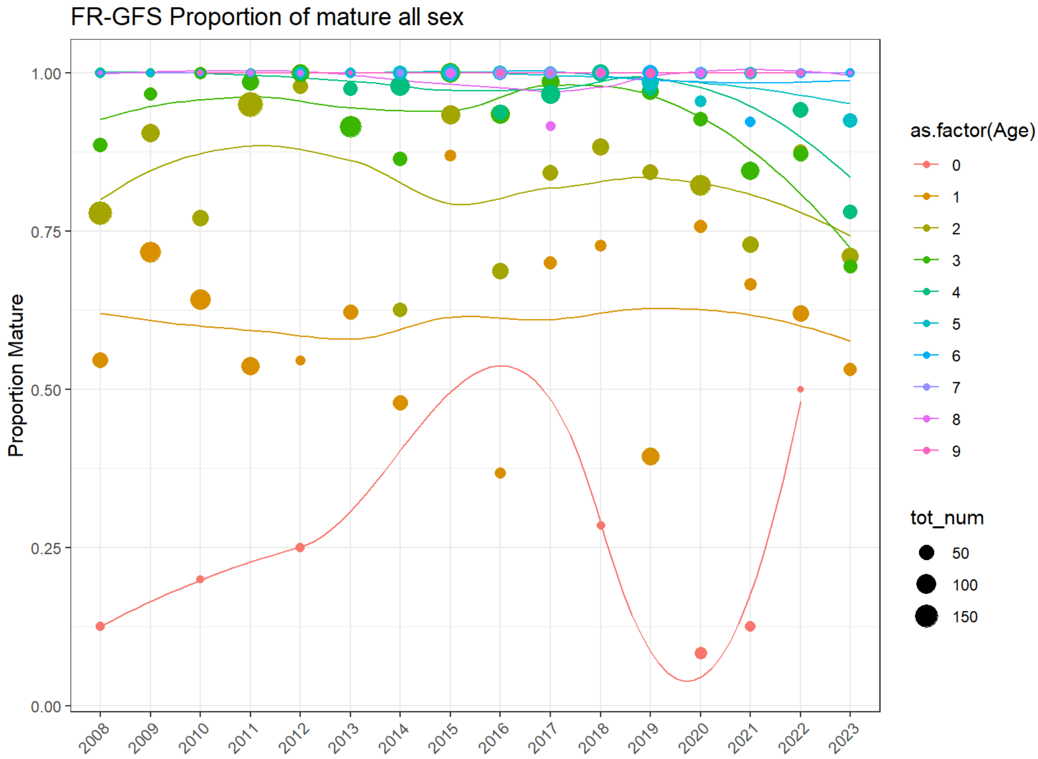

Figure 20: The proportion of matures over the period 2008 – 2023 from French data

2. Natural mortality

A constant natural mortality at age will be applied in the assessment model. Different methods will be tested during the benchmark using SAM model to select the appropriate method. Figure 21 represents the natural mortality at age estimated using different methods (exp. Lorenzen, Alverson_Carney, Peterson_Wroblewski).

Below the parameters used to estimate plaice natural mortality at age for the different methods:

- Linf = 42.25490829 # VGBF
- K = 0.319463137 # VGBF
- tm = 3 # age of maturity
- tmax = 17 # max observed age
- a = 0.00338 # coefficient Length-Weight relationship
- b = 3.241 # coefficient Length-Weight relationship
- a_M = 3 # Lorenzen scaling constant
- b_M = -0.288 # Lorenzen exponent

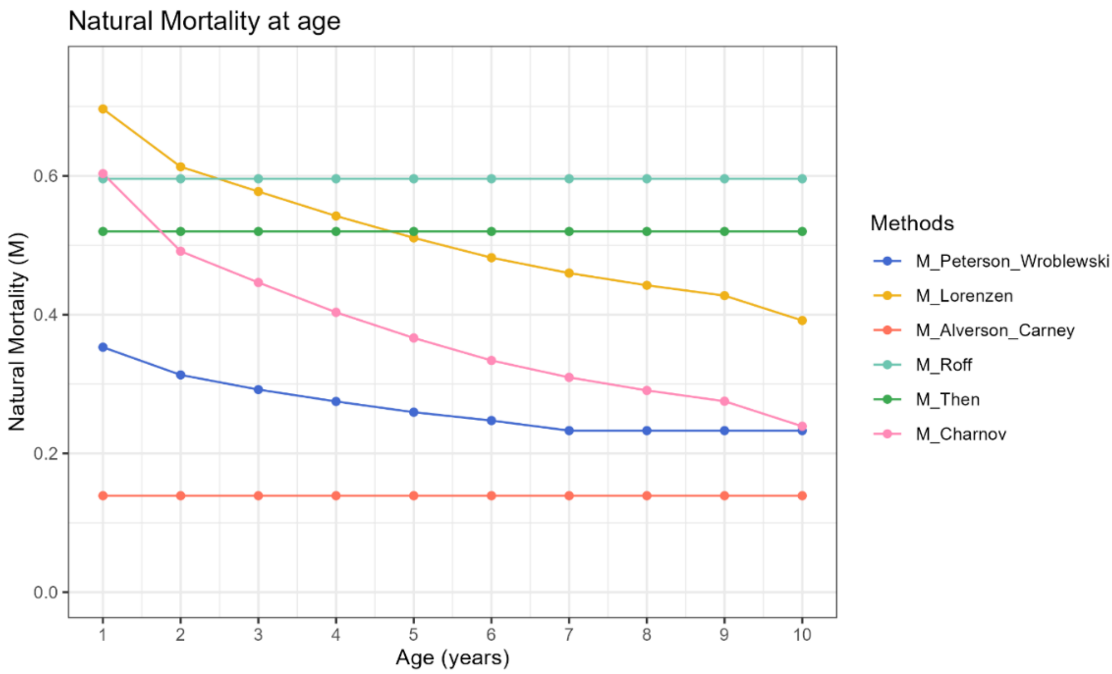

Figure 21 : The plaice natural mortality at age calculated using different methods from the R package fishmethods (Nelson, 2023)

3. Plaice migration

There is a high uncertainty about plaice migration due to :

- A lack of recent studies : the main tagging experiments were carried out between 1960s and 1990s and the percentage.
- The percentage of removals is fixed since WKFLAT 2010. There are no recent evidences about the variability of migration.

- There is a high uncertainty on the spatial distribution of fishing fleets in the past (which has an impact on the recapture of conventional tags).

However due to the potential impacts of any change of Q1 removals of plaice 7d on ple.27.420 and ple.27.7e stocks. It was decided to keep the current Q1 removals since there is no recent evidence which justify a change of migration. There is a need to organize a project in order to investigate plaice migration in the English Channel more in depth and discuss this issue with ple.27.420 and ple.27.7e stocks.

4. References

Nelson, G.A., 2023. fishmethods: Fishery Science Methods and Models. https://doi.org/10.32614/CRAN.package.fishmethods

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Preparation of catch data for plaice (*Pleuronectes platessa*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025)

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The historical time series of InterCatch data for the period 2002 – 2023 was updated due to a change in calculations methods in the French data for:

i) Deriving landings-at-age in 2020
ii) The calculation of discards.

1. Check the grouping of the raising procedure in InterCatch
   1.1. Raising discards

Discards data have been provided under the ICES InterCatch format by France, Belgium, and UK since WKPLE (ICES, 2015). The discard volumes of the missing strata have been raised annually using the grouping presented in Table 1 (all quarters were pooled).

Table 1: The grouping used to raise discards since 2015 Benchmark.

Season	Unsampled fleets*	Sampled fleets**
Whole year	TBB	TBB
	OTB, OTT	OTB, OTT
	Seines (SDN, SSC)	Seines (SDN, SSC)
	Nets (GNS, GTR)	Nets (GNS, GTR)
	Others (OTM, LLS, MIS, DRB, FPO)	All métiers

* Unsampled fleet are those fleets for which no discards data have been provided.

** Sampled fleet are those fleets for which the discards volumes are known.

1.1.1. Discards ratios

Figure 1 represents the discards ratios by fleet calculated from the data submitted in InterCatch. The current grouping shows that there are few Seine fleets where landings have associated discards. It was decided during WKBNSCS 2024 to include the Seine fleets in the group “Others” and use all available fleets to perform the raising annually (Figure 2). The new grouping to raise the discards is presented in Table 2.

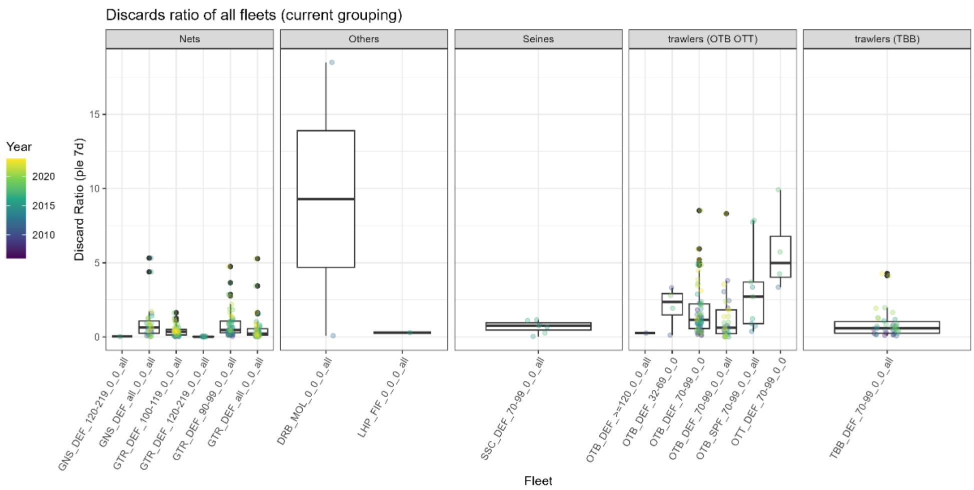

Figure 1: Discards ratios of the different fleets using the grouping of the last benchmark (2015)

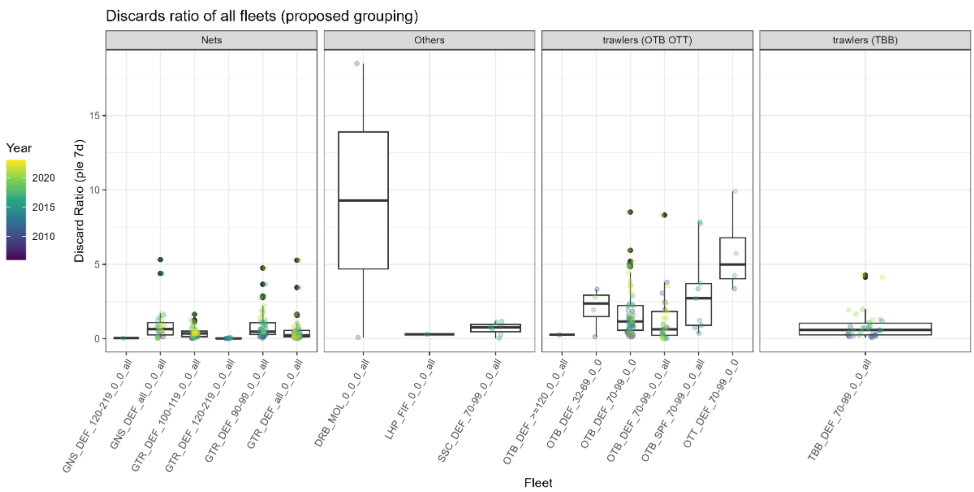

Figure 2: Discards ratios of the different fleets using the grouping of the current benchmark (WKBNSCS 2024)

Table 2: The new grouping to raise the discards (WKBNSCS 2024)

Season	**Unsampled fleets***	**Sampled fleets****
Whole year	TBB	TBB
	OTB, OTT	OTB, OTT
	Nets (GNS, GTR)	Nets (GNS, GTR)
	Others (LLS, MIS, DRB, FPO) + Seines (SDN, SSC)	All métiers

* Unsampled fleet are those fleets for which no discards data have been provided.

** Sampled fleet are those fleets for which the discards volumes are known.

1.2. Age allocation

The age structure of unsampled landings and discards were done per quarter and year using the groups of Table 3. The Figure 3 shows the variability of age structure through time using the grouping defined at the last benchmark in 2015. It was decided to keep the same procedure of age allocation to consider the variability between quarters.

Table 3: The grouping used for age allocation (2015 benchmark).

Season	Unsampled fleets*	Sampled fleets**
Quartely (Q1, Q2, Q3, Q4) & Yearly***	Nets (GNS, GTR)	Nets (GNS, GTR)
	Trawls (OTB, OTT, TBB), Seines (SDN, SSC)	Trawls (OTB, OTT, TBB), Seines (SDN, SSC)
	Others (OTM,LLS,MIS, DRB,FPO)	All métiers

* Unsampled fleet are those fleets for which no discards data have been provided.

** Sampled fleet are those fleets for which the discards volumes are known.

*** Yearly discards are raised using all seasons (Q1, Q2, Q3, Q4 and year)

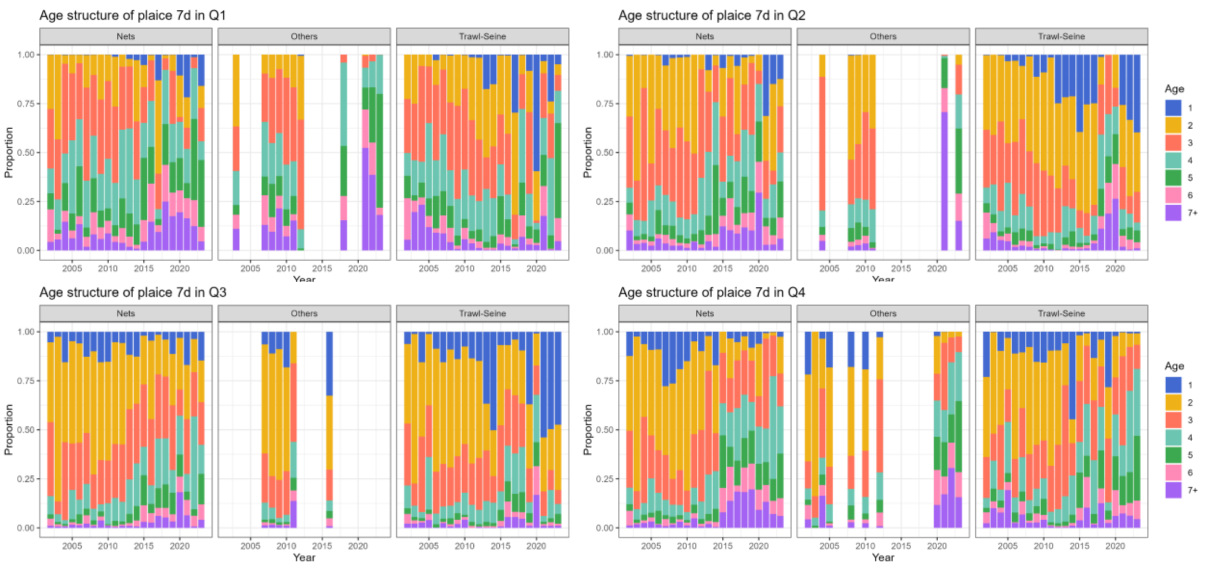

Figure 3: Age structure of plaice 7d by quarter and group (Nets, Others, Trawl-Seine)

2. InterCatch Export

2.1. Landings and discards number at age

The new InterCatch export showed a decrease of landings number for ages 2 and 3 in the recent years and increase of discards of lower ages in the same period.

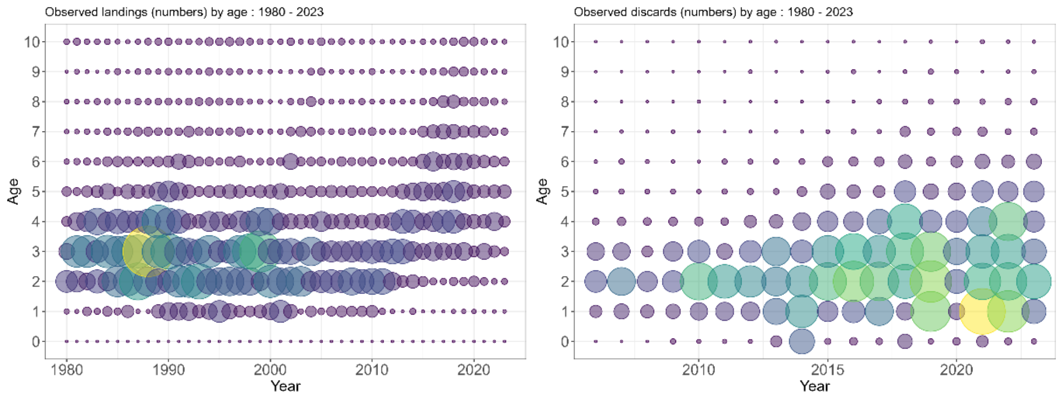

Figure 4: Observed landings and discards (numbers) at age

2.2. Weights at age

A general decrease of weight at age was observed from 2014 especially for higher ages (Figure 5). Similar trends were observed in the survey data of UK BTS and FR GFS (Figure 6).

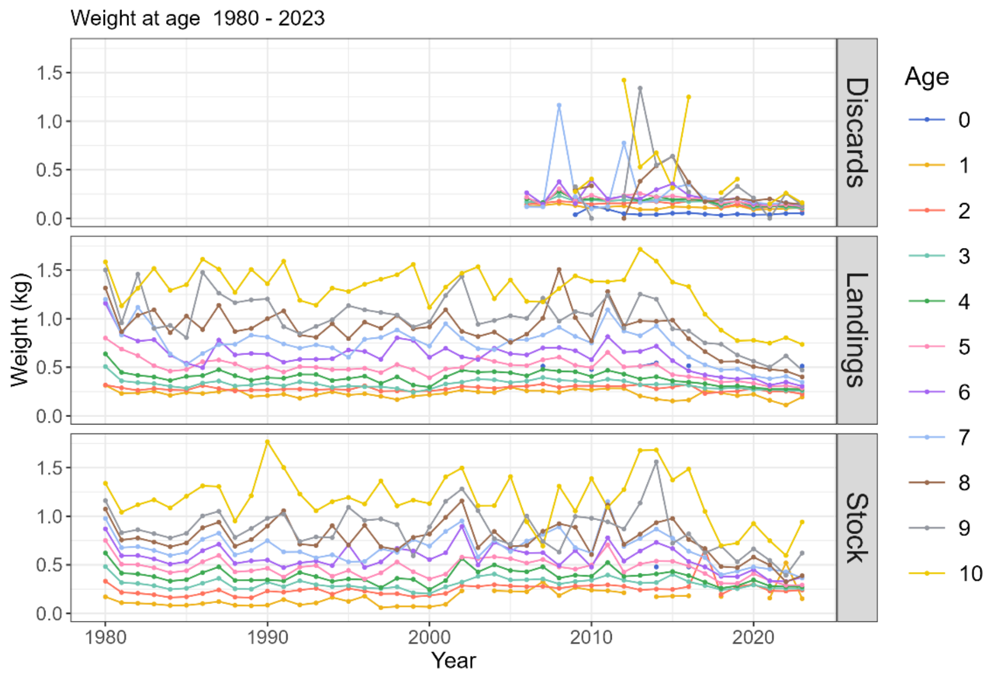

Figure 5: Weight at age (discards, landings and stock) for the period 1980 – 2023

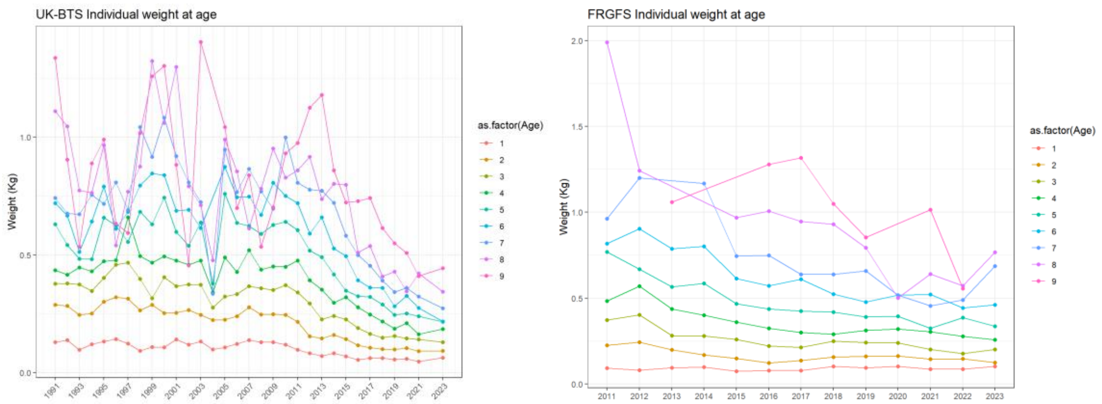

Figure 6: Weight at age in survey data FR GFS and UK BTS

2.3. Proportion of discards at age

A general increase of the proportion of discards at age was observed since 2011 (Figure 7).

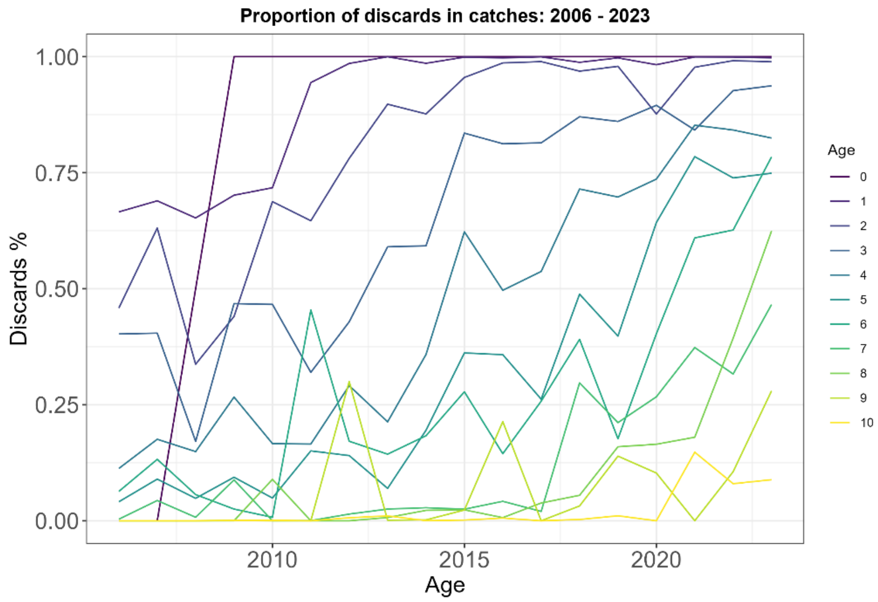

Figure 7: Proportion of discards by age in the catches for the period 2006 – 2023

3. Comparison of historical data and InterCatch exports

3.1. Landings and discards (Caton)

The comparison of total landings and discards of the current InterCatch exports (WKBSCS 2024) and the InterCatch export of the previous assessment (2023) showed a good consistency between the two dataset.

The main differences are explained by i) the update of the method of calculations of discards, ii) the estimation of landings at age in the French data and iii) the update of landings and discards for Belgium and United Kingdom.

The most important change was observed in the discards of 2021. This change is explained by the fact that in 2020 and 2021 discards were underestimated due to the COVID crisis.

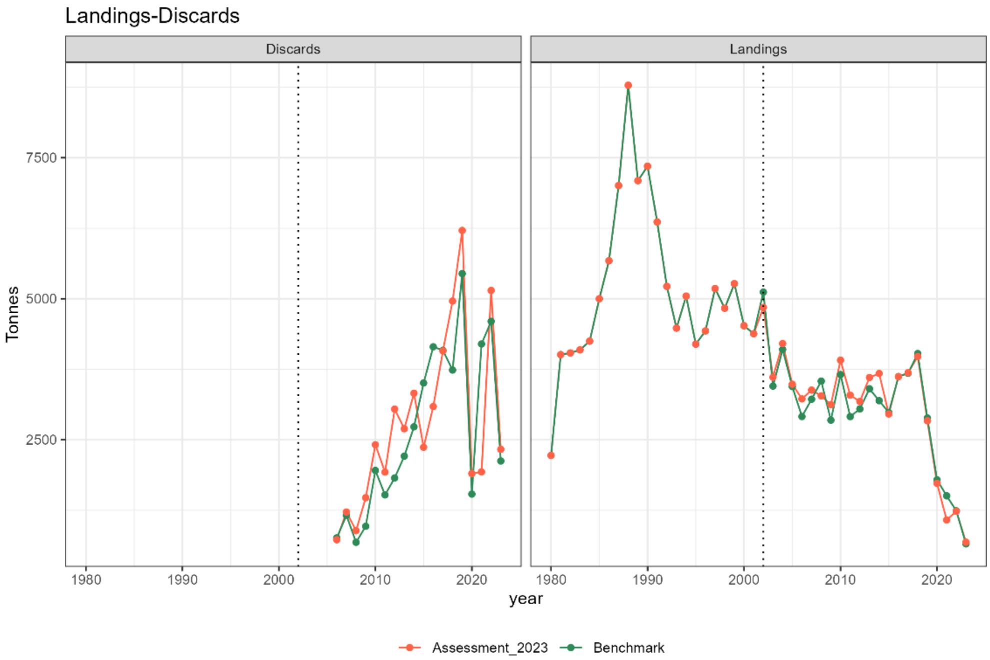

Figure 8: Total landings and discards calculated using the (WKBNSCS 2024) InterCatch export (green) and the InterCatch data used in 2023 assessment (red).

3.2. Landings and discards (numbers)

The comparison of landings and discards numbers between the InterCatch (WKBNSCS 2024) and InterCatch (assessment 2023) showed a low differences for ages 2 to 6 and the absence of clear trend except for 2021 where the discards and landings for all ages were updated upwards. The higher changes were observed for discards of old ages (green points) due to their small number.

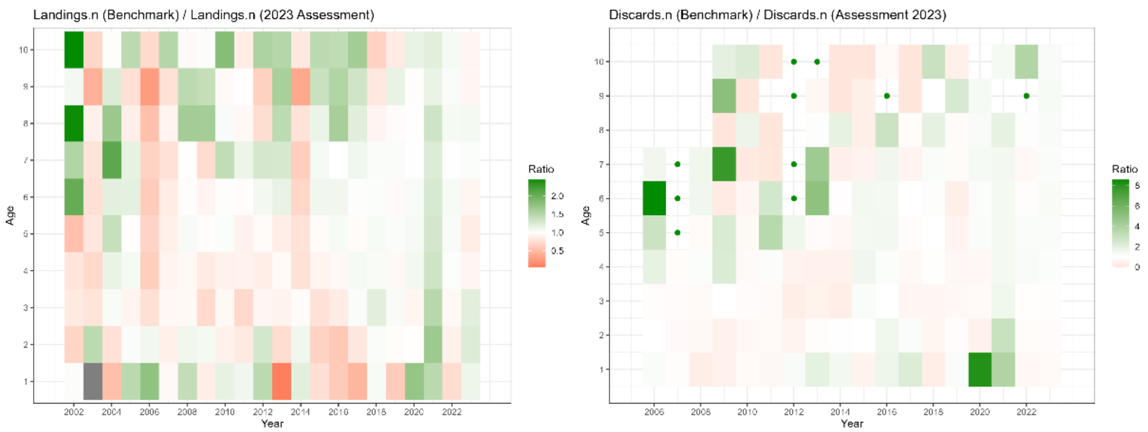

Figure 9: The change of landings and discards numbers at age calculated as the ratio between landings and discards number (WKBNSCS 2024) and landings and discards number (WKBNSCS 2024) from the InterCatch data used in 2023 assessment. Green points represent a ratio higher than 5.

3.3. Discard ratio

The comparison of discard ratios calculated using the current benchmark data (WKBNSCS 2024) (green) and those of 2023 assessment (red) showed a good consistency. The two datasets present the same trends characterized by an important increase of the discard ratio in the recent years from 2020 (Figure 10).

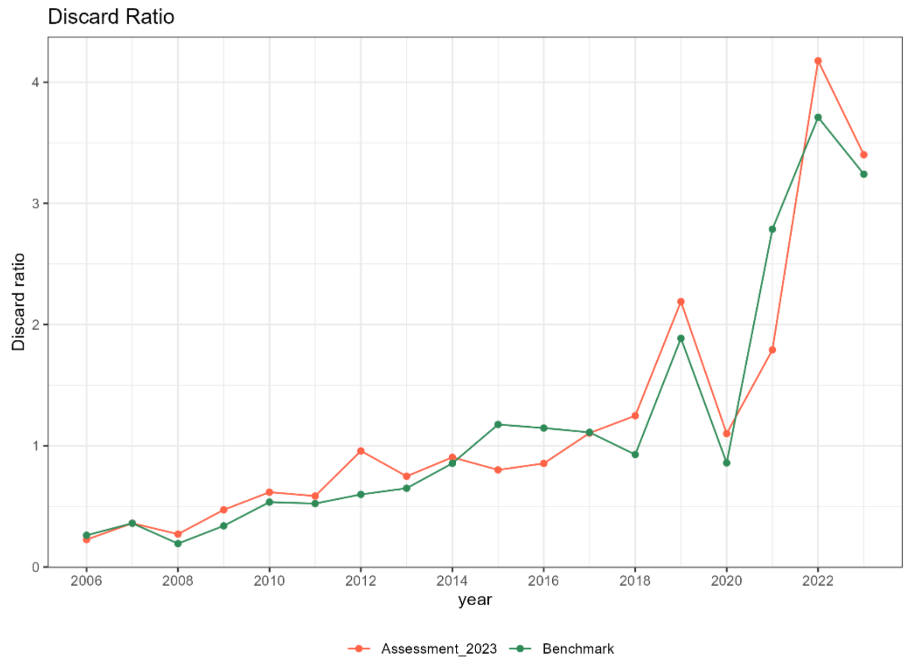

Figure 10: Discard Ratios calculated using InterCatch exports of the current benchmark (WKBNSCS 2024) (green) and InterCatch data used of 2023 assessment (red).

3.4. Weight at age

The weight at ages decreased in the last decade especially for higher ages (Figure 11). Similar trends were observed in the FR GFS and UK BTS indices. The comparison between the current benchmark data (WKBNSCS 2024) and those of 2023 assessment revealed some differences before 2015 in the discards due to the update of the calculation of discards in the French data. However, these changes were limited for the landings and stock weight at ages (except for age 10 in the landings) (Figure 12).

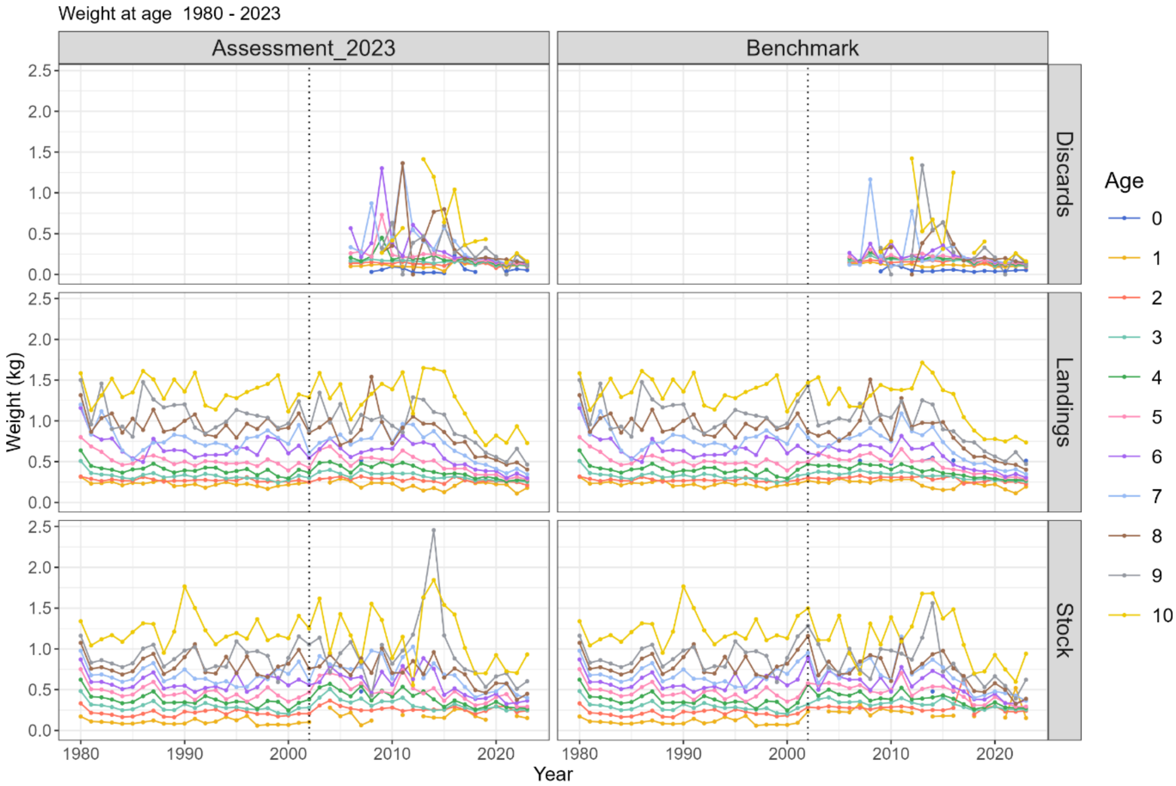

Figure 11: Weight at age from the current benchmark data (WKBNSCS 2024) and 2023 assessment in the discards, landings and stock. The dotted line represents the year from which InterCatch data are updated.

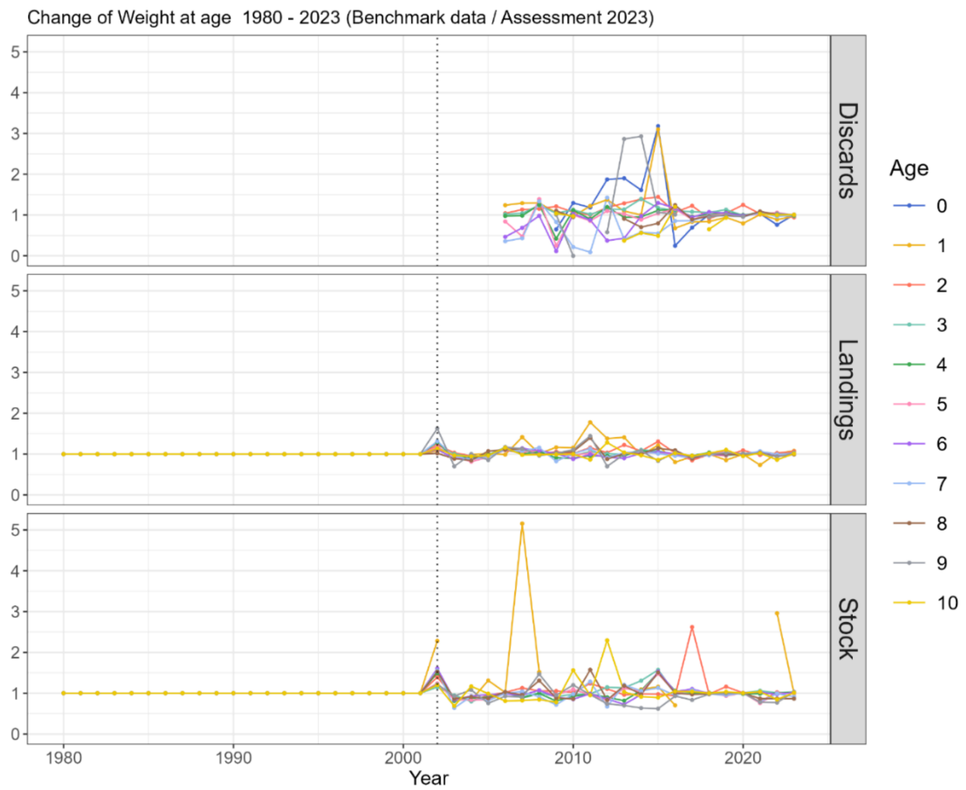

Figure 12: Comparison of the weight at age of the current benchmark data (WKBNSCS 2024) and those of 2023 assessment in the discards, landings and stock. The dotted line represents the year from which InterCatch data are updated.

4. Estimation of missing discards

The discards were not provided before 2006 and need to be estimated to run the SAM model (Figure 13). The ratio between discards and landings was used to estimate the missing discards. This ratio was calculated for the period 2006 – 2010 since there are no important changes during this period for age 1 (Figure 14). The age 1 was chosen to define the period to calculate the discard ratio since it’s highly discarded. Figure 14 showed that the discards ratio of age 1 starts to increase considerably from 2010 which could be considered as a regime shift. The discards number at age before 2006 were estimated using the mean discard ratio at age for the period 2006 – 2010 as a proportion of the landings at age between 1980 and 2006 (Figure 15).

The same period 2006 – 2010 was used to estimate the discards weight at age before 2006 to ensure consistency especially since the ratio of discards weight at age over landings weight at age seem to be stable over the whole time series (Figure 16). The average ratio of discards weight to landings weight by age from 2006 to 2010 was used to estimate discards weight by age as a proportion of landings weight by age for the period before 2006. (Figure 17).

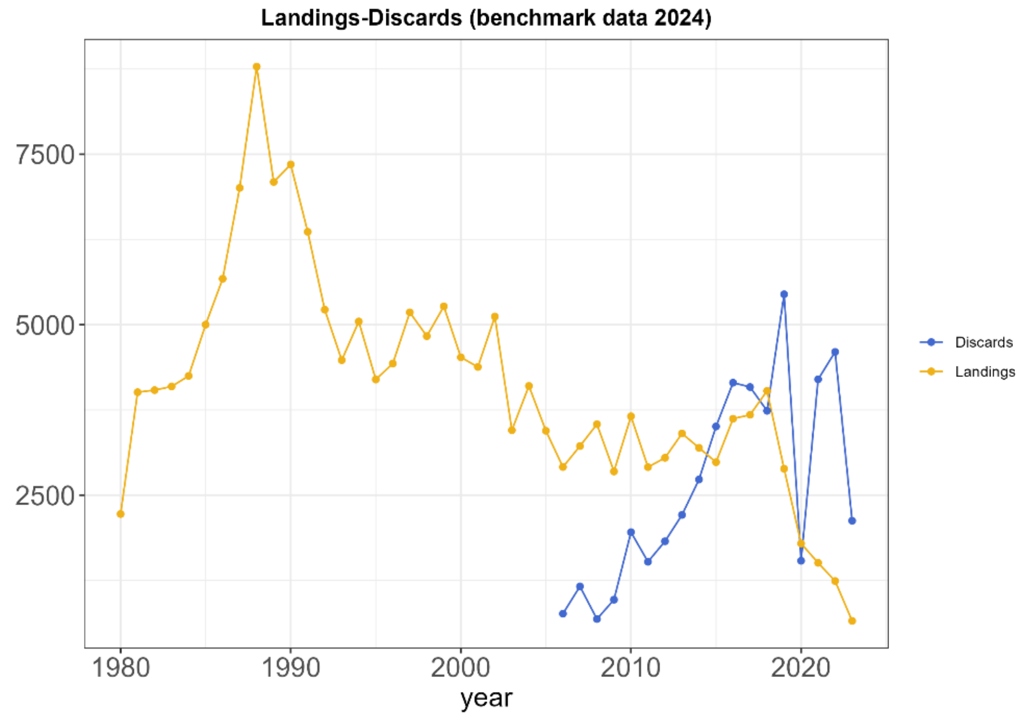

Figure 13: Time series of landings and discards between 1980 and 2023 (WKBNSCS 2024)

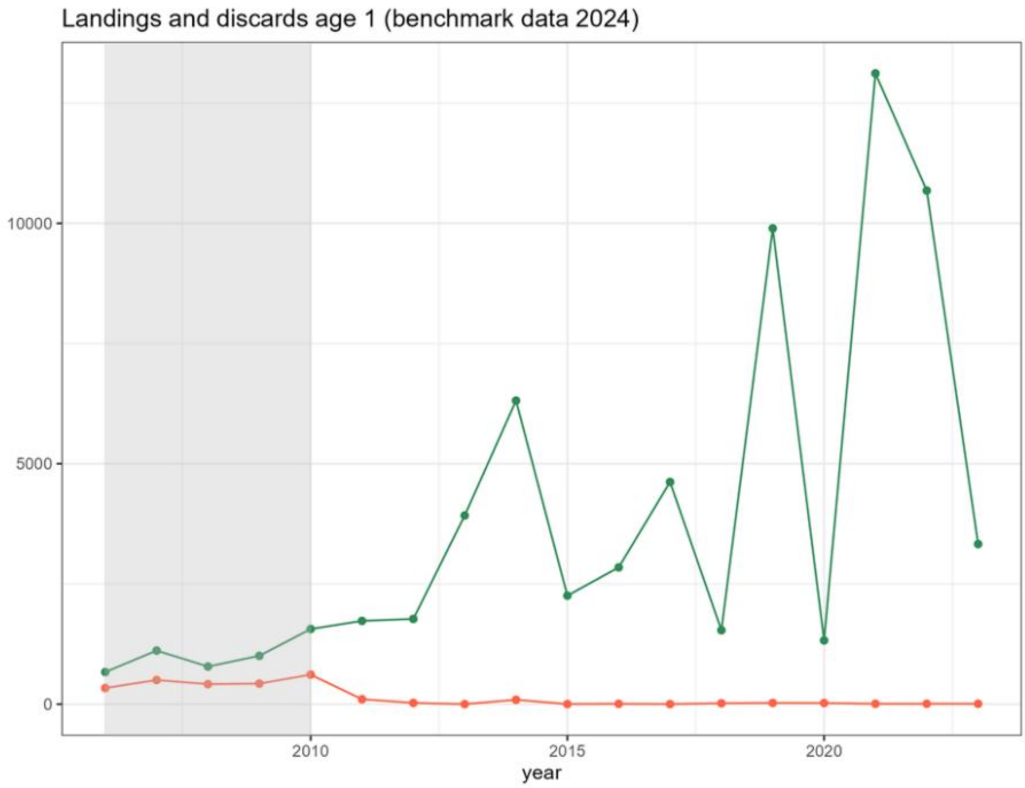

Figure 14: Time series of landings (red) and discards (green) of age 1 between 2006 and 2023 (WKBNSCS 2024)

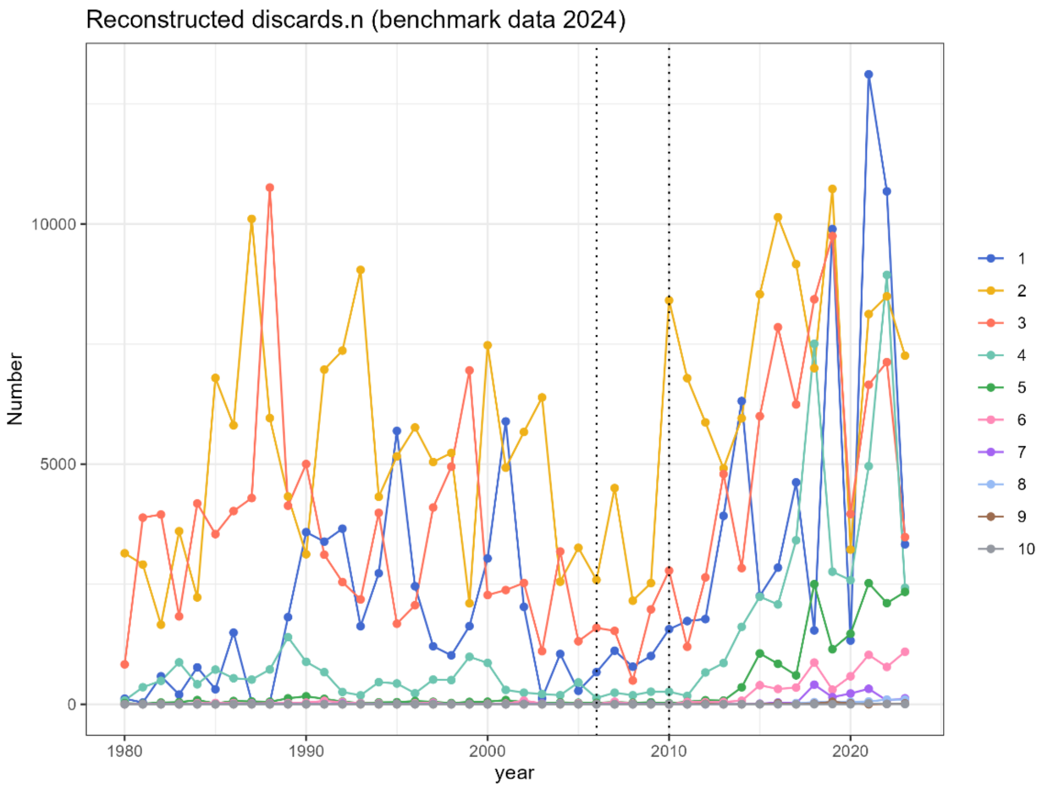

Figure 15: The time series of discards number at age for the period 1980 – 2023. The values before 2006 were estimated.

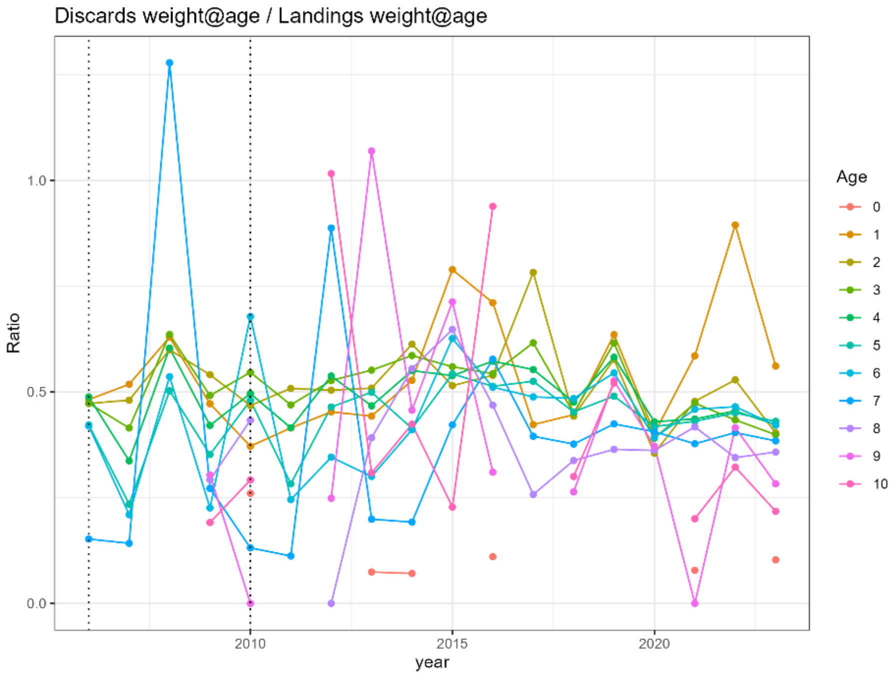

Figure 16: Time series of the ratio of discards weight at age over landings weight at age between 2006 and 2023.

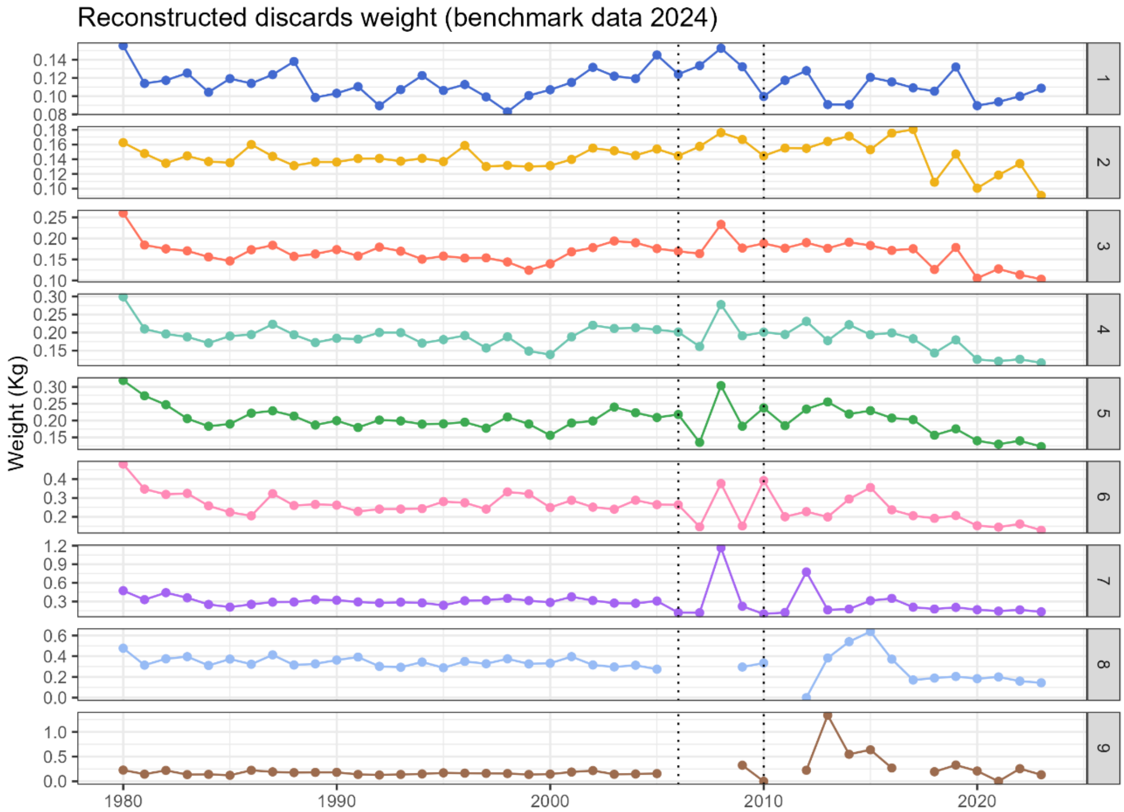

Figure 17: The time series of discards weight at age for the period 1980 – 2023. The values before 2006 were estimated.

5. Recreational catch

The reconstructed recreational catches of plaice in the English Channel are actually very small in comparison to the commercial catch (less than 1% each year). Therefore, they will not be included in the assessment.

Calculation of a recruitment index for plaice (*Pleuronectes platessa*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025)

Ghassen Halouani (IFREMER)*, Raphaël Girardin (IFREMER), Camille Vogel (IFREMER)

20-02-2025

1 Summary

1. A geostatistical spatial and spatiotemporal GLMM (generalized linear mixed model) using TMB with an SPDE (stochastic partial differential equation) approach was used to produce a standardized recruitment index for plaice in the Eastern English Channel.
2. The sdmTMB R package (Anderson et al. (2024)) was used to fit a GLMM model for age 1 plaice abundance based on data from the NOURSEINE survey.
3. The final model shows slight patterns in the Dharma residuals due to the presence of a few sampling points with very high abundance.
4. The final recruitment index present a similar trend to the SSB of the previous assessments between 1995 and 2023 with a maximum in 2020.

2 Introduction

The Eastern English Channel plaice (ple.7d) is currently assessed using two survey indices : UK-BTS [B2453] and FR-GFS index [G3425]. A new recruitment index was developed based on the French survey NOURSEINE which took place in the Bay of Seine (known to be a nursery ground for flatfishes). The sampling area of the NOURSEINE survey is represented in Figure 1.

The following documents presents the data and the sdmTMB model used to the standardization of the recruitment index for the purpose of WKBNSCS 2025. The R code developed for the calculation of the index is available in the Annex A.

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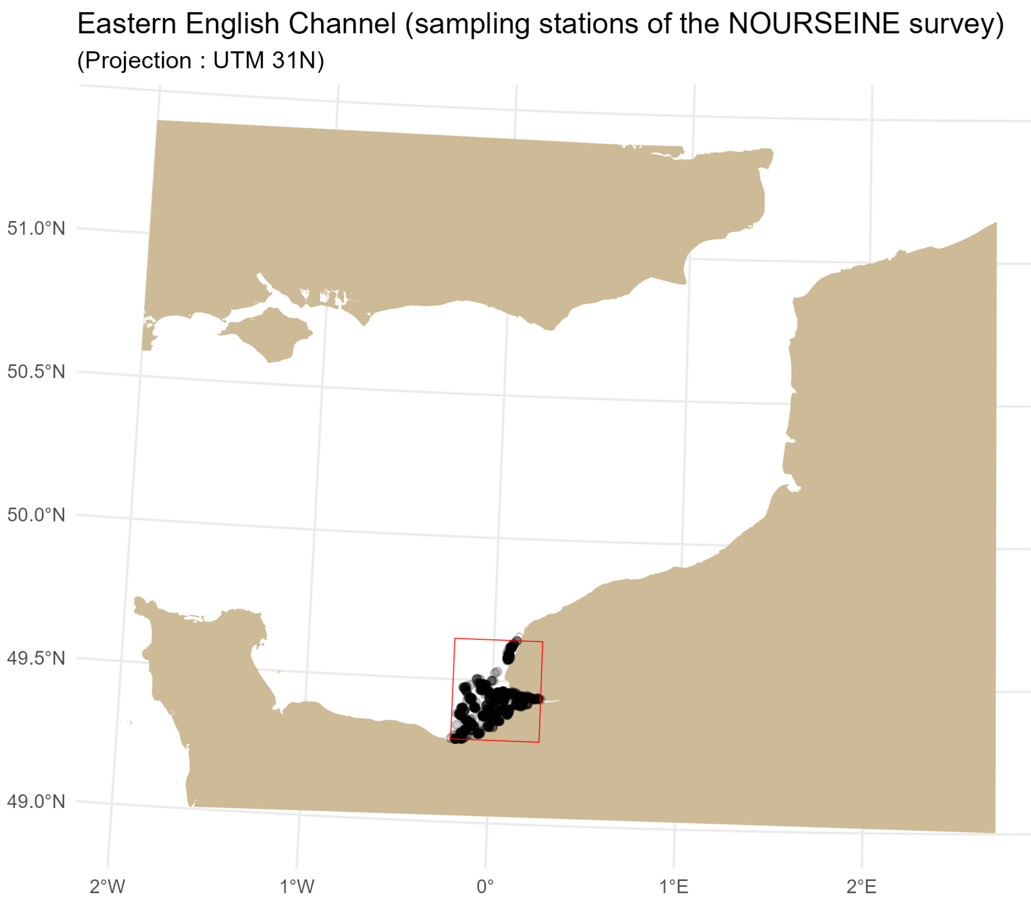

Figure 1: Sampling sites of NOURSEINE SURVEY (1995-2023).

3 Data

The abundance of age 1 data were extracted from the dataset of the NOURSEINE scientific survey (Cariou et al. (2021), Vogel and Morin (2015)). The objective of the survey is to monitor the juveniles of fish populations in the Seine Estuary. The survey started in 1995 and was conducted over three periods (1995–2002, 2008–2010 and 2017–2023), the Figure 2 shows the sampling sites.

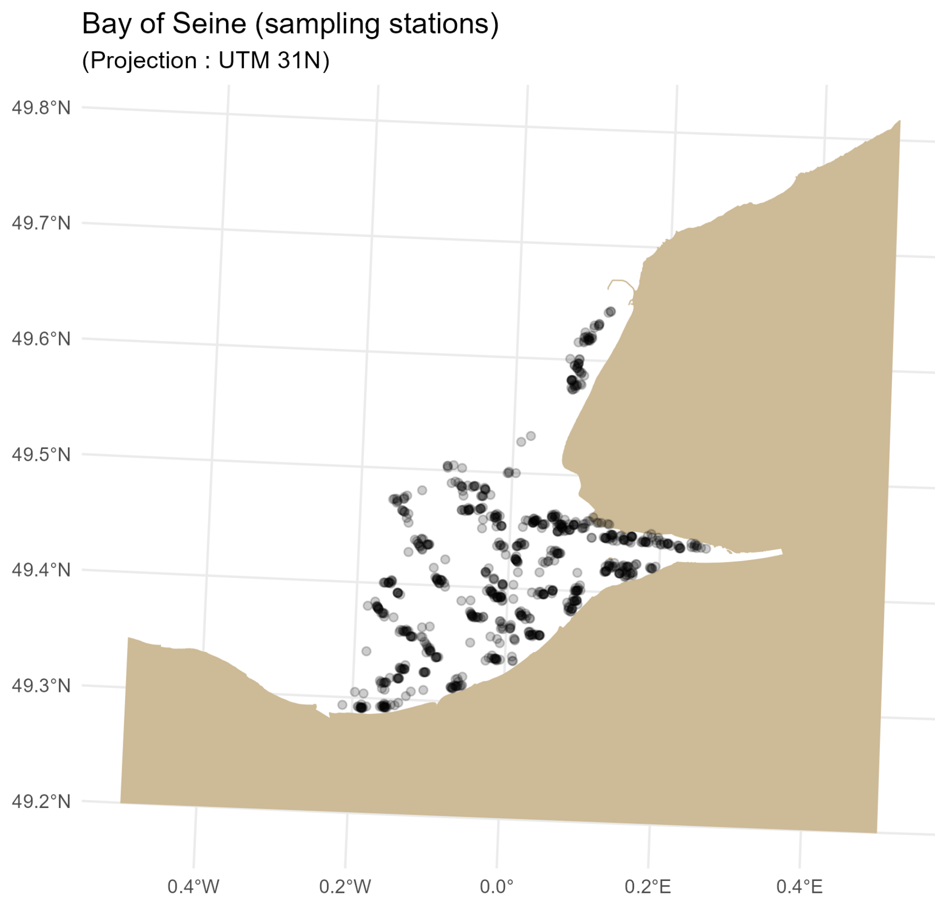

Figure 2: Sampling sites of NOURSEINE SURVEY (1995-2023).

3.1 Pre-pocessing : Age Length Key estimates

Empirical age length keys (ALK) were recorded for the period 1995-2010 in Ifremer Database and were used in the current analysis. Since 2020, only few biological samples per year were collected. Thus to derive the ALK, all the age-length information from the time series were binned together. The model of Berg and Kristensen (2012) without spatial effect is fitted to age and length data to obtain the ALK. Then it is applied to the length frequency for each haul to calculate numbers at age per haul. The approach consist of fitting a continuation ratio logits model to estimate probability of age given fish length. Model parameters are estimated in R with:

$$logit(p_a)[X_i]) = \alpha_a + \beta_a L_i$$

Where p is the conditional probability of a fish being of age a; i is the i^{th} fish; L corresponds to the length of the fish. To predict age distribution from the nursery survey data the ALK was fitted for ages 0-2+ 3.

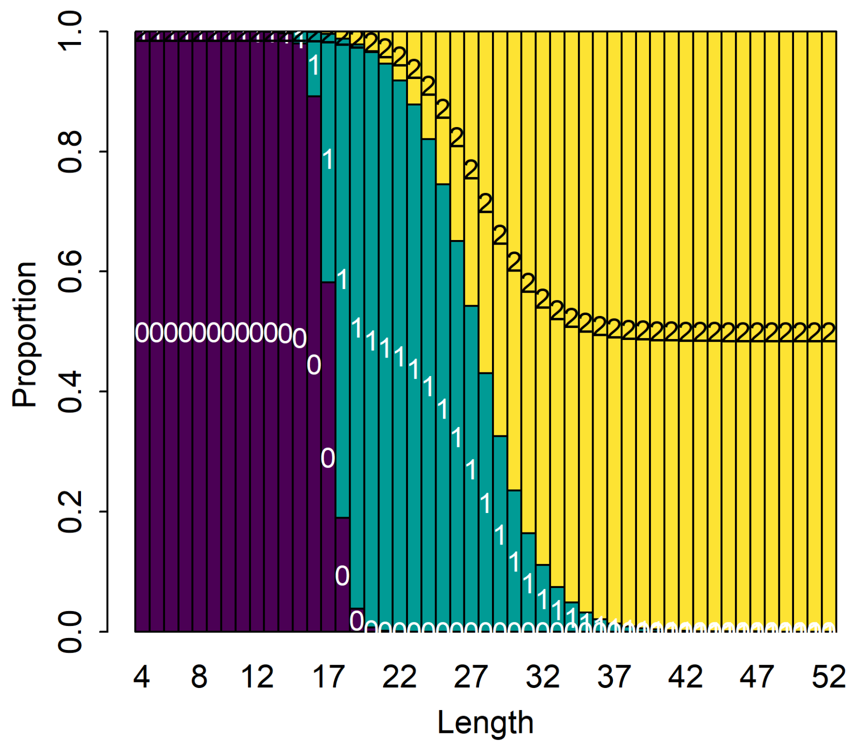

Figure 3: Proportions of fish for ages 0-2+ in the age length-key

4 Recruitment Index standardization

4.1 SPDE mesh

A convex triangle mesh of 615 points was created based on initial sampling locations to model the spatial variations (Figure 2). Different mesh resolution were tested. The mesh with a number of points (n = 615) was selected as it offered the best balance between speed and accuracy. The cutoff (the minimum allowed distance between points) was fixed to 1 (the unit is Km). Higher resolution mesh didn't improved the quality of the model.

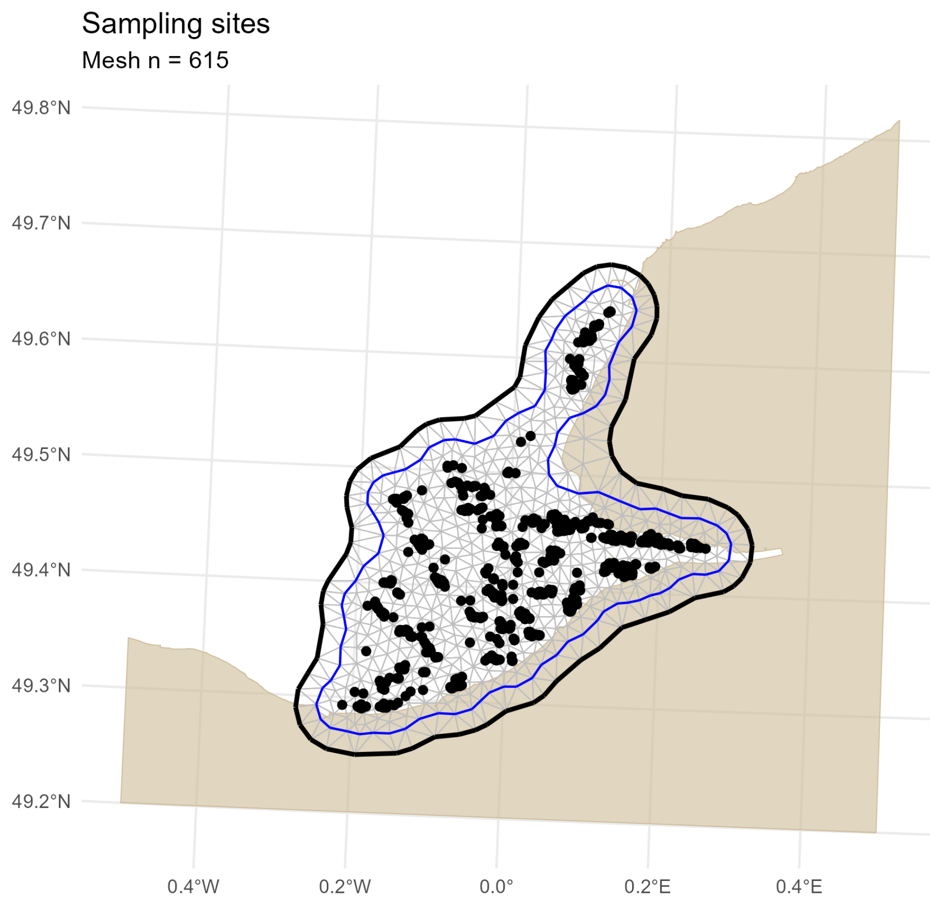

Figure 4: The mesh used to capture the spatial random field

4.2 The spatiotemporal generalized linear mixed effects model (GLMM)

The analysis was performed using the sdmTMB R package (Anderson et al. (2024)) to fit a spatiotemporal GLMMs using a Template Model Builder (TMB). The GLMMs were fitted for age 1 class using the Tweedie distribution (alternative distributions were tested but they provided worse results). The 5 illustrates the distribution of age 1 abundance in the NOURSEINE survey.

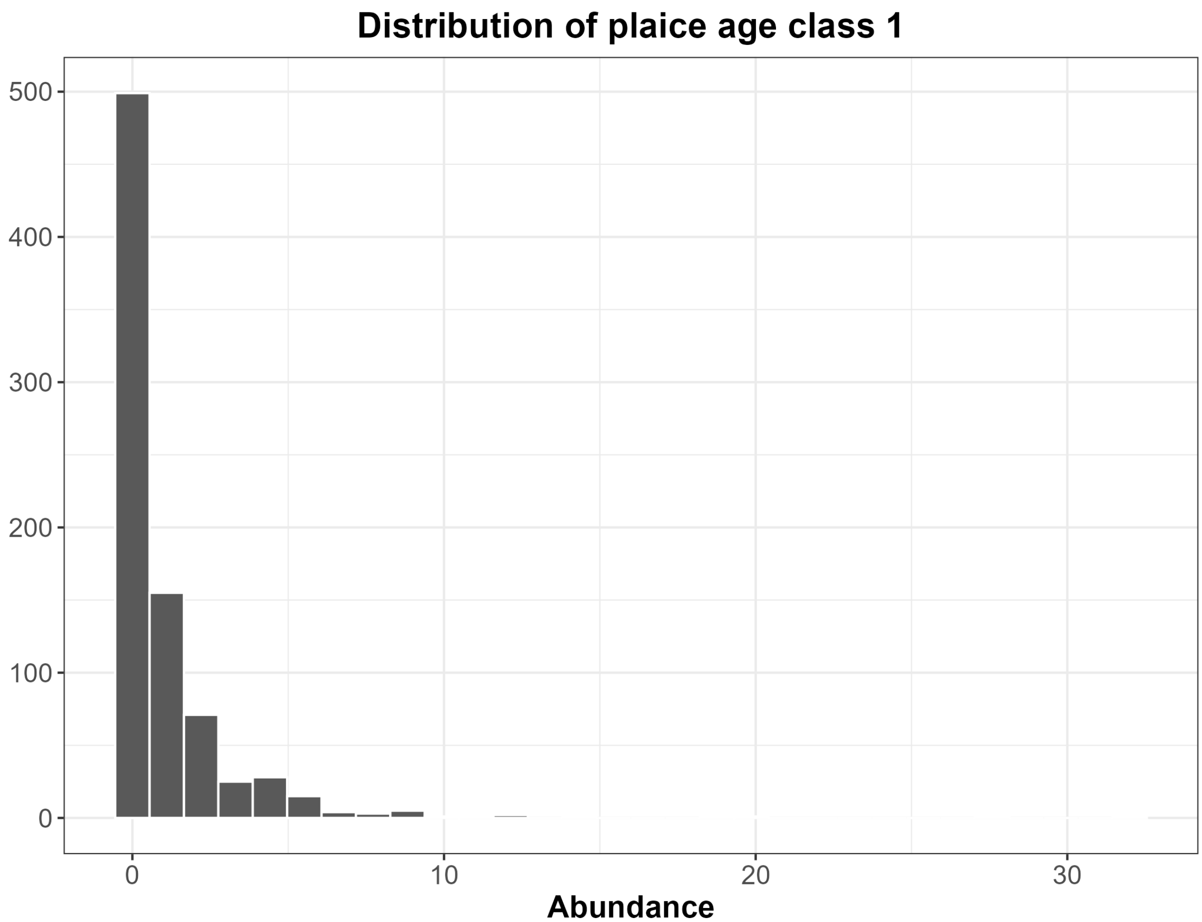

Figure 5: The distribution of plaice age 1 class abundance in the NOURSEINE survey

The tested GLMMs models are presented in the following table :

N	Model formula	Family	Link function
1	$Nage.1 \sim Year + TrawledSurface$	Tweedie	log
2	$Nage.1 \sim Year + TrawledSurface + Depth$	Tweedie	log
3	$Nage.1 \sim Year + TrawledSurface + log(Depth)$	Tweedie	log
4	$Nage.1 \sim Year + TrawledSurface + s(Depth)$	Tweedie	log
5	$Nage.1 \sim Year + TrawledSurface + BoatEngine$	Tweedie	Log
6	$Nage.1 \sim Year + TrawledSurface + BoatEngine + Depth$	Tweedie	log
7	$Nage.1 \sim Year + TrawledSurface + as.factor(BoatEngine)$	Tweedie	log
8	$Nage.1 \sim Year + TrawledSurface + as.factor(BoatEngine) + Depth$	Tweedie	log
9	$Nage.1 \sim Year + TrawledSurface$	Binomial, Gamma	logit, log
10	$Nage.1 \sim Year + TrawledSurface$	Binomial, lognormal	logit, log

The model 3 $Nage.1 \sim Year + TrawledSurface + log(Depth)$ was selected based on these checks :

- Convergence checks
- Model Comparison
- Model selection (Cross validation)
- Residuals checks

4.2.1 Convergence checks

The function `sanity()` of `sdm`TMB R package checks if the model's optimization algorithm successfully converged. It ensures that the estimated parameters are reasonable and there is no numerical issues during fitting process. The execution of this function over the tested models showed that models 5 and 9 had some numerical issues and convergence warnings.

```
## [1] "====================== Model 5 ====================== "
## v Non-linear minimizer suggests successful convergence
## v Hessian matrix is positive definite
## v No extreme or very small eigenvalues detected
## v No gradients with respect to fixed effects are >= 0.001
## v No fixed-effect standard errors are NA
## v No standard errors look unreasonably large
## v No sigma parameters are < 0.01
## v No sigma parameters are > 100
## v Range parameter doesn't look unreasonably large
## [1]
## [1] "====================== Model 9 ====================== "
## v Non-linear minimizer suggests successful convergence
## x Non-positive-definite Hessian matrix: model may not have converged
## i Try simplifying the model, adjusting the mesh, or adding priors
## v No extreme or very small eigenvalues detected
## v No gradients with respect to fixed effects are >= 0.001
## v No fixed-effect standard errors are NA
## v No standard errors look unreasonably large
## v No sigma parameters are < 0.01
## v No sigma parameters are > 100
## v Range parameters don't look unreasonably large
```

4.2.2 Model comparison

The AIC was used to compare the selected models (models 5 and 9 were removed due convergence issues). The model comparison showed small differences in AIC between the tested models (if we exclude model 10) (see table below). Adding more predictors (i.e Depth, Boat engine power) did not improved significantly the AIC.

N	Model formula	AIC
1	$Nage.1 \sim Year + TrawledSurface$	2278.061
2	$Nage.1 \sim Year + TrawledSurface + Depth$	2279.789

N	Model formula	AIC
3	$Nage.1 \sim Year + TrawledSurface + log(Depth)$	2278.336
4	$Nage.1 \sim Year + TrawledSurface + s(Depth)$	2281.007
6	$Nage.1 \sim Year + TrawledSurface + BoatEngine + Depth$	2281.785
7	$Nage.1 \sim Year + TrawledSurface + as.factor(BoatEngine)$	2279.699
8	$Nage.1 \sim$ $Year + TrawledSurface + as.factor(BoatEngine) + Depth$	2281.403
10	$Nage.1 \sim Year + TrawledSurface$	2348.193

4.2.3 Model selection (Cross validation)

Cross validation was used to quantify model performance (predictive accuracy) and compare sdmTMB models with different structures. In this analysis, cross-validation was employed to assess the model's performance in terms of predictive accuracy and to compare the tested sdmTMB models. The cross valisation analysis was carried out using the function `sdmTMB_cv()` with 10 k_folds (each fold represents a subset of the data that is sequentially held out and used as a test set). The table below summarize the sum of the log likelihoods for each left-out fold and the total summed across the left-out folds of the 3 best models.

N	Model formula	sum log-likelihoods
1	$Nage.1 \sim Year + TrawledSurface$	-1154.882
2	$Nage.1 \sim Year + TrawledSurface + Depth$	-1154.688
3	$Nage.1 \sim Year + TrawledSurface + log(Depth)$	-1155.534

The cross-validation comparison revealed only minor differences between the models. Model 2 ($Nage.1 \sim Year + TrawledSurface$) was chosen as it had the highest sum of log-likelihoods."

4.2.4 Residuals checks

A simulation-based approach was applied via the R package `DHARMa` to generate simulated residuals that are independent of model structure. Below, we present Dharma residual plots :

The DHARMa nonparametric dispersion test (Figure 6) compared the dispersion of simulated residuals to the observed residuals and indicated the absence overdispersion or underdispersion.

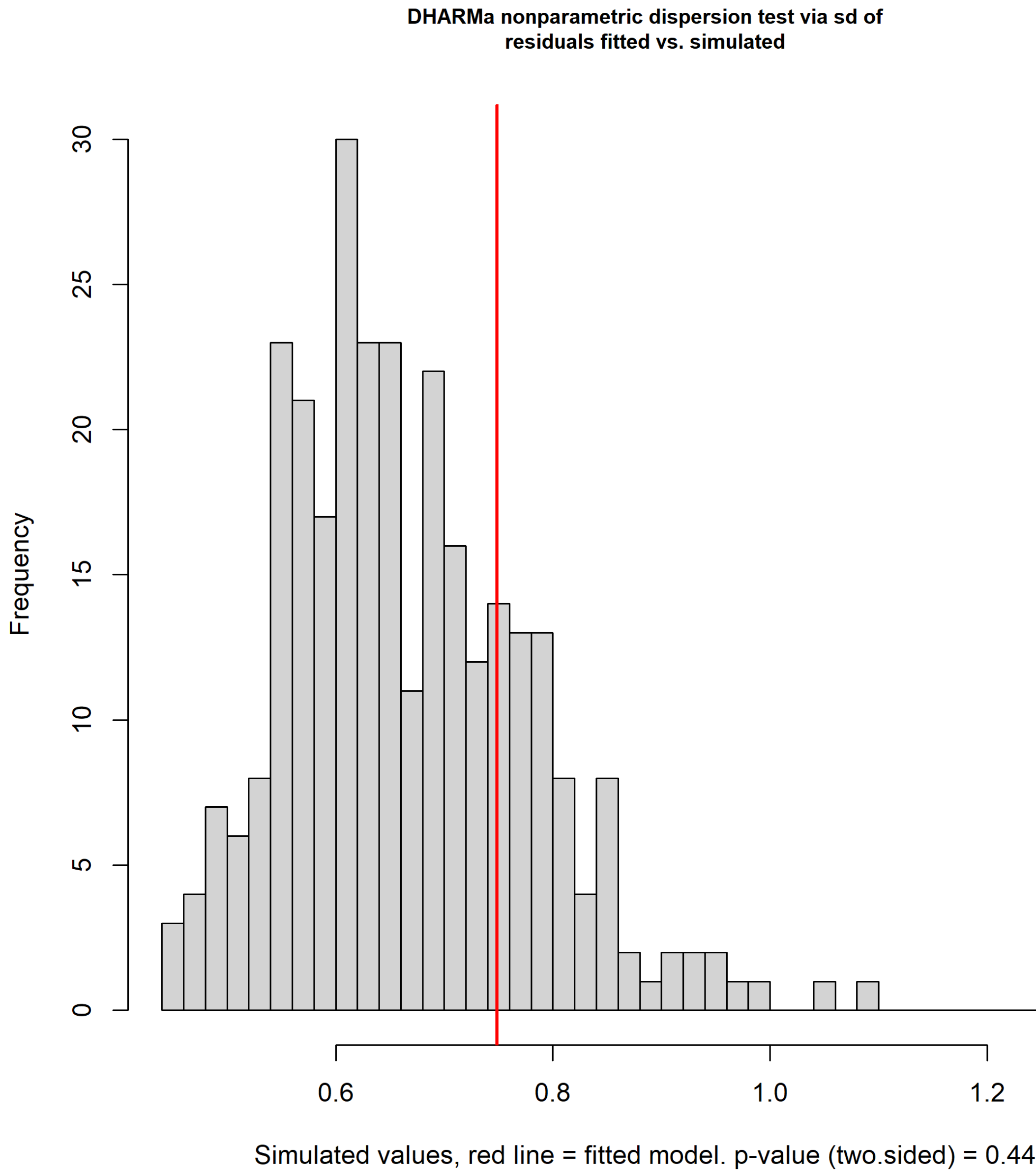

Figure 6: Non-parametric dispersion test

The comparison of the distribution of the observed zeros in the data against the expected zeros using DHARMa zero-inflation test indicated no inflation in the simulated zeros.

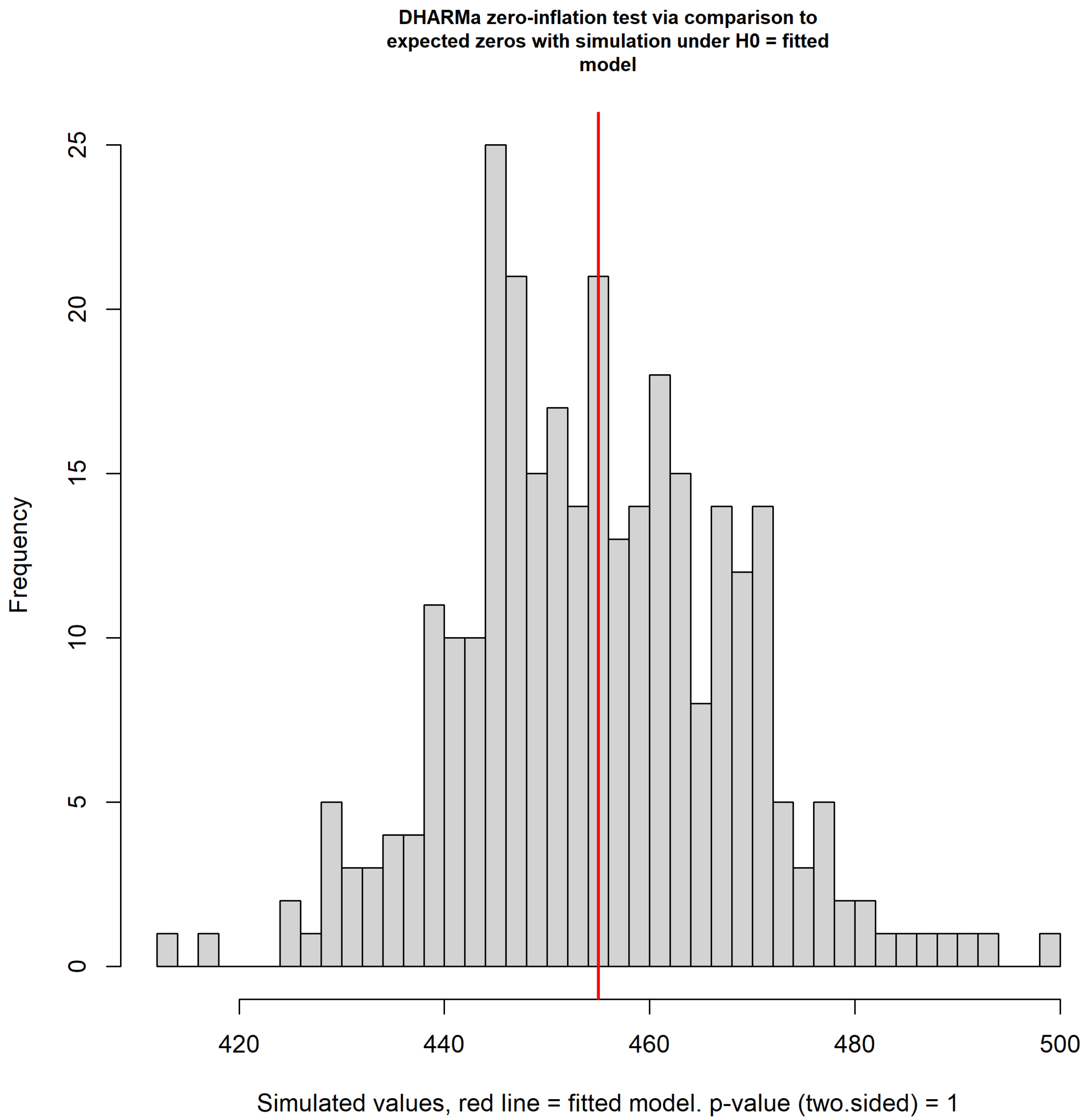

Figure 7: Zero inflation test

The QQ plot indicated no deviations from the expected distribution (Figure 6). Residuals are uniformly distributed. The model seems to captures the data, with no major discrepancies between observed and predicted values.

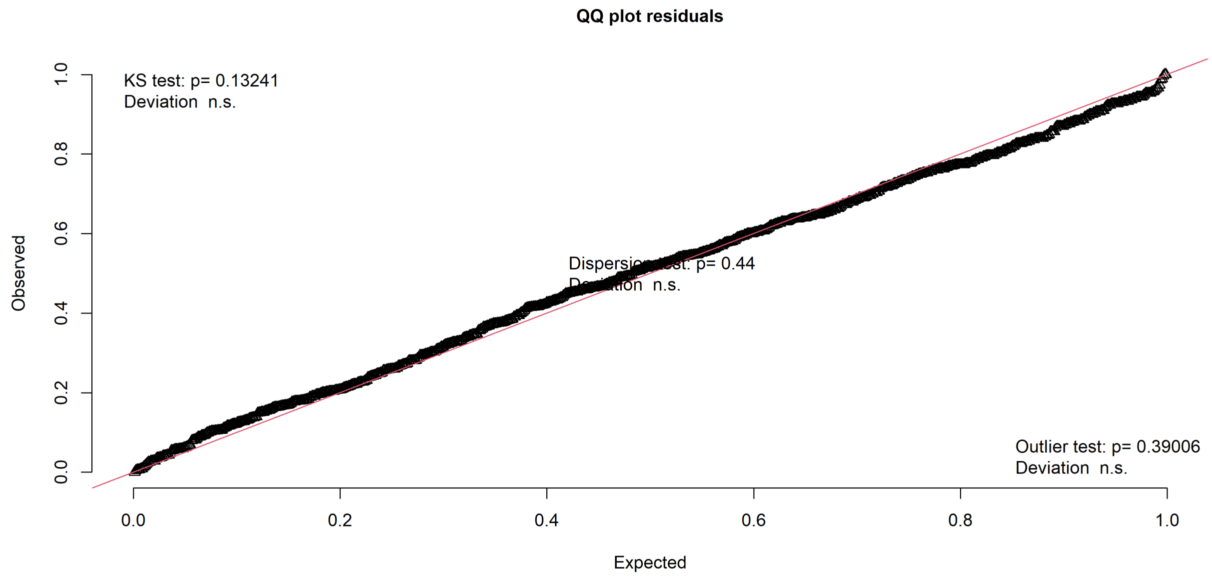

Figure 8: QQplot residuals

Quantile deviations were detected in the residuals. Figure 6 showed heavy tails (at extreme values) which suggest the presence of outliers not well explained by the model (Delta models and negative binomials models were tested but didn't fixed the issue of quantile deviations).

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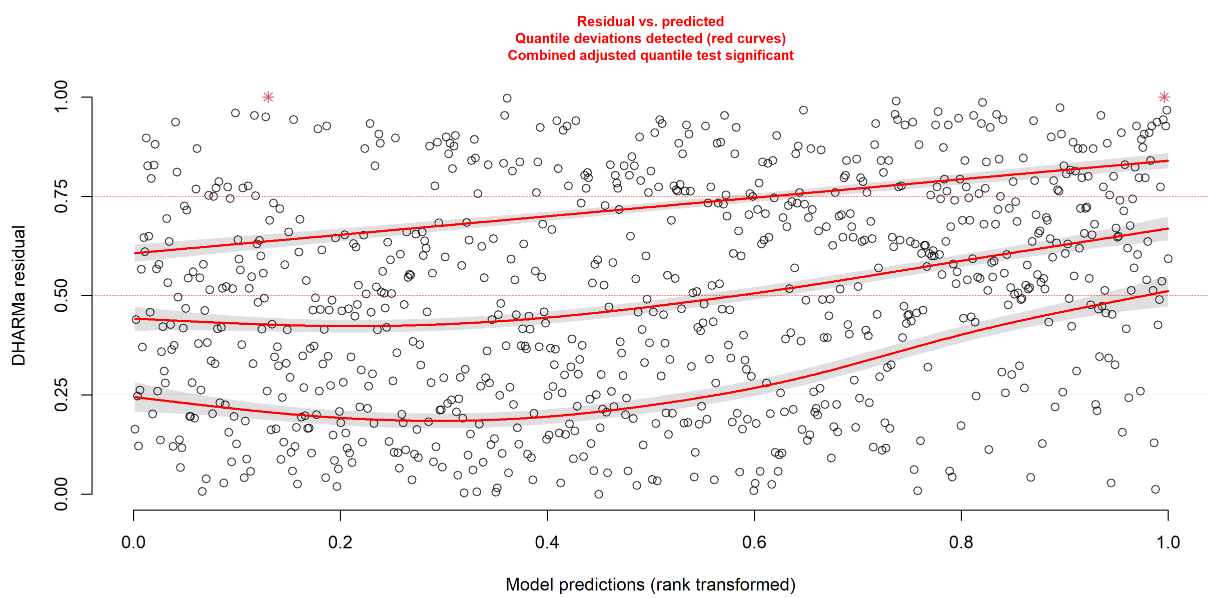

Figure 9: The residuals against the predicted value

Figures 10 and 11 show the residuals against the predictors (year and trawled surface). The two figures indicate no significant problems, except two outliers.

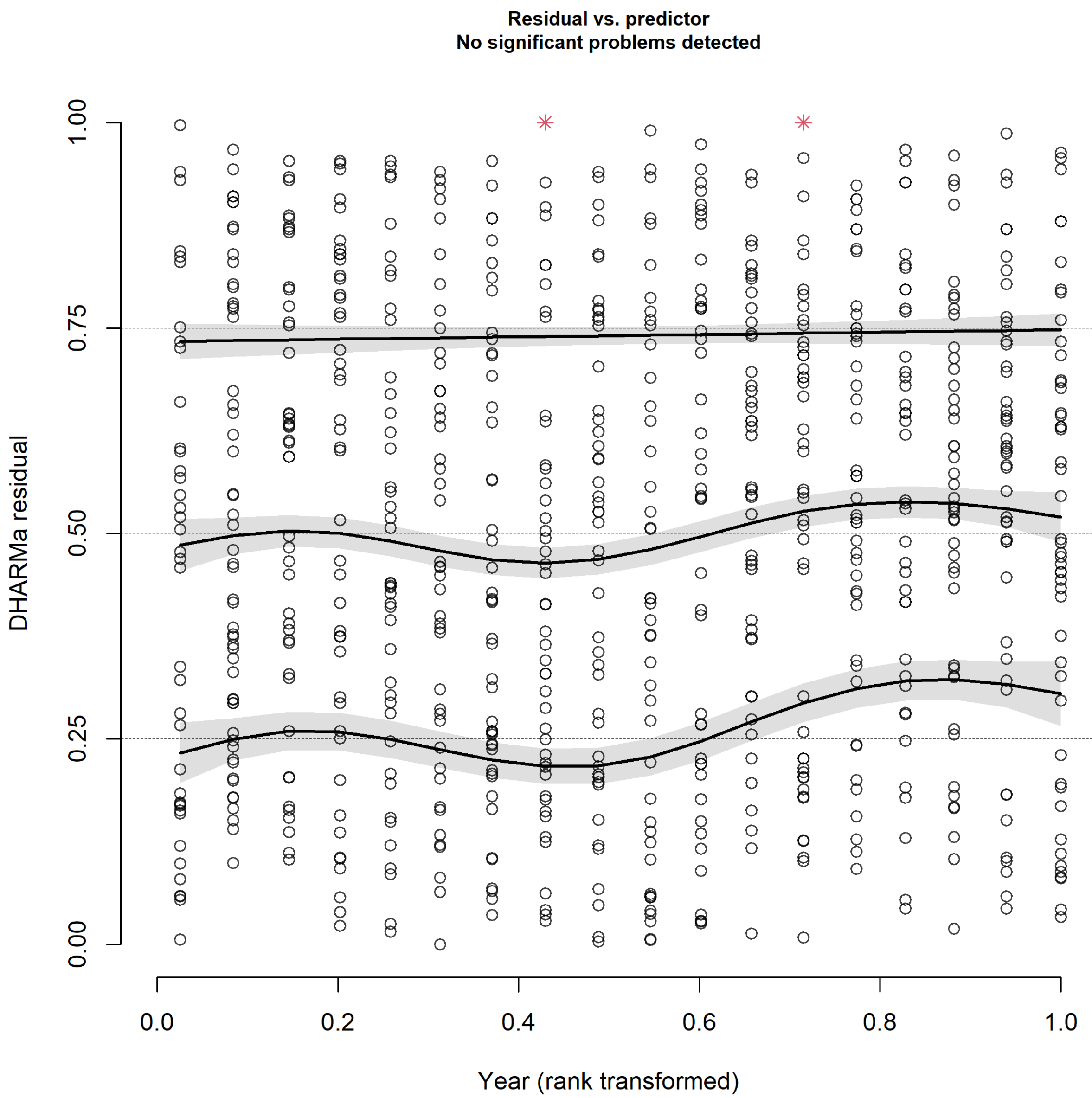

Figure 10: Residuals vs Year (predictor)

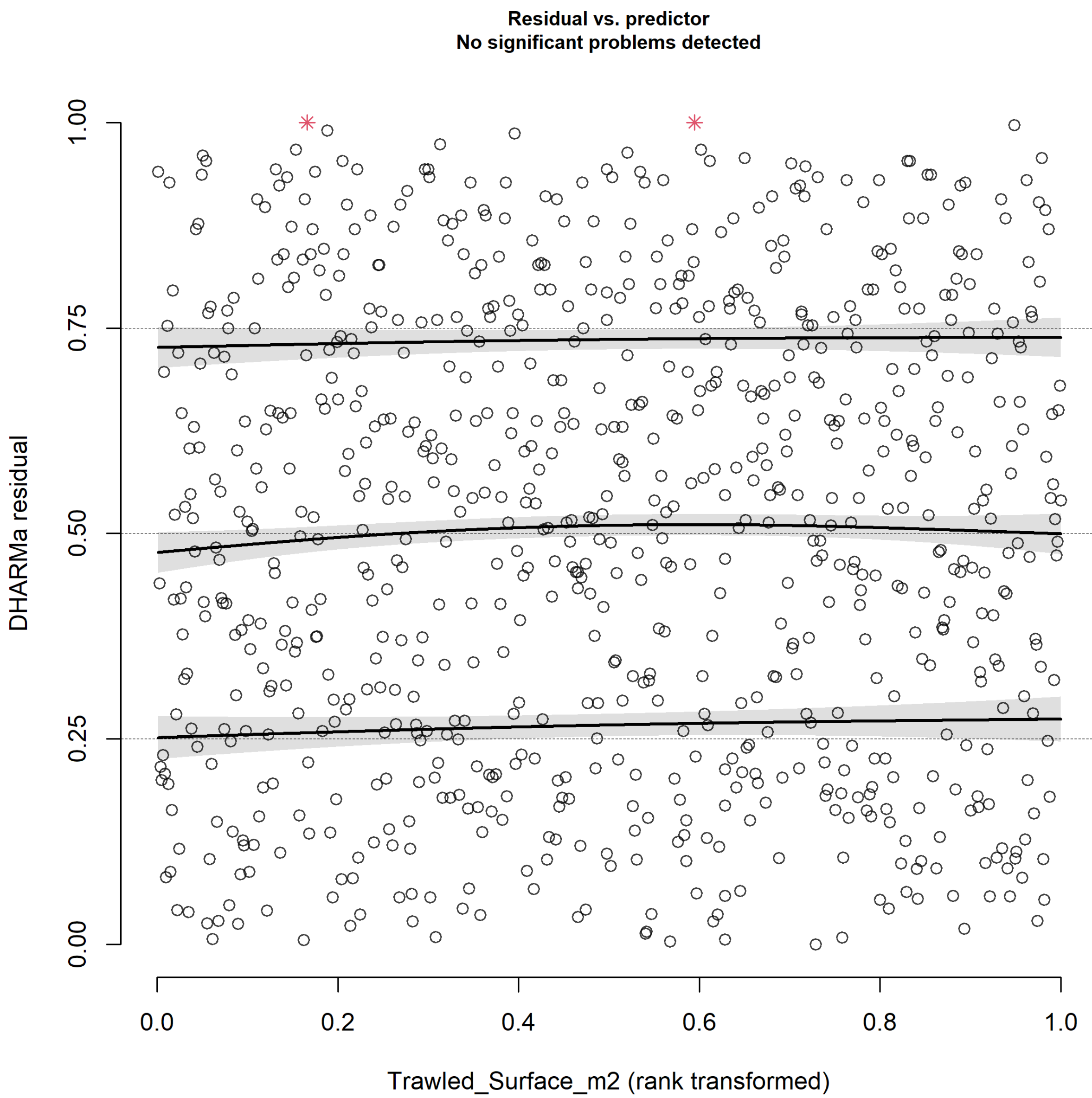

Figure 11: Residuals vs Trawled surface (predictor)

5 Results

5.1 Model predictions

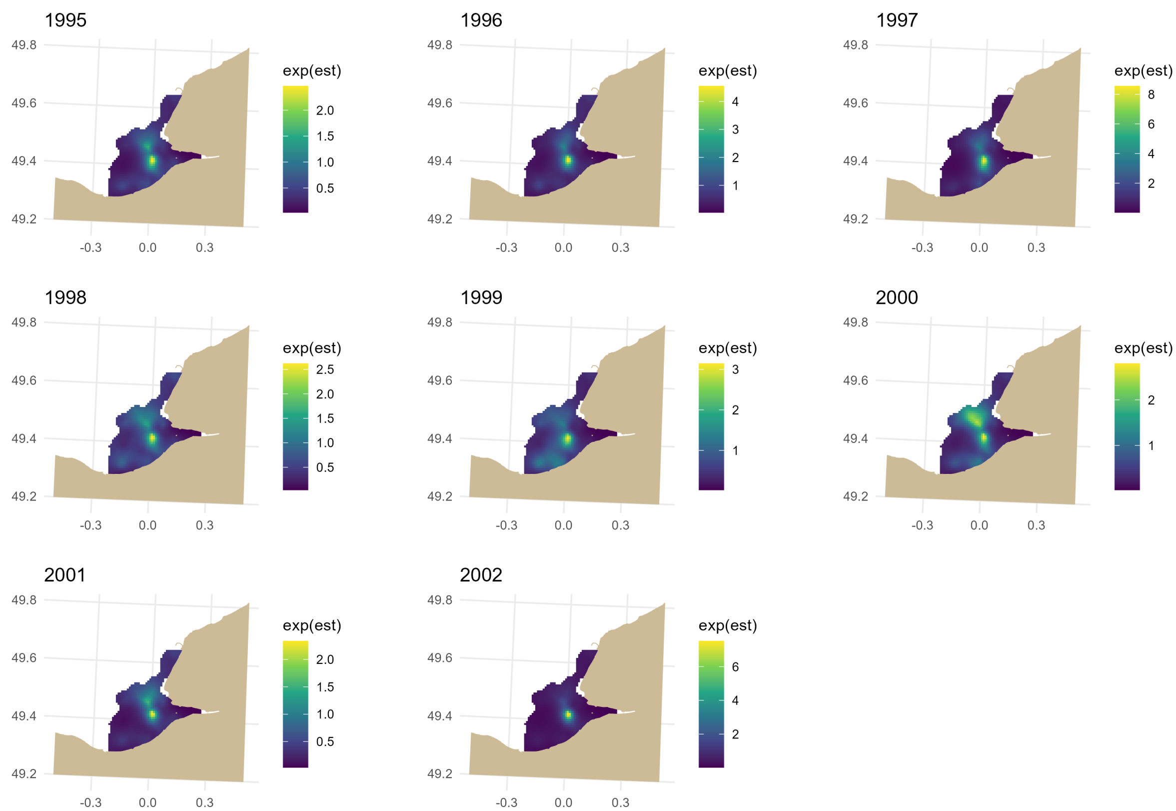

Figure 12: Prediction of abuandace of plaice age 1 (1995-2002)

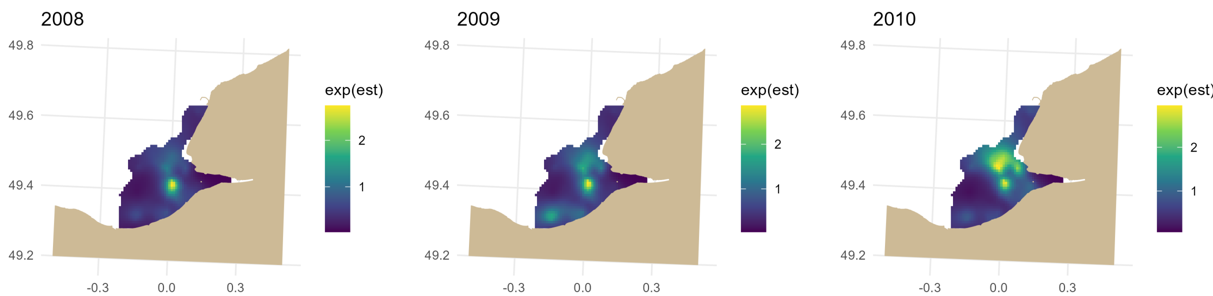

Figure 13: Prediction of abuandace of plaice age 1 (2008-2010)

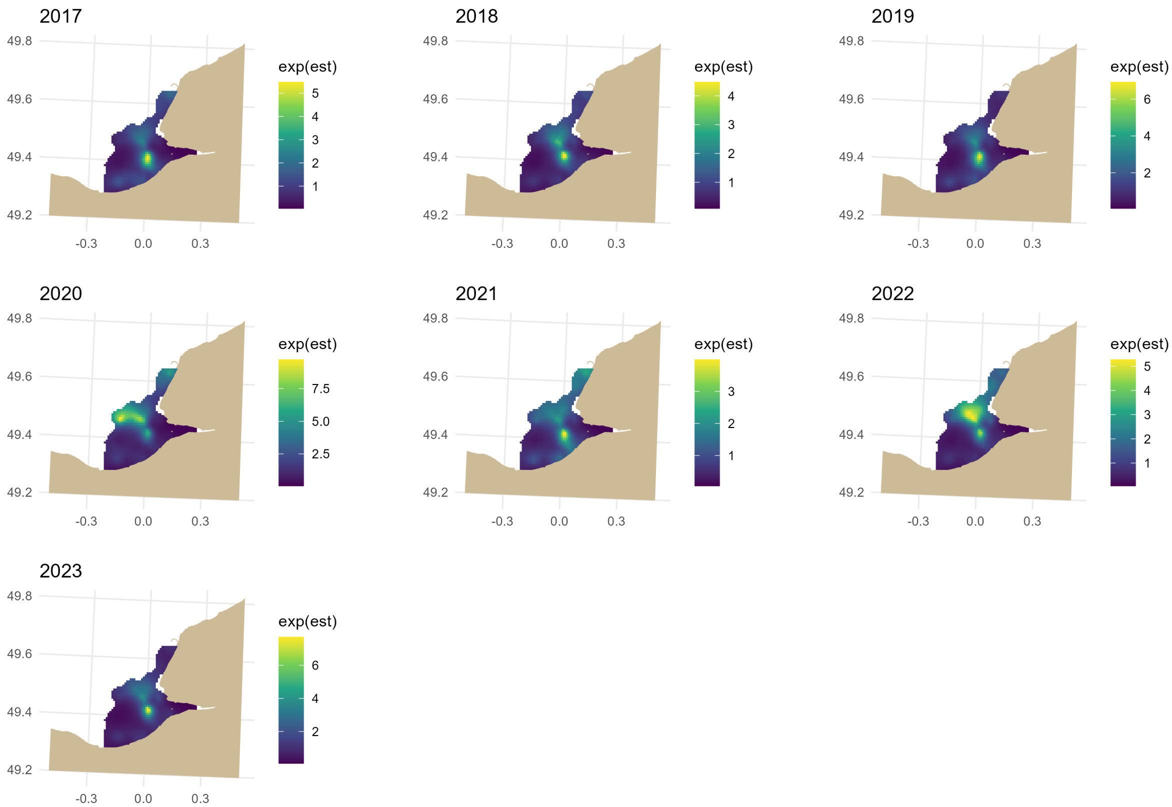

Figure 14: Prediction of abuandace of plaice age 1 (2017-2023)

5.2 Area-weighted Index standadization

The function `get_index()` of sdmTMB R package was used to calculate a relative abundance index of plaice age 1 on a grid of $0.7 \times 0.7Km$ over the survey domain and estimate the standard errors. The resulted index is shown in the Figure 15.

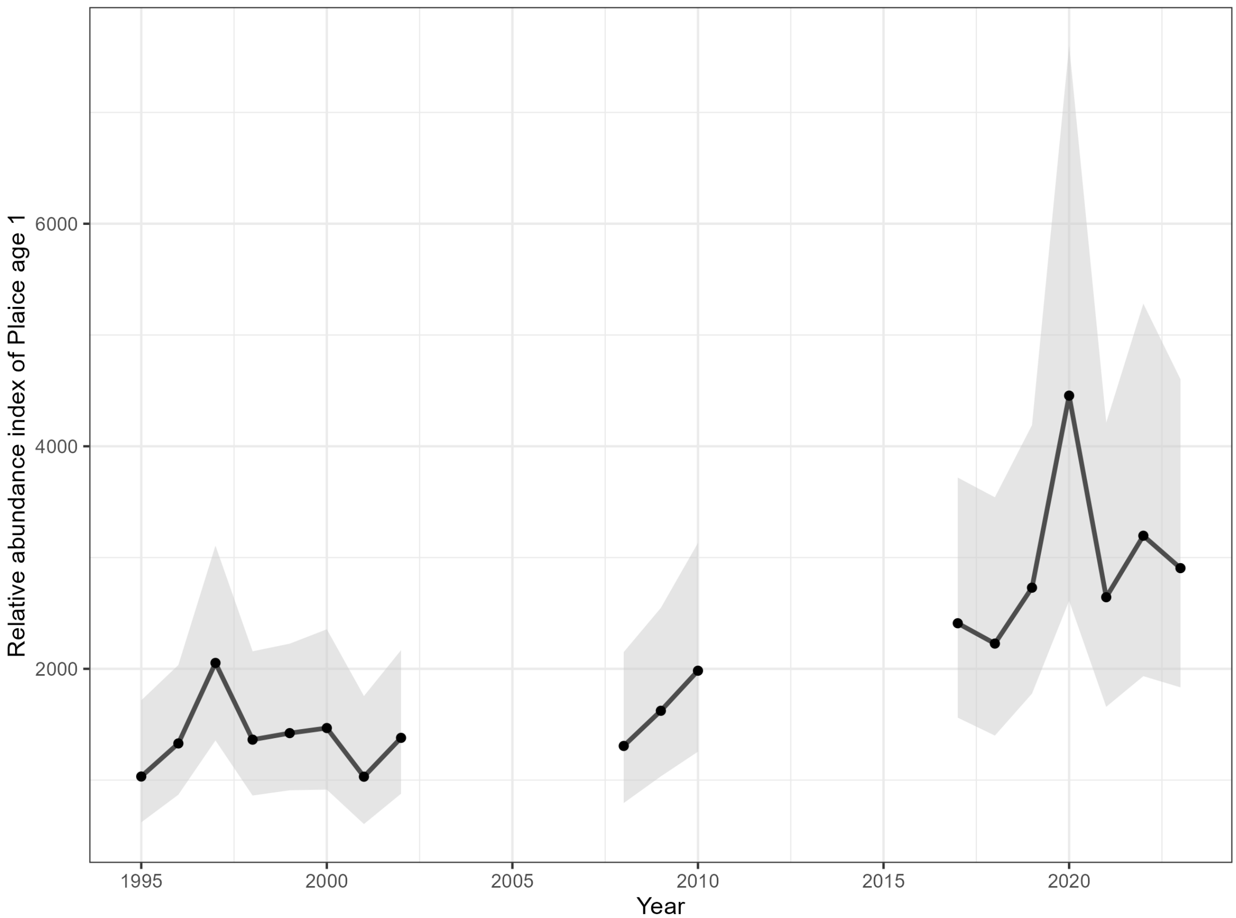

Figure 15: Index of plaice age 1

6 References

Anderson, Sean C., Eric J. Ward, Philina A. English, Lewis A. K. Barnett, and James T. Thorson. 2024. "sdmTMB: An R Package for Fast, Flexible, and User-Friendly Generalized Linear Mixed Effects Models with Spatial and Spatiotemporal Random Fields." bioRxiv. https://doi.org/10.1101/2022.03.24.485545.

Berg, Casper W., and Kasper Kristensen. 2012. "Spatial Age-Length Key Modelling Using Continuation Ratio Logits." *Fisheries Research* 129-130 (October): 119–26. https://doi.org/10.1016/j.fishres.2012.06.016.

Cariou, Thibault, Laurent Dubroca, Camille Vogel, and Nicolas Bez. 2021. "Comparison of the Spatiotemporal Distribution of Three Flatfish Species in the Seine Estuary Nursery Grounds." *Estuarine, Coastal and Shelf Science* 259 (September): 107471. https://doi.org/10.1016/j.ecss.2021.107471.

Vogel, Camille, and Jocelyne Morin. 2015. "NOURSEINE." Set of cruises. https://doi.org/10.18142/244.

7 Appendix A

7.1 Test Residuals

Uniformity

```
Asymptotic one-sample Kolmogorov-Smirnov test
data:  simulationOutput$scaledResiduals
D = 0.039075, p-value = 0.1664
alternative hypothesis: two-sided
```

Dispersion

```
DHARMa nonparametric dispersion test via sd of residuals fitted vs. simulated
data:  simulationOutput
dispersion = 1.1522, p-value = 0.3067
alternative hypothesis: two.sided
```

Outliers

```
DHARMa outlier test based on exact binomial test with approximate expectations
data:  simulationOutput
outliers at both margin(s) = 4, observations = 814, p-value = 0.8268
alternative hypothesis: true probability of success is not equal to 0.006644518
95 percent confidence interval:
0.001340475 0.012533637
sample estimates:
frequency of outliers (expected: 0.00664451827242525 ) 0.004914005
```

Update of reference points of plaice (*Pleuronectes platessa*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025)

Ghassen Halouani (IFREMER)*

25-02-2025

1 Introduction

The new reference points were updated during the benchmark of plaice 7d (WKBNCS 2025). The Eqsim methodology was applied following the ICES technical guidelines (ICES 2021). The code developed for the reference points calculation is available in the Annex A.

2 Inputs

This analysis is based on the results of the final SAM model configuration validated during WKBNCS meeting that took place in Copenhagen (03-07 February 2022). The following inputs and settings was used to run the SAM model:

- Landings-at-age data, years 1980-2023, ages 1-7+
- Discards-at-age data, years 1980-2023, ages 1-7+
- Indices of abundance:
  - UK BTS, years 1989:2023, ages 1-6
  - FR CGFS, years 1990:2023, ages 1-6
- Fbar: ages 3-6

The assessment model estimates recruitment as independent yearly parameter, so no stock-recruitment relationship is assumed or estimated (Figure 1).

3 Methods

The analysis was conducted applying the methodology presented in ICES (2021) for a category 1 stock, and using version 0.1.19 of the `msy` package. Simulation runs have been conducted for 2500 iterations (`nsmap = 2500`). Selectivity patterns, maturity, weights-at-age and natural mortality were sampled from the last five years (2019-2023). The full time-series of the stock and recruitment was used without the last year recruitment (2023) because of a high uncertainty around this value.

4 Results

An initial stock-recruitment model fit conducted the FLStock object of the last assessment of plaice 7d to explore the support for two alternative stock-recruitment relationships (SRR); Beverton and Holt and segmented regression. The model fit suggests that the observed relationships support the Beverton and Holt model (96%) (Figure 2)

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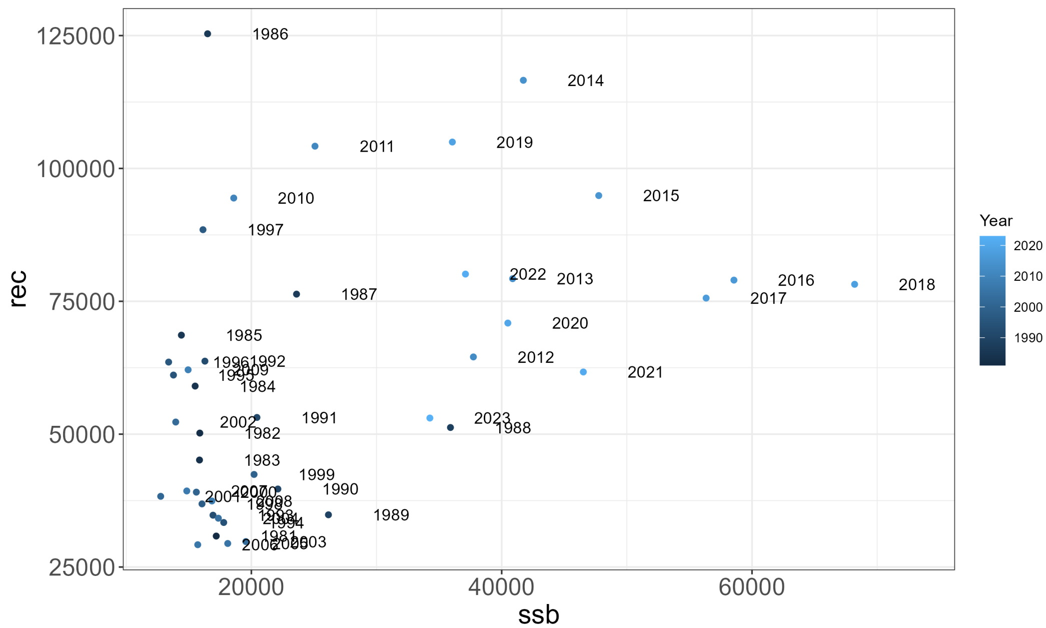

Figure 1: Estimates of number of age 1 recruits (in thousands) against the SSB (in tonnes) in the previous year obtained from the ple.7.d stock assesment model run used for the reference points analysis. Labels refer to the recruitment year.

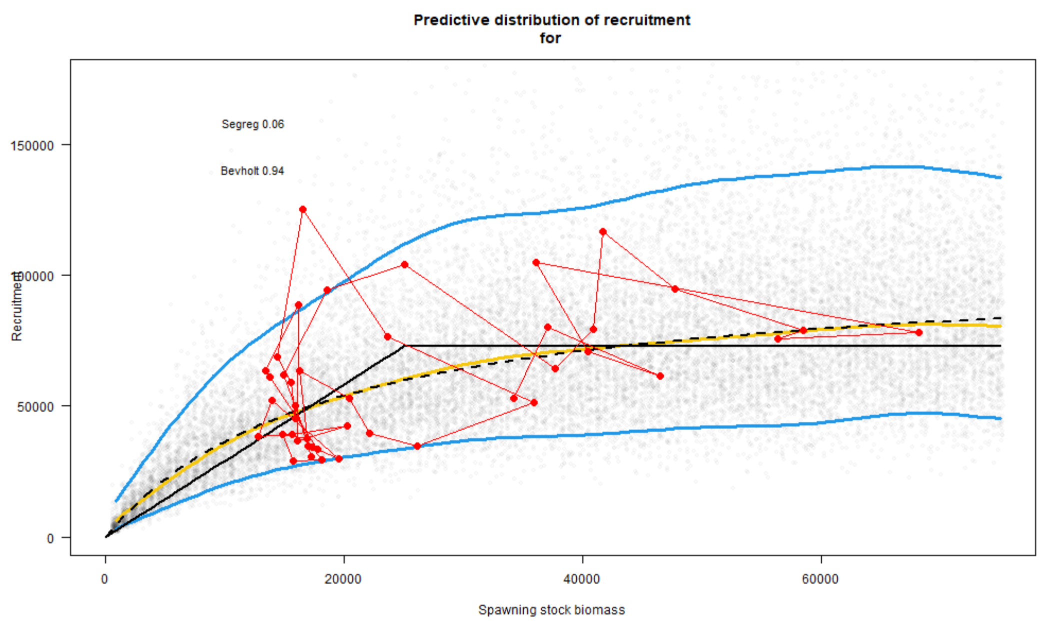

Figure 2: Fit of the two initial stock-recruitment relationships to the ple.7.d SSB and recruits time series.

The decision was taken to conduct all analyses using Beverton and Holt and the segmented regression SRR, except for the estimation of (B_{lim}) for which only the segmented regression SRR was used. The stock was classified by the group as following under *Type 2* [1] according to the relevant ICES guidelines (ICES 2021), so the biomass limit reference point (B_{lim}) will be set to the inflection point of the segmented regression curve, in this case 25082 t.

[1] Stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired (B_{lim} = segmented regression change point).

Following this, the Precautionary Approach (PA) level of biomass, considered to ensure that the probability of the spawning stock biomass falls below B_{lim} is less than 5%, is set as a product of this reference point times the PA factor, ϕ, defined in this case as the default value of $exp(1.645 \times \sigma SSB)$. The σSSB was estimated in the SAM model (σSSB = 0.2098). This calculation produces a B_{pa} value of 35421 t.

The first forward simulation was conducted assuming no error in the assessment estimates for the advice year 2024, or autocorrelation in those errors (`Fcv = 0, Fphi = 0`). This allowed the calculation of the fishing mortality that would lead the SSB to the level set by B_{lim}, $F_{lim} = 0.533$.

A new model fit was carried out in which the last year of data was removed. From a forward simulation based on those results, this time conducted with standard values for assessment error and autocorrelation (`Fcv = 0.212, Fphi = 0.423` default suggested values from (ICES 2021)), an initial estimate of F_{MSY} was obtained. A subsequent simulation run provided an initial value for MSY$B_{trigger}$. This value was then applied in a new simulation run to calculate the value of F_{pa} = 0.308 (Figure 3). A comparison of this value with the candidate F_{MSY} led to keep the value of F_{MSY} candidate for F_{MSY}, $F_{\text{MSY}} = 0.252$.

(F_{MSY} is not allowed to be above F_{pa}; therefore, if the F_{MSY} value calculated initially is above F_{pa}, F_{MSY} is reduced to F_{pa})

The $F_{MSY\,upper}$ was limited to the value of F_{pa} since the first estimate of $F_{MSY\,upper}$ was higher than F_{pa}. The value of the MSY$B_{trigger}$ reference point was set to equal B_{pa}, at a level of 35421 t since the plaice stock hasn't been fished at or below F_{MSY} for 5 years or more.

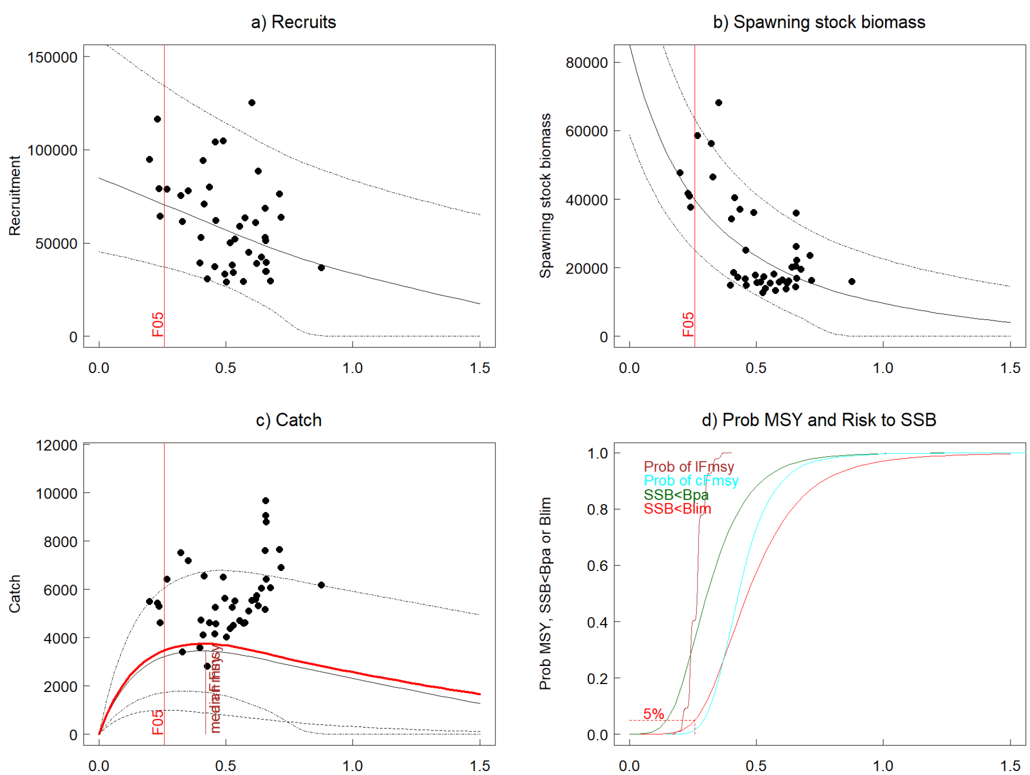

Figure 3: Summary plot of the final eqsim simulation.

4.1 Proposed reference points

The complete table of proposed reference points, obtained from the analysis presented above, can be found in the following table :

Reference point	Value	Technical basis
$MSYB_{trigger}$	35421 t	B_{pa}
F_{MSY}	0.252	EQsim analysis based on the recruitment period 1980-2023
B_{lim}	25082 t	Break-point of hockey stick stock-recruit relationship, based on the recruitment period 1980-2021
B_{pa}	35421 t	$B_{lim} \cdot \exp(1.645 \cdot \sigma SSB)$
F_{lim}	0.533	EQsim analysis, based on the recruitment period 1980-2023
F_{pa}	0.308	The F that provides a 95% probability for SSB to be above Blim
MAP MSY $B_{trigger}$	35421 t	B_{pa}
MAP range $F_{MSYlower}$	0.183-0.252	Consistent with ranges provided by ICES, resulting in no more than 5% reduction in long-term yield compared with MSY
MAP range $F_{MSYupper}$	0.252-0.308	Consistent with ranges provided by ICES, resulting in no more than 5% reduction in long-term yield compared with MSY. Limited to the value of $Fmsy_{upper}$

5 Discussion

Reference points are different from those estimated in the previous benchmark in 2022. The new $MSYB_{trigger}$ is 6.6% higher than the previous $MSYB_{trigger}$ and the new F_{MSY} increased by 62%. These changes could be explained by :

- The update of the historical time series of catch data (from 2002)
- The update of the biological data (maturity and natural mortality)
- The change of the assessment model. The state-space SAM model was used as the new assessment model instead of AAP model

6 References

ICES. 2021. "Technical Guidelines - ICES Fisheries Management Reference Points for Category 1 and 2 Stocks (2021)." https://doi.org/10.17895/ICES.ADVICE.7891.

7 Appendix A: Reference points calculation in R

```
# model_refpts.R - Estimate reference points for Plaice 7d
# Iago MOSQUEIRA (WMR) <iago.mosqueira@wur.nl>
# Distributed under the terms of the EUPL-1.2
# Modified April 2022 by Ghassen Halouani, WGNSSK (2022)
# Modified February 2025 by Ghassen Halouani, WKBNCS (2025)

## Packages installation
# install.packages("devtools")
# install.packages("FLCore", repo = "http://flr-project.org/R")
# library(devtools)
# install_github("ices-tools-prod/msy")


rm(list=ls())

library(msy)
library(FLCore)

config <- 43
load(paste0("output/FLR_stock_objects_MIXFISH/ple7d_FLStock_estimated_config_", config,"_2024.

# SETTINGS
Fs <- seq(0, 1.5, length=51)
nsamp <- 2500
set.seed(14)

# LOAD assessment stock object
ass.stock <- stock_estimated
ass.stock@discards.wt
units(ass.stock@harvest) <- "f"

# USE 5 y for selectivity and biology
bio.years <- c(2019, 2023)
sel.years <- c(2019, 2023)

# REMOVE n years (we are not confident about the rec of the last years)
remove.years <- 1

# FIT all models
srfit0 <- eqsr_fit(ass.stock, nsamp = nsamp, models = c( "Segreg", "Bevholt"))

png(paste0("output/reference_points/SRR_segreg_bevholt_config", config, ".png"), width = 1000,
eqsr_plot(srfit0)
dev.off()

## Blim estimation ====
# NOTE Segreg CHOSEN for Blim
# FIT segreg to obtain BLIM & BPA (Type 2)
srfit1 <- eqsr_fit(ass.stock, nsamp = nsamp, models = "Segreg")

png(paste0("output/reference_points/SRR_segreg_config", config, ".png"), width = 1000, height
eqsr_plot(srfit1)
dev.off()

Blim <- srfit1[["sr.det"]][,"b"]
```

```r
# SigmaSSB is derived from SAM model fit$sdrep$sd[idx][fit$data$years==max(years)].
# If sigmaSSB cannot be derived we can use the default value 0.2
sigmaSSB <- 0.2098184 # from sam model 8 (benchmark)
# sigmaSSB <- 0.2
## Bpa estimation ====
pa <- exp(1.645 * sigmaSSB)
Bpa <- Blim * pa
Bpa
## Flim and Fpa estimation ====
# SIMULATE all models w/10 y, Fcv=Fphi=0, Btrigger=0
srsim1 <- eqsim_run(srfit1,
                    bio.years = bio.years, sel.years = sel.years,
                    Fcv = 0, Fphi = 0,
                    Btrigger=0, Blim = Blim, Bpa = Bpa,
                    Fscan = Fs,
                    verbose = T)

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

## cFmsy (=Fmsy candidate) and F05 estimation ====
# Segreg and Bevhold models are choosed to estimate the remaing refpts,
srfit2 <- eqsr_fit(ass.stock, nsamp = nsamp,
                   models = c( "Segreg", "Bevholt"),
                   remove.years=remove.years)

# SIMULATE, Fcv=0.212, Fphi=0.423 (WKMSYREF4)
srsim2 <- eqsim_run(srfit2,
                    bio.years = bio.years, sel.years = sel.years,
                    bio.const = FALSE, sel.const = FALSE,
                    Fcv=0.212, Fphi=0.423,
                    Btrigger=0, Blim = Blim, Bpa = Bpa,
                    Fscan = Fs,
                    verbose = T)

cFmsy <- srsim2$Refs2["lanF", "medianMSY"]
F05 <- srsim2$Refs2["catF", "F05"]

png(paste0("output/reference_points/eqsim_diagnostic_srsim2_config", config, ".png"), width =
eqsim_plot(srsim2)
dev.off()

## Btrigger estimation ====
# SIMULATE for Btrigger
srsim3 <- eqsim_run(srfit2,
                    bio.years = bio.years, sel.years = sel.years,
                    bio.const = FALSE, sel.const = FALSE,
                    Fcv = 0, Fphi = 0,
                    Btrigger=0, Blim = Blim, Bpa = Bpa,
                    Fscan = Fs,
                    verbose = FALSE)

# Btrigger < Bpa -> Bpa
x <- srsim3$rbp[srsim3$rbp$variable=="Spawning stock biomass", ]
cBtrigger <- x[which(abs(x$Ftarget - cFmsy) == min(abs(x$Ftarget - cFmsy))), "p05"] # Fp05 = F

# SIMULATE
srsim4 <- eqsim_run(srfit2,
```

```
                    bio.years = bio.years, sel.years = sel.years,
                    bio.const = FALSE, sel.const = FALSE,
                    Fcv=0.212, Fphi=0.423,
                    Btrigger=cBtrigger, Blim = Blim, Bpa = Bpa,
                    Fscan = seq(0, 1.2, len = 40),
                    verbose = FALSE)

F05 <- srsim4$Refs2["catF", "F05"]

# If F05 < Fmsy, then Fmsy = F05
if(cFmsy > F05) {
  Fmsy <- F05
} else {
  Fmsy <- cFmsy
}

# IF Btrigger < Bpa, then Btrigger = Bpa, then redo srsim4
# OR IF Fbar 5yrat or below Fmsy
if(cBtrigger < Bpa | all(tail(fbar(ass.stock), 5) > Fmsy)) {

  Btrigger <- Bpa

  srsim4 <- eqsim_run(srfit2,
                      bio.years = bio.years, sel.years = sel.years,
                      bio.const = FALSE, sel.const = FALSE,
                      Fcv=0.212, Fphi=0.423,
                      Btrigger=Btrigger, Blim = Blim, Bpa = Bpa,
                      Fscan = seq(0, 1.2, len = 40),
                      verbose = FALSE)

  cFmsy <- srsim4$Refs2["lanF", "medianMSY"]
  F05 <- srsim4$Refs2["catF", "F05"]

  # If F05 < Fmsy, then Fmsy = F05
  if(cFmsy > F05) {
    Fmsy <- F05
  }
} else {Btrigger <- cBtrigger}

png(paste0("output/eqsim_diagnostic_srsim4_config", config, ".png"), width = 1000, height = 60
eqsim_plot(srsim4)
dev.off()

# The new definition of Fpa (2021)
Fpa <- F05

# FMSY (low - up) w/o Btrigger
lFmsy <- srsim3$Refs2["lanF", "Medlower"]
uFmsy <- srsim3$Refs2["lanF", "Medupper"]

if(uFmsy > Fpa) {
  uFmsy <- Fpa
}

# REFPTS
refpts <- FLPar(Btrigger=Btrigger, Fmsy=Fmsy, Blim=Blim, Bpa=Bpa,
                Flim=Flim, Fpa=Fpa, lFmsy=lFmsy, uFmsy=uFmsy,
                units=c("t", "f", rep("t", 2), rep("f", 4), rep("t", 2)))
```

```r
refpts_df <- as.data.frame(refpts)
names(refpts_df) <- c("Reference point", "", "Value")
refpts_df <- refpts_df[,-2]
write.csv(refpts_df, paste0("output/reference_points/refpts_plaice7d_config_", config,".csv"),
save.image(file = "my_work_space_refpts_estim.RData")
```

Update FR-GFS survey index time series from DATRAS for plaice (*Pleuronectes platessa*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on selected North Sea and Celtic Sea stocks (WKBNSCS 2025)

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Since WGNSSK 2020 (ICES, 2020), and the changes in methodology to derive DATRAS survey index data product, it was decided for every stocks in WGNSSK to only update the last data year of DATRAS survey time series to estimate survey index for stock assessment. Historical data would be updated only during Benchmark or Inter-benchmark.

For WKBNSCS 2025 benchmark, to estimate ple.27.7d survey index from FR-GFS [G3425] the methodology approved during WGNSSK 2022 was applied (ICES, 2022). The time series from 1990-2023 of survey hauls data from DATRAS was extracted and updated (ICES, 28 October 2024).

In Figure 1 and 2, index and index CVs by ages between FR-GFS index used to give advice for ple.27.7d in 2024 (ICES, 2024) and the index estimated for WKBNSCS 2025 are compared. The update of FR-GFS has no impact on the estimation of the average index at age. Some minor change in estimates of uncertainty can be observed early in the time series and in 2020 for age 1 (Figure 2). As only minor changes in uncertainty estimation were observed, the cause of those changes were not investigated in details.

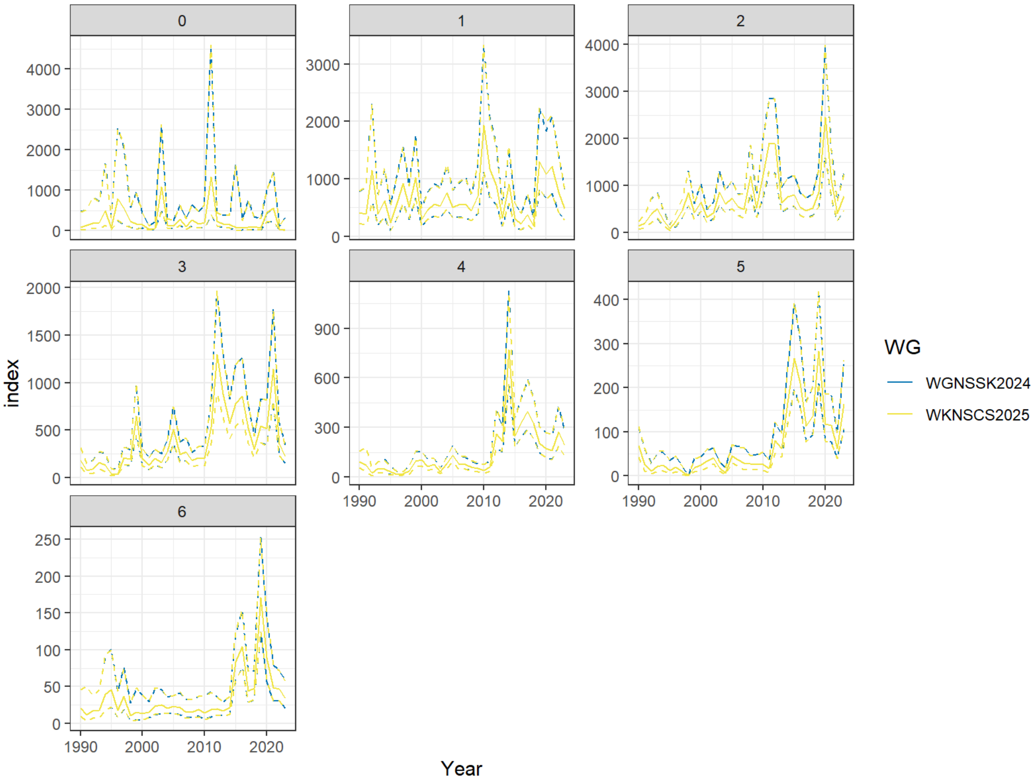


Figure 1: FR-GFS ple.27.7d survey index at age: comparison between WGNSSK 2024 estimates and WKNSCS 2025.

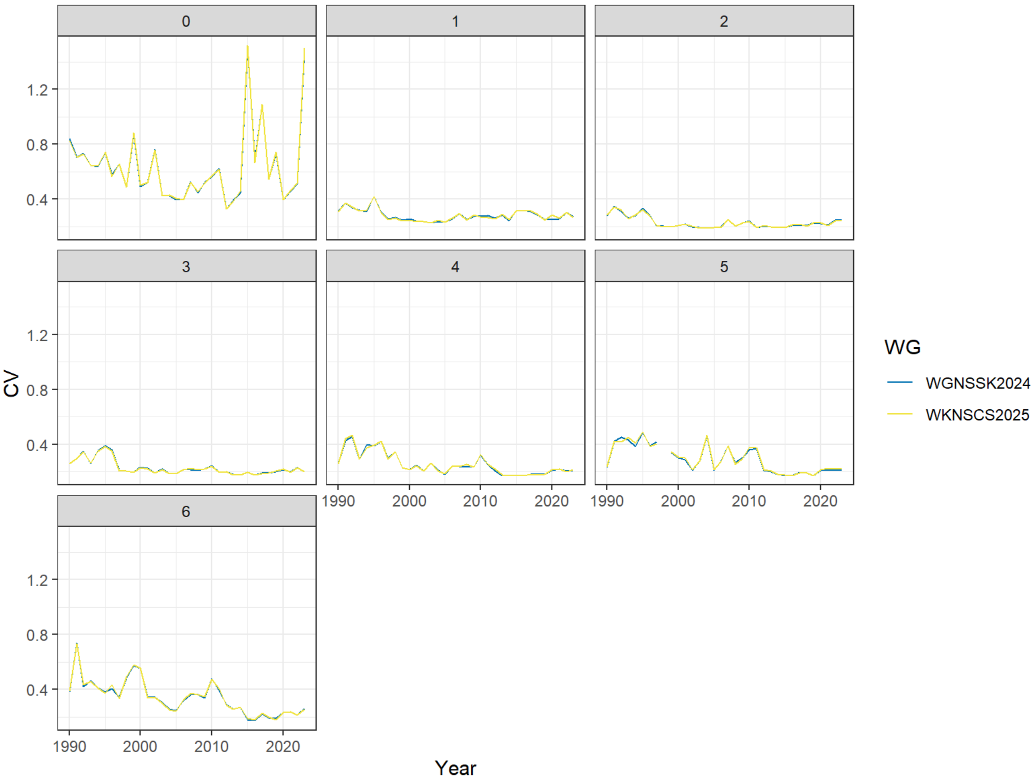


Figure 2: FR-GFS ple.27.7d survey index CVs at age: comparison between WGNSSK 2024 estimates and WKNSCS 2025.

References

ICES, 2024. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. https://doi.org/10.17895/ICES.PUB.25605639

ICES, 2022. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) (report). ICES Scientific Reports. https://doi.org/10.17895/ices.pub.19786285.v1

ICES, 2020. 2020 Report Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. https://doi.org/10.17895/ICES.PUB.6092

Working Document: Maturity for North Sea turbot (tur.27.4)

Author: Justin C. Tiano (WMR, The Netherlands)

Introduction

Since becoming a category 1 stock, the assessment of the tur.27.4 stock has used a maturity vector based on the female maturity ogive developed during IBPNEW (ICES, 2012). Due to inconsistent data for males and issues with historical data, the decision was made to rely solely on female data from 2004 to 2009 for deriving the maturity ogive used in subsequent assessments. The female maturity ogive was derived from a General Linear Model using maturity data from 2004 – 2009. The dataset used to create this ogive consisted entirely of market samples from the Netherlands, without accounting for the time of year the data were collected.

Updating the maturity ogive to incorporate additional years of data and samples specifically collected during the peak spawning season (quarter 2) would enhance its relevance and accuracy for the new assessment.

Data and methods

The updated maturity ogive for North Sea turbot uses quarter 2 data from Dutch market samples from 2003 – 2023 and samples from a Belgian commercial sampling program from 2017 – 2023 consisting of 7385 sampled female turbot. A maturity ogive was generated using a binomial generalized linear model (GLM) with a logit link. Ogives were fitted as a function of length using the R package *sizeMat* and was subsequently converted to age.

Updated female maturity ogive for North Sea turbot

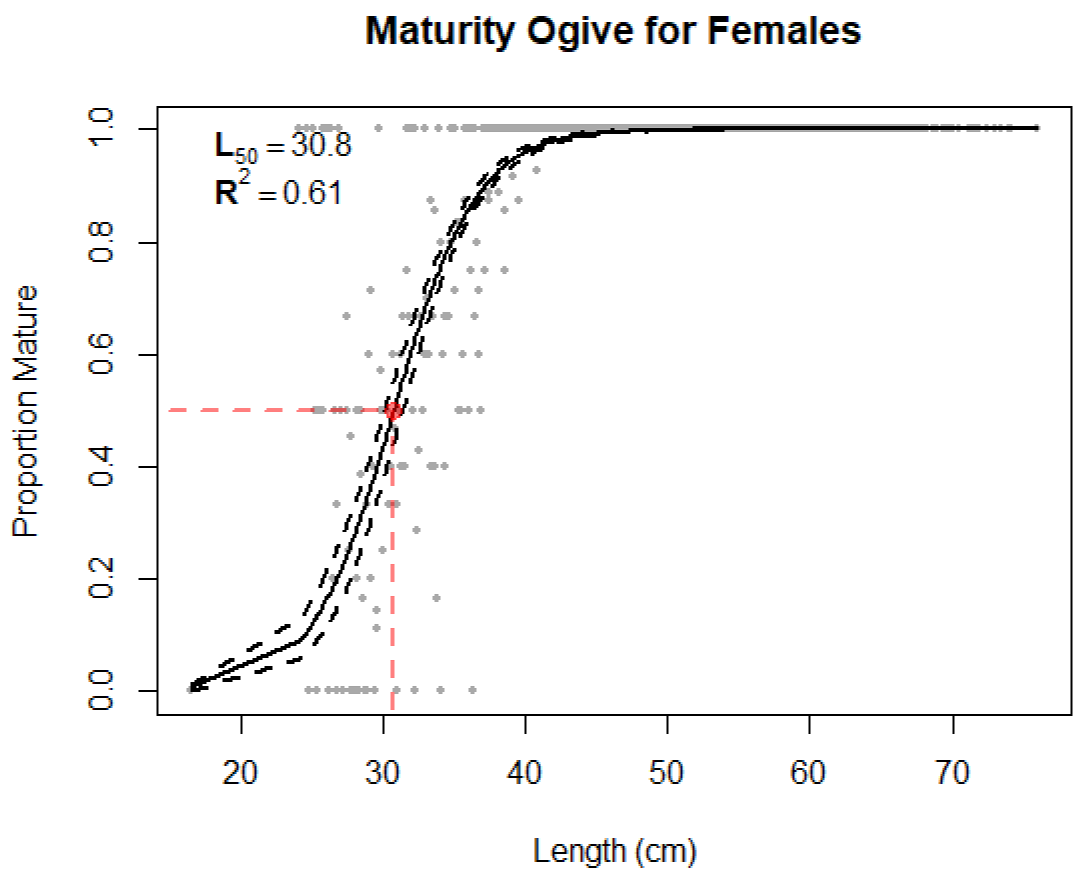


Figure 1. Maturity ogive for female North Sea turbot based on the proportion mature at length.

The estimated length at 50% maturity (L50) over the entire dataset is 30.8 cm. The plot for proportion mature over age shows maturation of female turbot between 2 to 4 years of age. In comparison to the previous maturity ogive, the updated ogive suggests a slightly lower proportion of maturing females at age 2 (from 4 to 1%) and a higher percentage of mature turbot aged 3 (58% compared to 47% in the previous ogive).

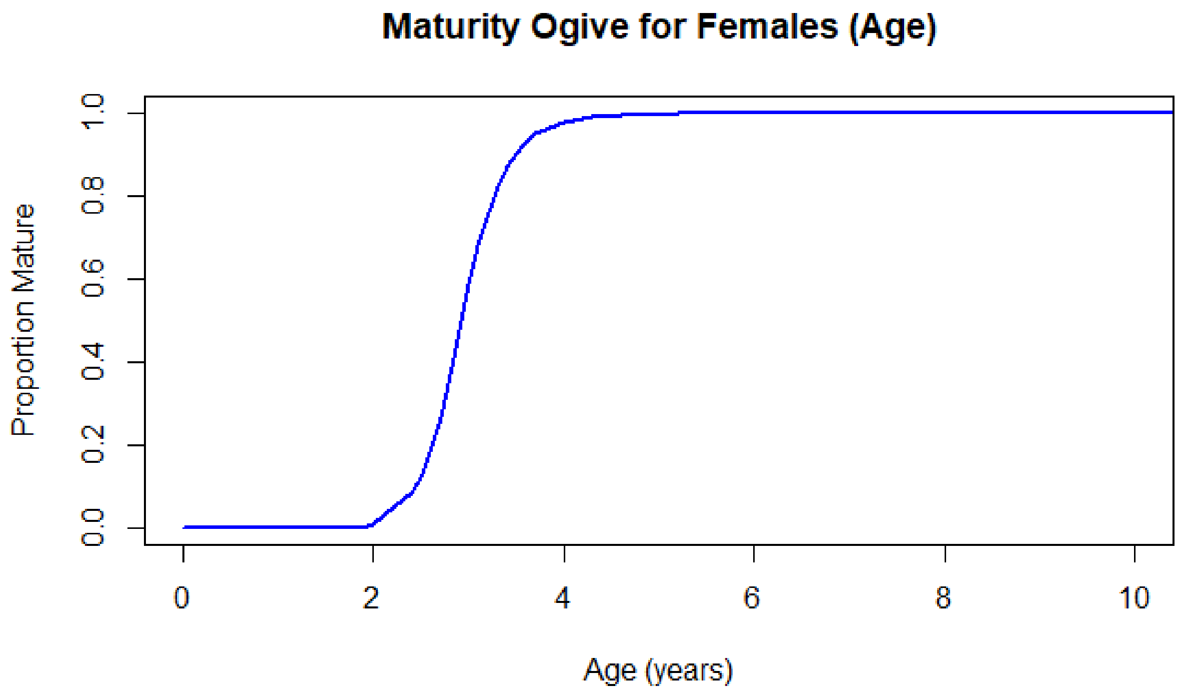


Figure 2. Female maturity ogive based on proportion mature at age.

Previous

2004-2009

1	2	3	4	5	6	7	8	9	10
0	0.04	0.47	0.95	1	1	1	1	1	1

Updated

2003-2023

1	2	3	4	5	6	7	8	9	10
0	0.01	0.58	0.98	1	1	1	1	1	1

Figure 3. Comparison of proportion mature at age with previous maturity ogive and updated version.

References

ICES. 2012. Report of the Inter-Benchmark Protocol on New Species (Turbot and Sea bass; IBPNew 2012), 1–5 October 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:45. 239 pp.

Working Document: Updated survey indices developed for North Sea turbot (tur.27.4)

Author: Justin C. Tiano (WMR, The Netherlands)

Introduction

Since IBP Turbot in 2018, three indices of abundance have informed the North Sea turbot SAM assessment: the Beam Trawl Survey performed on the RV Isis, (BTS-ISIS), the Sole Net Survey (SNS) and a Dutch North Sea fisheries derived LPUE (ICES, 2018a). Both scientific surveys are conducted in quarter 3 by Dutch vessels and use stratified mean CPUE values. The SNS (ages 1-6) provides nearshore data designed to monitor juvenile flatfish in coastal areas while the BTS-ISIS (ages 1-7) collects offshore data. Although these surveys offer relevant information for North Sea turbot, catchabilities for older ages are notably low, and internal consistencies between the surveys are weak. This results in their lower weighting in the SAM assessment.

Consequently, the scientific surveys hold a lower influence on the assessment outcomes compared to the LPUE index and fisheries catch data. In recent years, the reduced fishing effort and area coverage of Dutch beam trawl fisheries have raised concerns about the reliability of the NL LPUE as an unbiased indicator for the turbot assessment. In the 2018 inter-benchmark for turbot, the LPUE index was argued to have an unrealistically high weighting in the assessment (ICES, 2018b).

Following recommendations from ICES expert working groups, a scientific survey utilizing Dutch fishing vessels was established in 2018 to improve survey indices for turbot and brill in the North Sea. This this Dutch 'industry survey' (BSAS) has been designed to collect data in key areas for evaluating turbot stock status.

This following describes the development of model-based indices from all relevant North Sea surveys including the new BSAS survey.

Data and methods

There are 5 scientific surveys that are able to potentially provide useful information on the North Sea turbot stock assessment:

- Beam Trawl Surveys (BTS); offshore
- Sole Net Survey (SNS); nearshore
- Demersal Young Fish Survey (DYFS); nearshore
- International Bottom Trawl Survey (IBTS); offshore
- Industry survey for turbot and brill (BSAS); offshore

Survey timelines are restricted to years when annual biological information (age, maturity etc.) are available for turbot which starts at 1991 for the BTS, 2003, for the DYFS, 2004 for the SNS and IBTS and 2019 for BSAS.

To develop new modelled indices for North Sea turbot, the R package surveyIndex was used. To replace stratified mean CPUE-based BTS-ISIS index currently used in the North Sea turbot assessment, a combined index using BTS surveys from all relevant North Sea countries (NL, GB, BE, DE) was developed. To account younger age classes which are currently informed in the assessment by the CPUE-based SNS survey, a combined model-based index using both SNS and DYFS surveys (NL, DE, BE) was developed. A model-based index for BSAS was developed using the same methodology as for the other scientific surveys. The IBTS has only limited biological information on turbot due to low catchability. While it was still possible to obtain a stratified CPUE-based index based on IBTS data, the limited information on turbot proved challenging to incorporate within a model-based index using the surveyIndex package. Therefore the IBTS was left out from further analysis.

Model selection was guided by AIC (Akaike's Information Criterion) and BIC (Bayesian Information Criterion) to identify the best performing model. “Delta-GAM” hurdle models which feature a presence/absence component modelled with a logistic distribution combined with a positive abundance model component using either lognormal or gamma distributions, were compared with models using tweedie distributions (Berg et al., 2014).

The abundance-at-age indices were modelled using the following formulation:

$$log(N_{age}) = B0 + f1(lon, lat) + f2(lon, lat, Year) + f3(Depth) + f4(Ship) + B1 * Gear + B2 * Year + \log(SweptArea + 1)$$

where:

- N_{age} is the expected count for individuals at each age.
- $B0$ is the intercept term, representing the baseline abundance at age.
- $f1(lon, lat)$ is a time-invariant spatial effect, modelled using a two-dimensional Duchon spline with penalties for smoothness.
- $f2(lon, lat)$ is a time-varying spatial effect, modelled using a Duchon spline varying by year with basis dimension: $k = 10$.
- $f3(Depth)$ is a smooth function of depth, modelled with thin-plate regression splines with basis dimension: $k = 6$.
- $f4(Ship)$ represents a random effect for different vessels carrying out the survey.
- $B1$ and $B2$ are fixed effects for gear type and year, respectively.
- $\log(SweptArea + 1)$ is an offset term to standardize for the survey area coverage, ensuring estimates are comparable.

Results and Discussion

Locations of hauls from all surveys are illustrated in **Fig. 2**. This shows clear spatial differences for all surveys with the offshore BTS covering most of the North Sea and the DYFS and SNS taking place in coastal areas along the southwest North Sea coastline. The BSAS survey, like the BTS, is conducted offshore but has a more limited spatial coverage, focusing on offshore locations in the southeastern North Sea. This limitation is primarily due to budget constraints, which currently allow only three Dutch fishing vessels to participate. There have been discussions about expanding BSAS internationally by including vessels from Belgium and Denmark to increase its coverage.

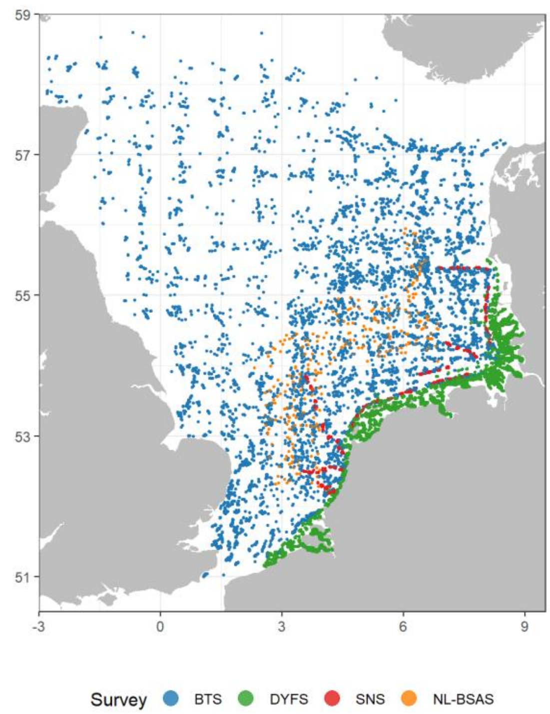


Fig. 2. North Sea hauls locations per survey.

Four countries participate in the BTS surveys, typically covering waters near their respective coastlines (**Fig. 3**). The Netherlands is an exception, as its survey range extends from the waters near the English Channel in the west to the eastern Scottish coast and the waters off western Denmark.

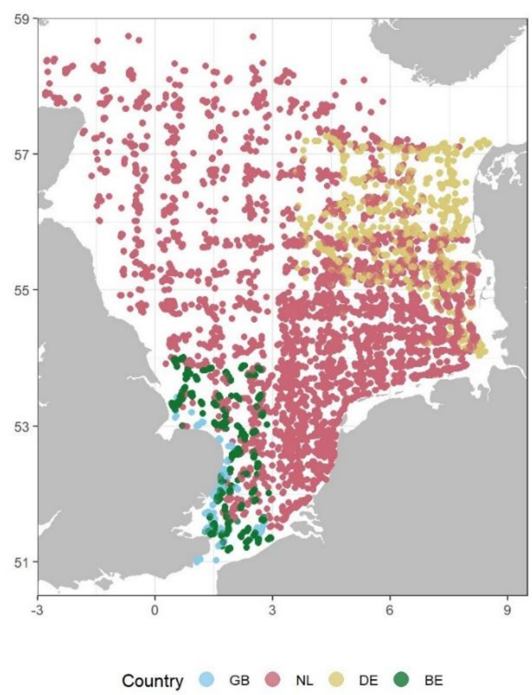


Fig. 3. BTS hauls locations per country.

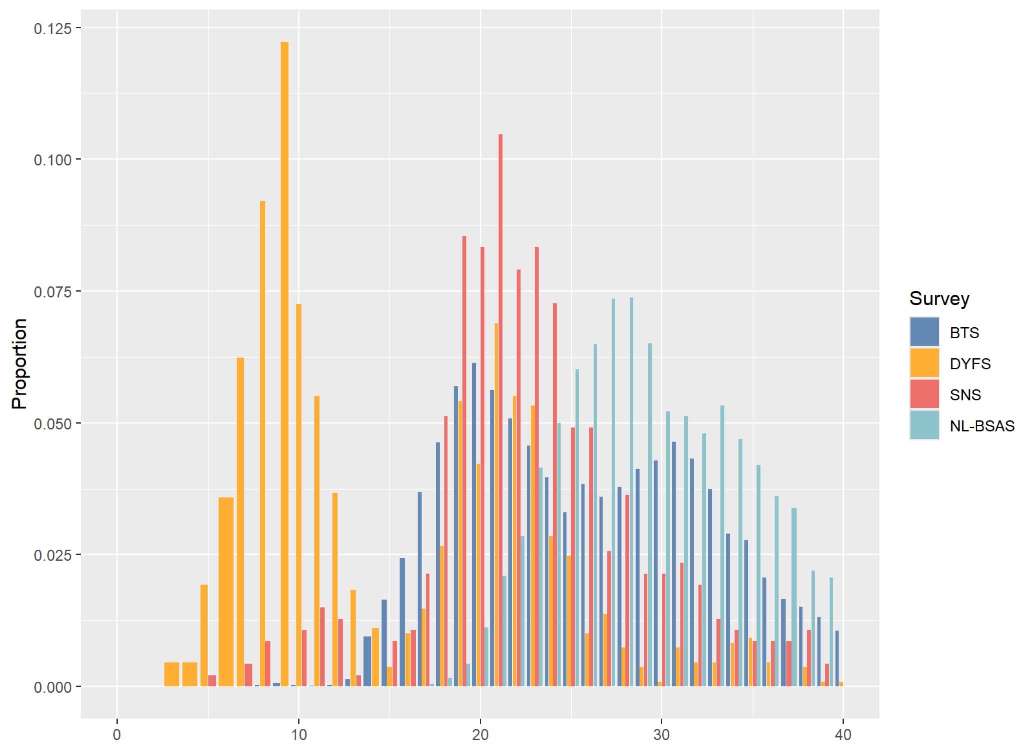


Fig. 4. Length-frequency plot per survey.

A comparison of mean CPUE from 2019 to 2023 between the current SNS and BTS indices used in the turbot assessment and the new BSAS survey reveals a clear disparity in older age classes, which are better represented in BSAS than in the other surveys (**Fig. 5**). While some cohort tracking may be deduced in the SNS and BTS CPUE plots, CPUE declines sharply from age 4 onwards in these surveys. In contrast, BSAS offers a distinct advantage with its more robust representation of older age classes.

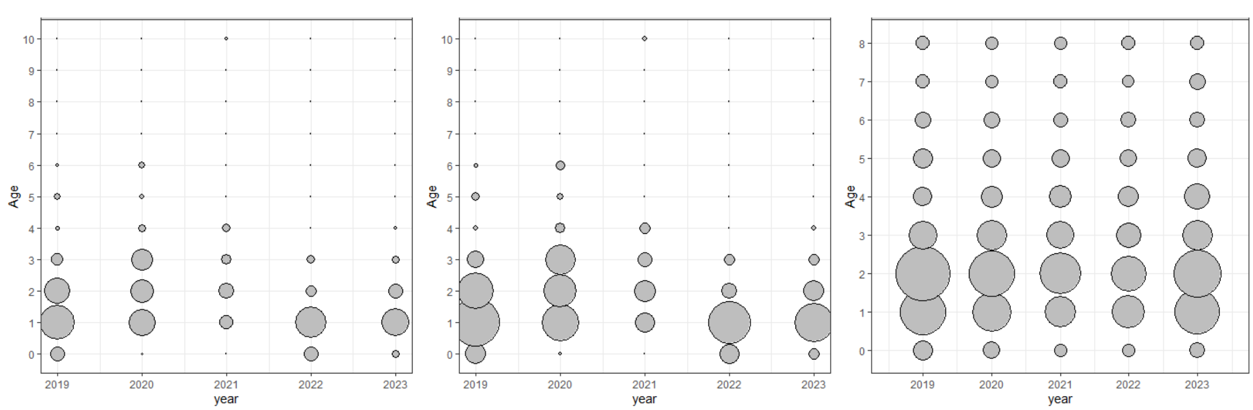


Fig. 5. Comparison of mean CPUE at age between SNS (left), BTS (middle), and BSAS (right).

Since 2019, BSAS has collected the highest numbers of turbot samples in the North Sea, followed by the BTS, DYFS, and SNS (**Fig. 6**).

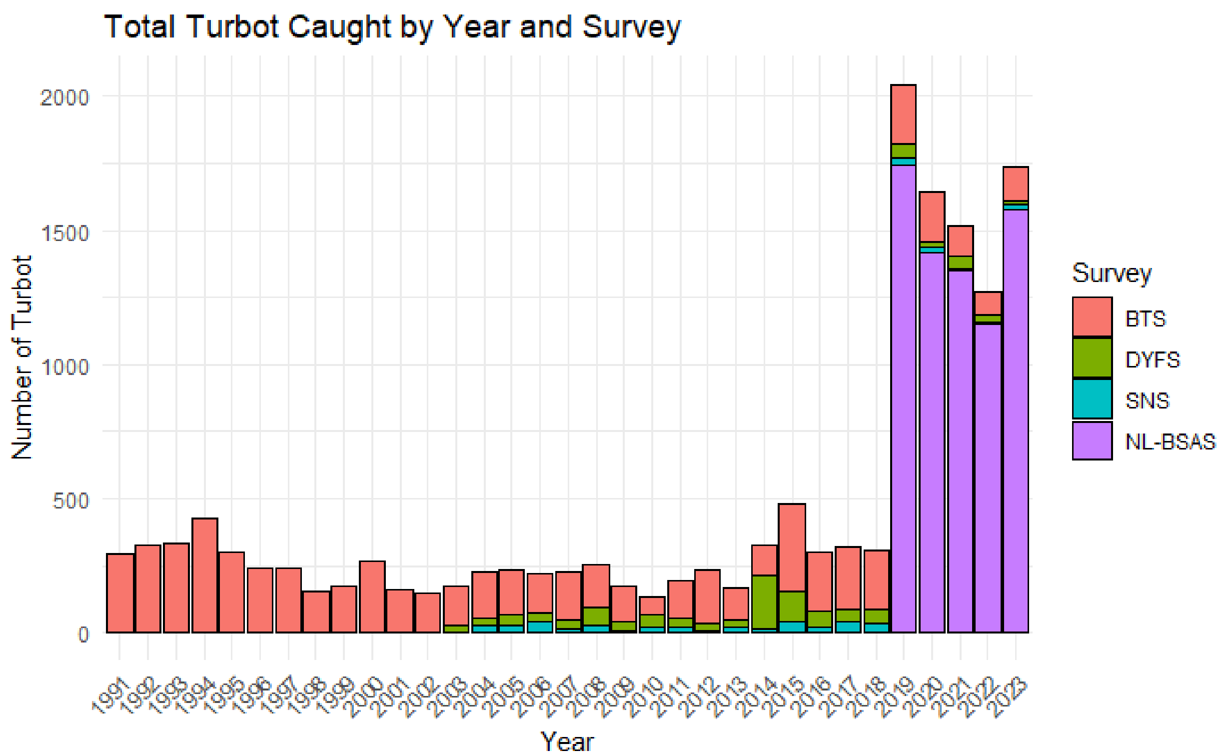


Fig. 6. A direct comparison of the total number of turbot caught in the North Sea per survey.

AIC scores from simple to more complicated models were compared for the new survey indices (**Table 1**). Final models for all surveys included independent time-invariant and time-varying spatial components to be able to account for both year to year spatial changes as well as longer-term underlying spatial patterns. The spatial components included Duchon (bs= 'ds') splines with specified smoothness parameters to allow for flexibility in spatial information informing the model. Final models also included a random effect for ship and a smooth term for depth using a thin plate spline with shrinkage basis (bs= 'ts') to allow the model to penalize the smooth term down to zero if it doesn't contribute significantly to avoid from overfitting. The depth component uses the same k setting as the North Sea sole index models which also uses the BTS, SNS, and DYFS surveys (ICES, 2024).

Delta and tweedie gam models were tested during index development in order to obtain models that appropriately account for potentially differing variance structures between surveys. Delta models use a hurdle model structure with one presence/absence model using a binomial distribution and another positive abundance model (Berg et al., 2014). Tweedie distributions provide another option for data which feature high zero inflation and also overdispersion. Delta models featuring lognormal variance structures exhibited lower model AIC scores for BTS and COAST (DYFS+SNS) indices compared to Delta models with gamma or tweedie variance structures. In contrast, the BSAS indices using tweedie models displayed lower AIC scores when using tweedie models compared to either delta model (**Table 2**). Additional model diagnostic plots can be viewed in the supplemental materials (**Annex 2-4**).

Table 1. Comparison of goodness of fit of various survey models used for BSAS, applied to a combination of all surveys. Exploration of options was carried out on the time-invariant models to decrease the computational needs. Note: BSAS models lack a specific 'gear' effect as the survey operates using the same gear type. Models that include any other surveys include a gear component as a fixed effect.

Model	**description**	**simplified formula**	**AIC**
TIV+ship	time-invariant spatial effect + ship	*Year + Ship + s(lon,lat,bs='ds',m=c(1,0.5),k) + offset(log(SweptArea))*	*6033*
TIV+rShip	time-invariant spatial effect + random(ship)	*Year + s(Ship,bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + offset(log(SweptArea))*	*6016*
TIV+TV+ rShip	time-invariant and time-varying spatial effects + random(ship)	*Year + s(Ship, bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + s(lon,lat,bs='ds',m=c(1,0.5),k=10,by=Year,id=1) + offset(log(SweptArea))*	*5991*
TIV+TV+ depth	time-invariant and time-varying spatial effect + random(ship) + depth	*Year + s(Ship, bs='re') + s(lon,lat,bs='ds',m=c(1,0.5),k) + s(lon,lat,bs='ds',m=c(1,0.5),k=10,by=Year,id=1) + s(Depth,bs='ts',k=6) + offset(log(SweptArea))*	***5886***

Table 2. BSAS example of AIC comparisons made between delta-lognormal, delta-gamma, and tweedie models. Similar comparisons were made for other surveys.

Model	**description**	**AIC**	**BIC**
Delta-Lognormal	Hurdle model combining a logistic regression for presence/absence and a lognormal distribution for positive abundances.	*5886*	*7039*
Delta-Gamma	Hurdle model combining a logistic regression for presence/absence and a gamma distribution for positive abundances.	*5857*	*6979*
Tweedie	A single-component model for count data, capable of handling overdispersion and zero-inflation.	***5688***	***6637***

North Sea beam trawl surveys (BTS)

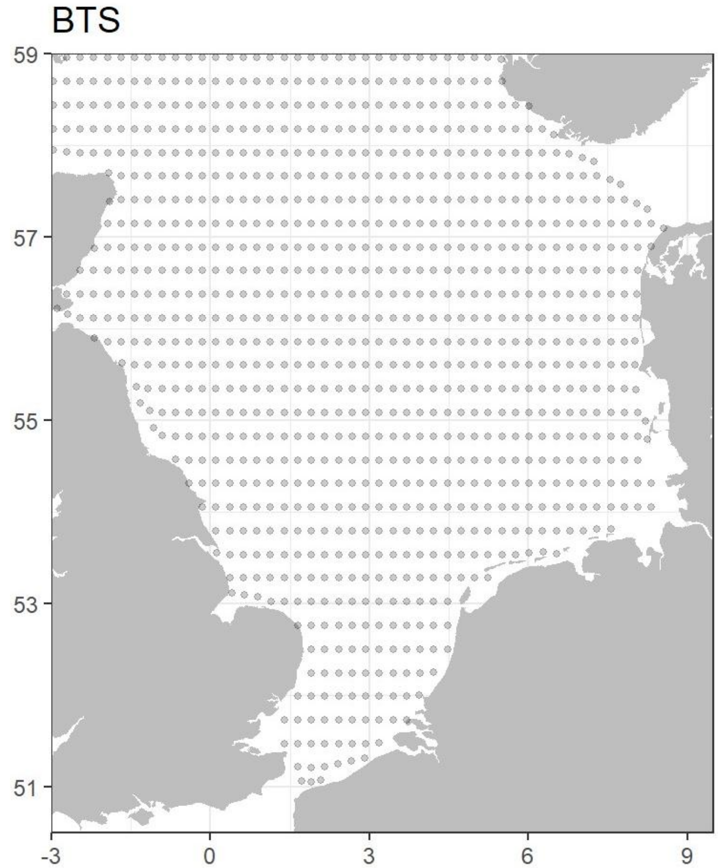


Fig. 7. Geographic grid used in the BTS index.

The BTS index used a North Sea grid spanning through all of ICES Subarea 4. Compared to the current CPUE index (ages 1-7), the new model based BTS index (ages 1-7) displayed higher internal consistencies from ages 1 through 5 (**Fig. 8**). Ages 6 and 7 in the modelled index still shows poor internal consistencies however, improved cohort tracking is visible in young to intermediate ages. The modelled BTS index shows markedly higher internal consistencies (cohort tracking ability) in more recent years (2007-2023) compared with older information (1991-2006; **Fig. S2**). Estimated indices at age for the BTS suggest a potential average increase in age 1 individuals throughout the years (**Fig. 9**). Higher upper bound credible intervals are associated from ages 3 to 7.

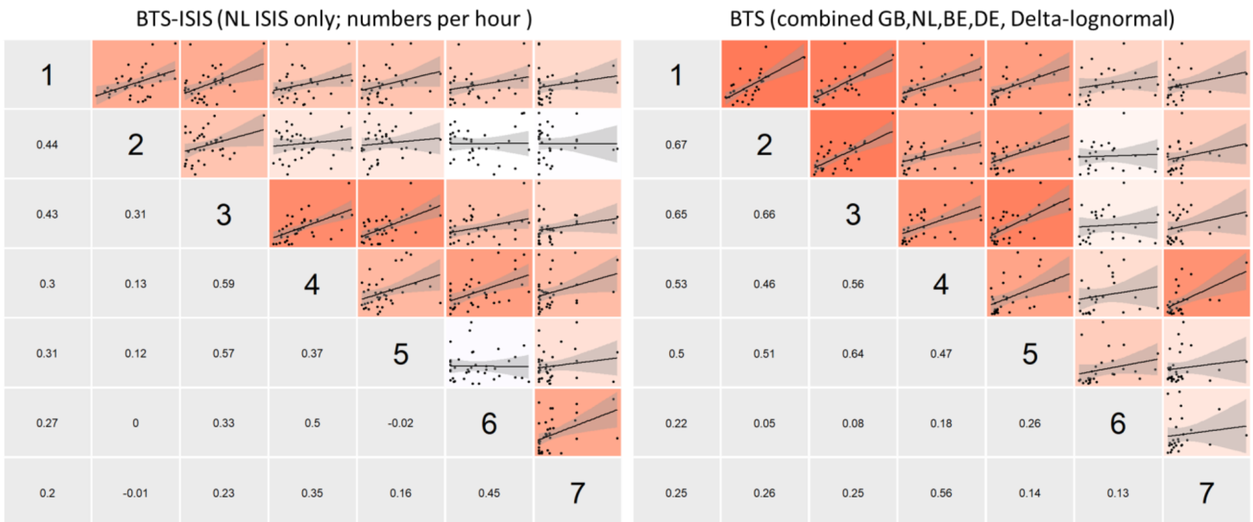


Fig. 8. Age correlation plots comparing the current BTS-ISIS index used in the North Sea turbot assessment and the new combined delta-lognormal BTS index (right).

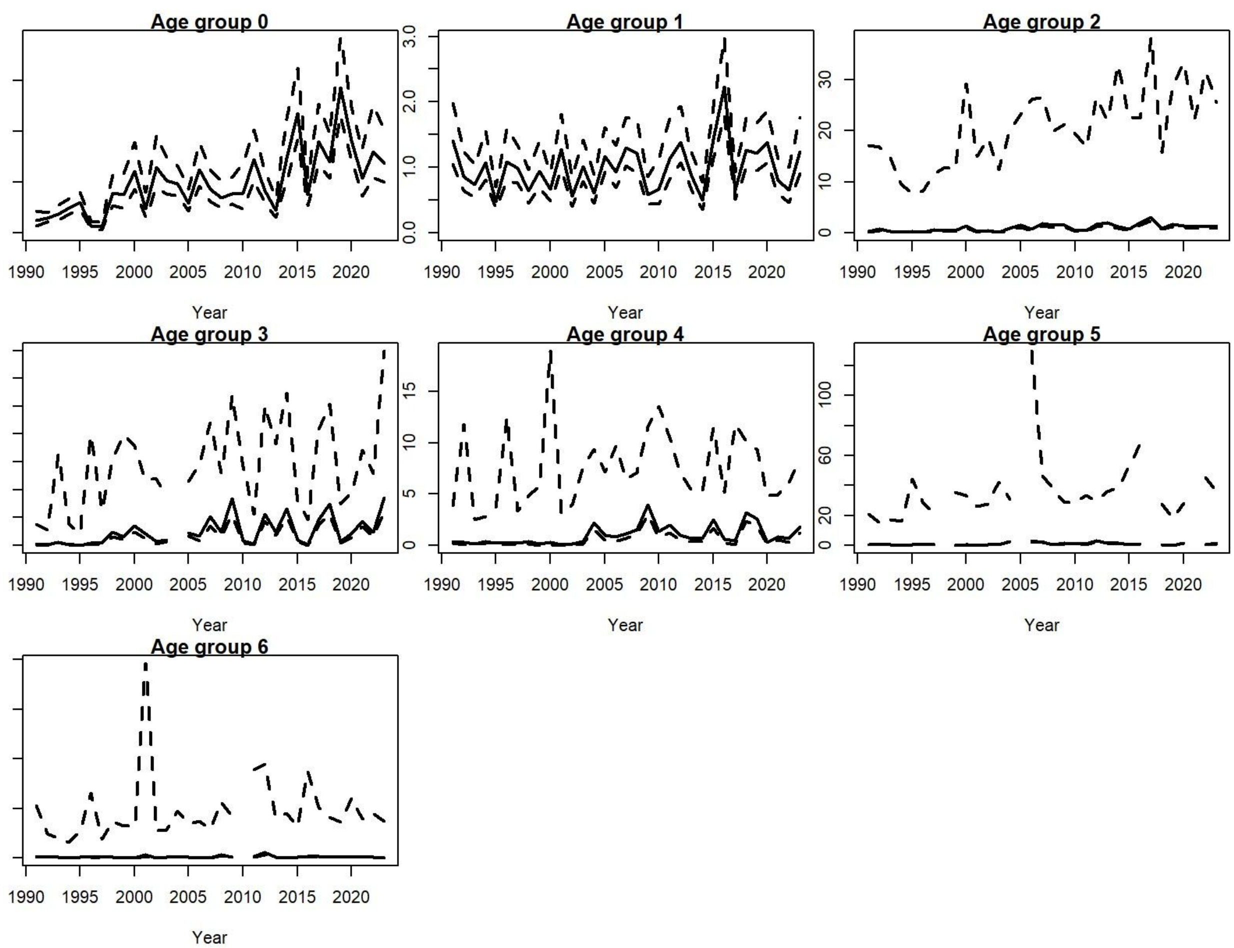


Fig. 9. Relative abundances at age from the index of abundance based on the BTS survey, showing the estimated value and credibility intervals. Note here age group 0 corresponds to age 1 and so on. The final age is a plus group.

Coastal surveys (SNS+DYFS = COAST)

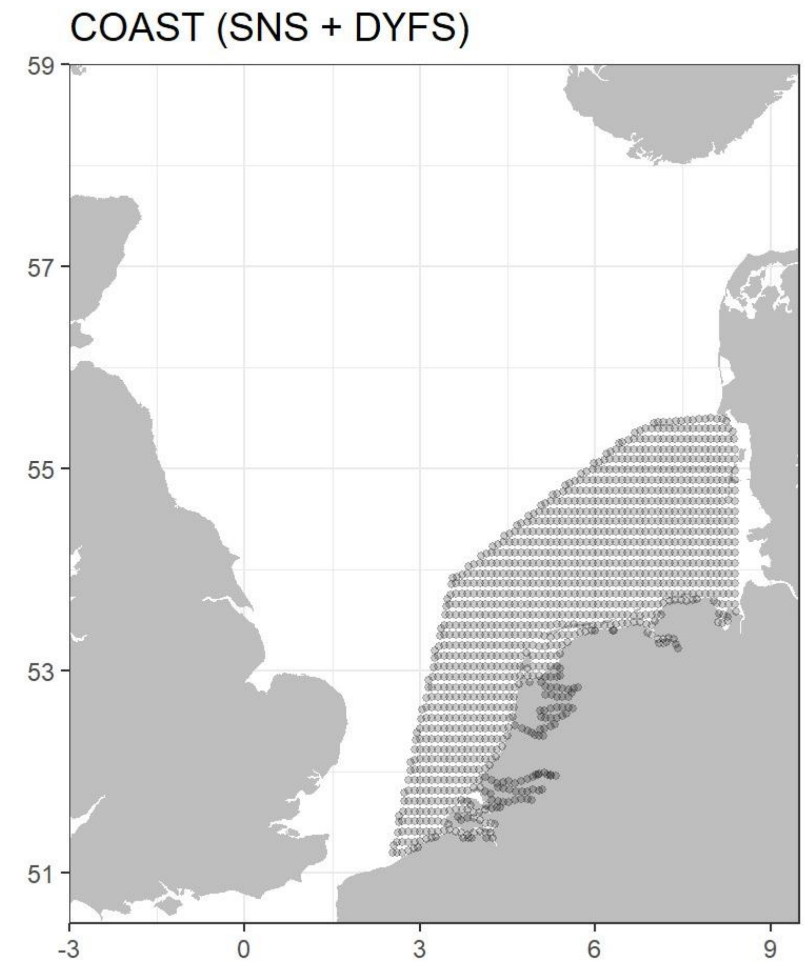


Fig. 10. Geographic grid used for COAST index.

The modeled index for COAST uses a grid which covers only areas where the coastal surveys occur (**Fig. 10**). The current SNS CPUE-based index (ages 1-7) is associated with very low internal consistencies compared to the combined COAST (SNS+DYFS; ages 0-3) delta-lognormal index (**Fig. 11**). Similar to the BTS modelled index, the COAST index shows improved internal consistencies with more recent years (2013-2023) compared to previous years (2003-2012; **Fig. S11**). Results for ages 0 and 1 suggest a peak in abundances in 2014 and 2015 respectfully (**Fig. 12**). This does not seem to be reflected in older age groups where former juveniles may be migrating towards deeper locations offshore.

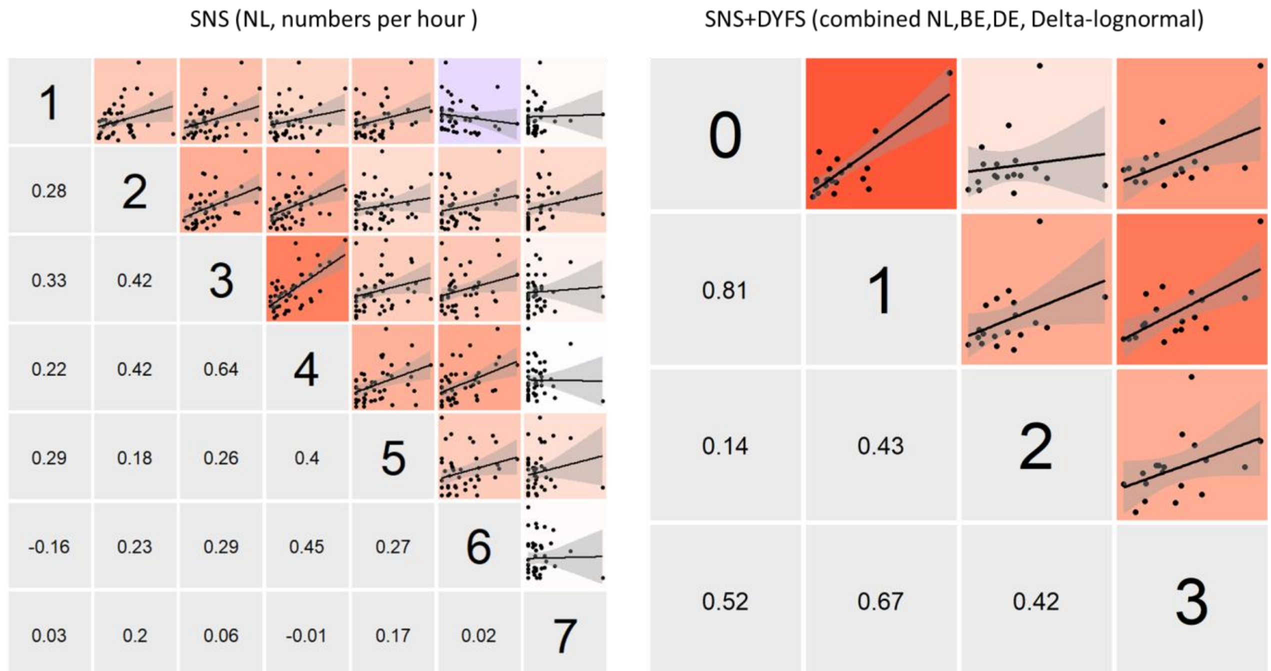


Fig 11. Age correlation plots comparing the current SNS index used in the North Sea turbot assessment and the new combined delta-lognormal COAST (SNS+DYFS) index (right).

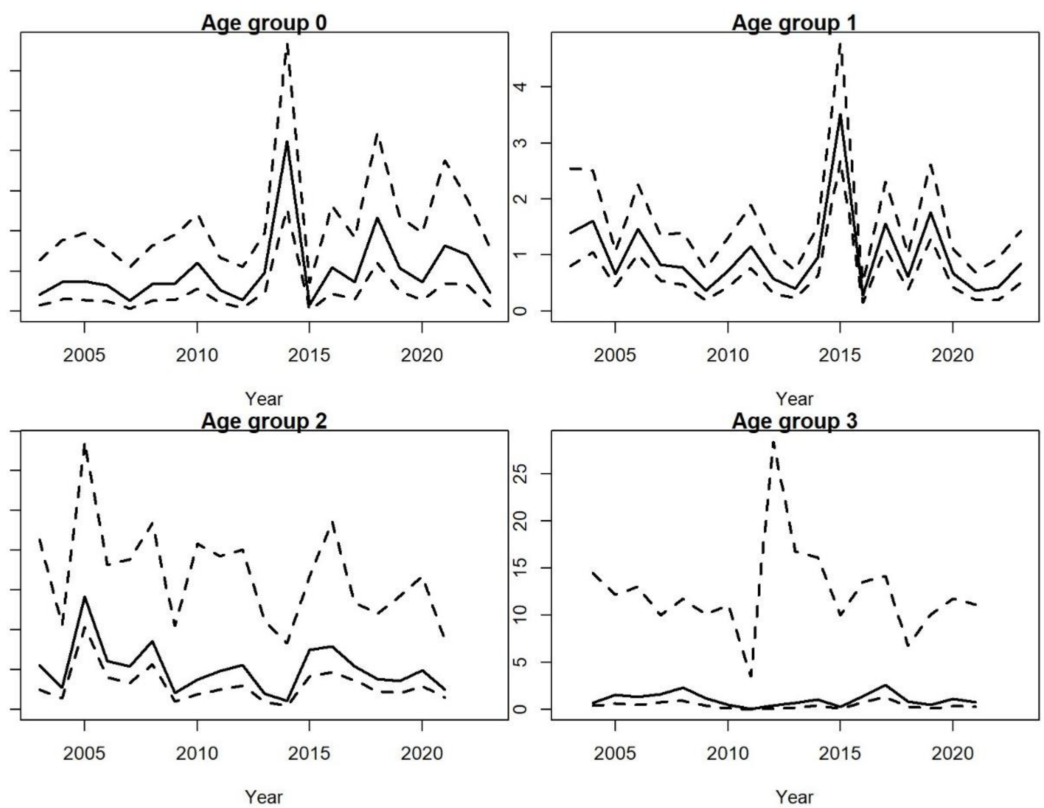


Fig. 12. Relative abundances at age from the index of abundance based on the BTS survey, showing the estimated value and credibility intervals. Note age group 0 corresponds to age 0 and so on. The final age is a plus group.

Dutch industry survey (BSAS)

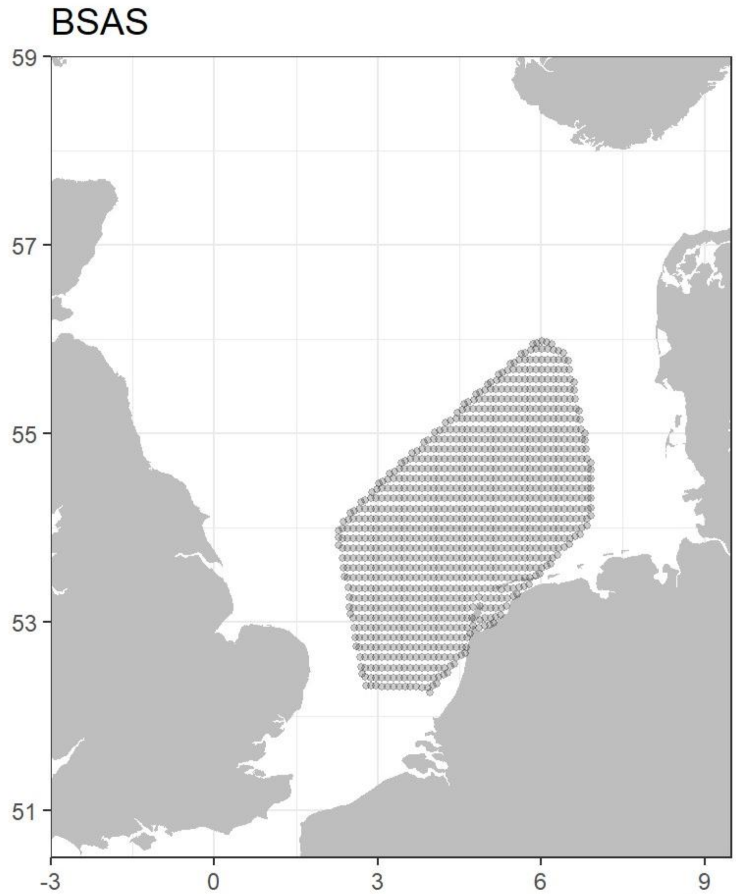


Fig. 13. Geographic grid used in the BSAS index.

The tweedie BSAS index (ages 1-8+) uses a grid specified for only the area which it covers (**Fig. 13**). Internal consistencies are much higher for younger (ages 1-3) and older ages (5-8+) compared to other surveys (**Fig. 14**). Intermediate ages, however, do not have good internal consistencies from the given time-frame (2019-2023). Upon further inspection, it seems that correlations relating to individuals with ages 3 and 4 in 2023 show low correlations or even negative values. These particular ages are associated particularly weak age classes from 2020 and 2021. In 2021 the recruitment has been estimated to be the second lowest in the entire assessment time series and is the lowest since the 1980's. These poor recruitment years appear to be disrupting the correlations for age classes 3 and 4. Older ages in particular seem to track particularly well with this survey providing an advantage compared to all other North Sea surveys used in the turbot assessment.

The relative abundances at age for BSAS show shifting dynamics amongst age groups between years 2019-2023 (**Fig. 15**). Compared to other survey indices, BSAS has much less uncertainty in its abundance at age estimations, which is similar with all age groups. The BTS and COAST surveys, both show much more uncertainty (wider credible intervals) regarding older ages (**Fig. 9 and 12**).

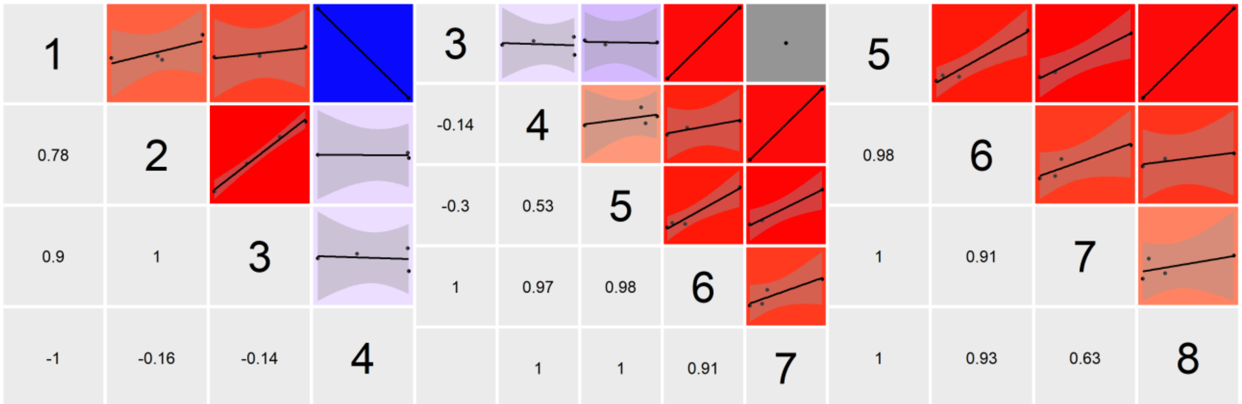


Fig. 14. Age correlation plots for the new Tweedie BSAS index showing correlations between ages 1-4 (left), 3-7 (middle), and 5-8 (right).

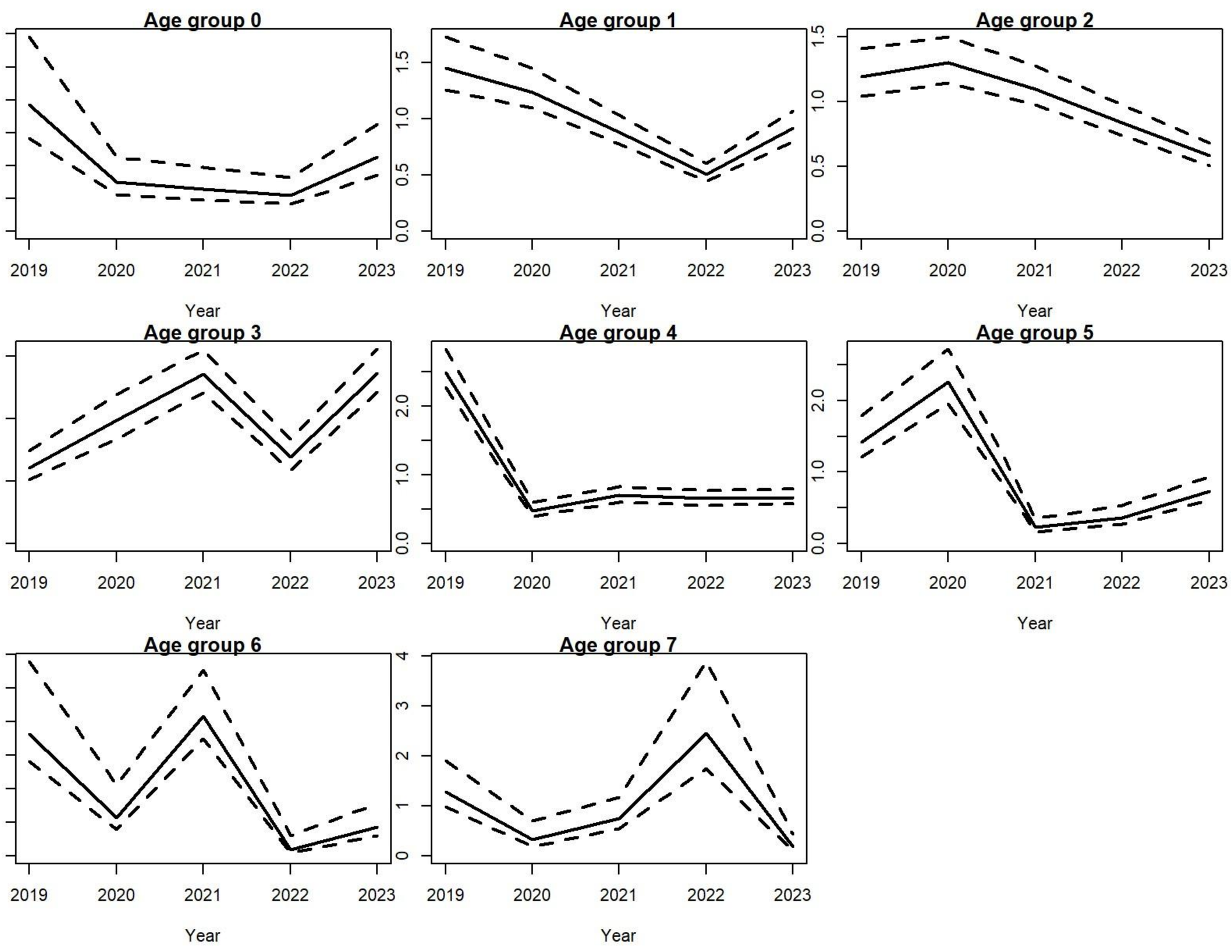


Fig. 15. Relative abundances at age from the index of abundance based on the BSAS survey, showing the estimated value and credibility intervals. Note, here age group 0 corresponds to age 1 and so on. The final age is a plus group.

Comparing trends-at-age between survey indices

The scaled relative indices at age show mostly similar patterns throughout their duration (**Fig. 16**). When focusing in on the years when BSAS has been in existence, BSAS shows similar trends at age for most years compared to BTS and COAST indices (**Fig. 17**). Perhaps the largest difference between survey trends can be seen in age 3 where the BTS index shows some divergence compared to the other indices estimating decreased abundances from 2020-2022 and higher abundances in 2023 (**Fig. 18**).

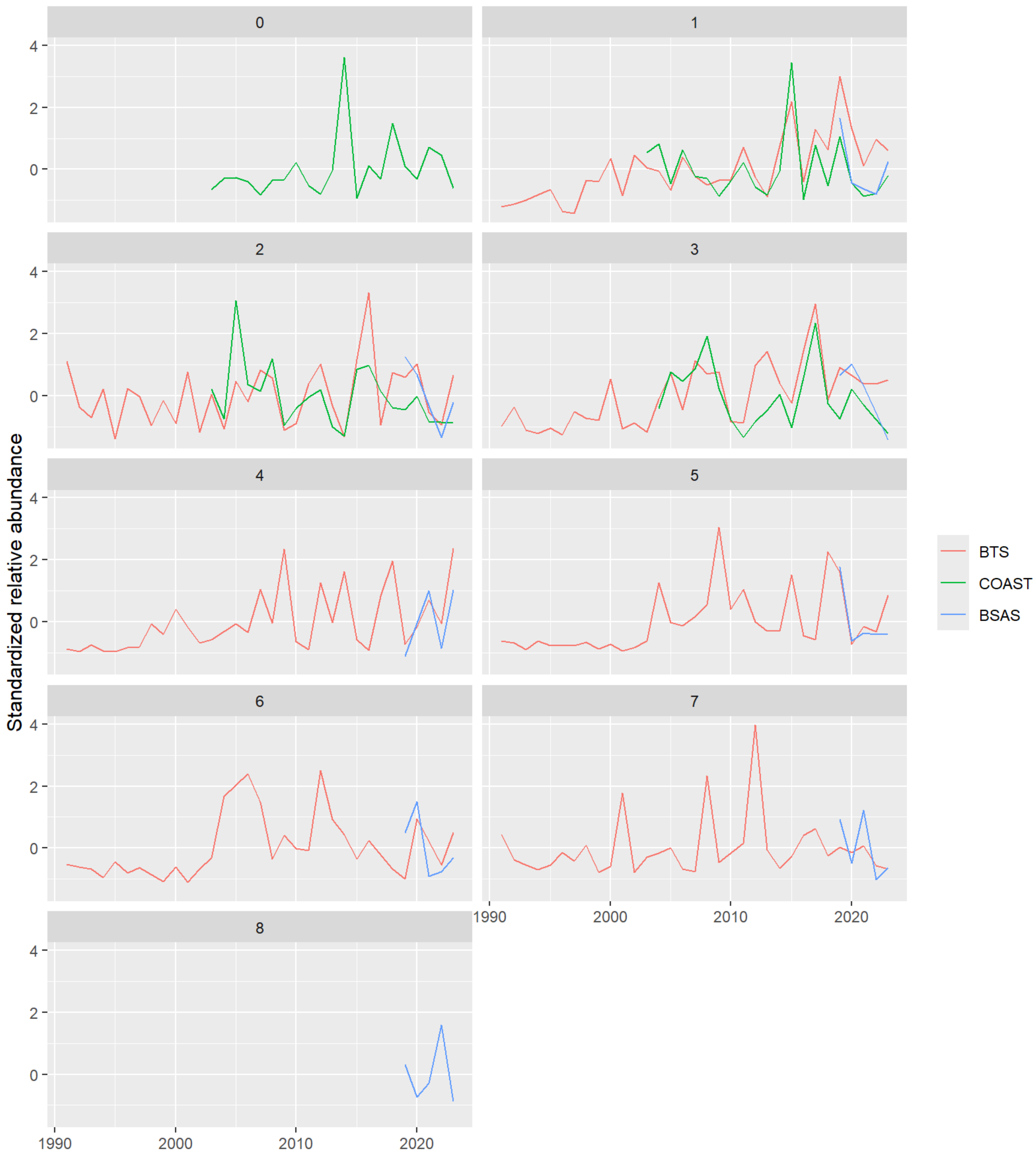


Fig. 16. Scaled relative index at age comparison from 1991-2023 for the BTS, COAST, and BSAS surveys.

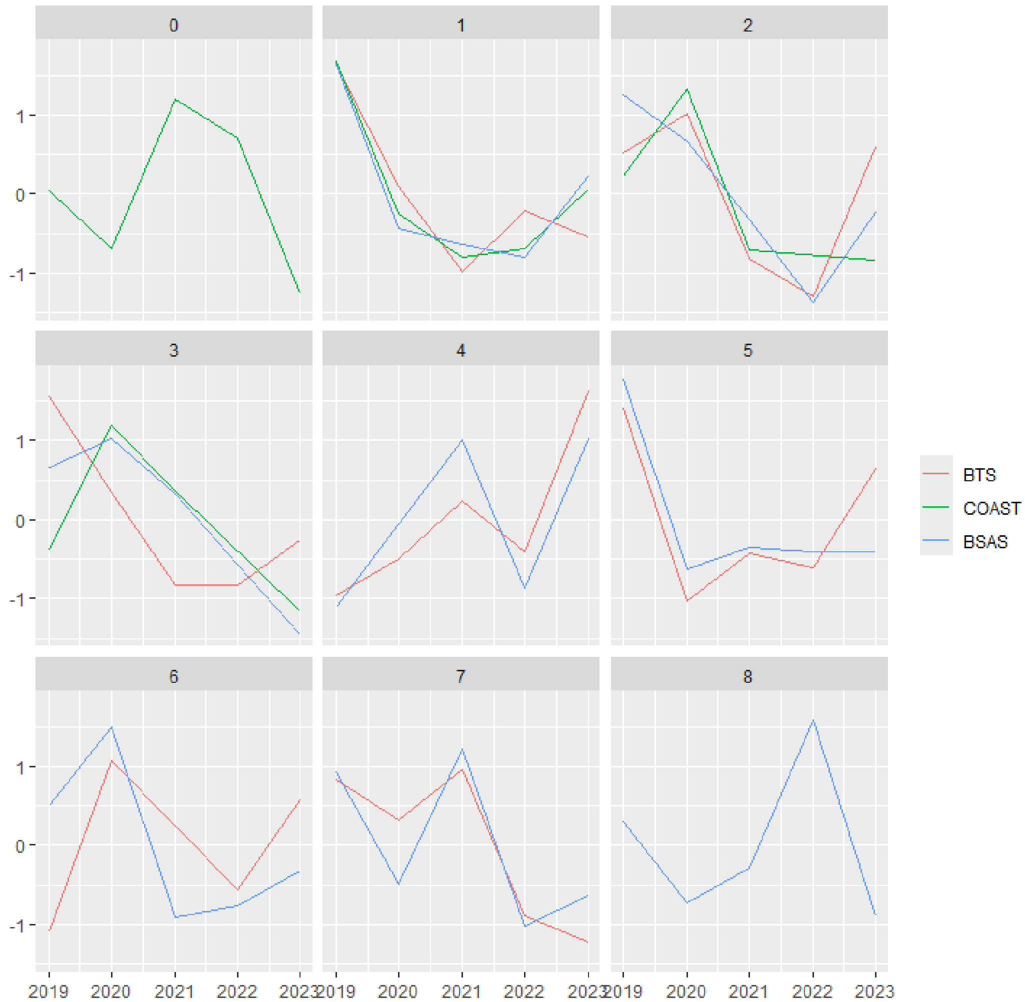


Fig. 17. Scaled relative index at age comparison from 2019-2023 for the BTS, COAST, and BSAS surveys.

In preparation for the 2025 ICES benchmark for the turbot assessment, several models have been prepared for testing (**Table 3**). Currently, the most promising survey index options in terms of the best internal consistencies seem to come from separate indices for the new modelled BTS, COAST, and BSAS surveys. Another option to test may be to combine the BTS and BSAS surveys upon the establishment of BSAS in 2019. Combining all available surveys can also be tested to see if it improves the assessment model diagnostics. A final option for survey index combinations can be to combine the BTS and COAST surveys. All potential index combinations have been paired with the inclusion or exclusion of the current Dutch LPUE index (**Table 3**).

Table 3. Different combinations of indices to run during the 2025 North Sea turbot benchmark

Model Run Description:				
Indices used	**All separated surveys except coast (DYFS+SNS)**			
	BTS (1991-2023)	BSAS (1991-2023)	COAST (1991-2023)	
	BTS (1991-2023)	BSAS (1991-2023)	COAST (1991-2023)	LPUE (1995-2023)
	Combining BTS and BSAS after 2019			
	BTS (1991-2023)	COAST (2003-2023)	BTS/BSAS combined (2019-2023)	
	BTS (1991-2018)	COAST (2003-2023)	BTS/BSAS combined (2019-2023)	LPUE (1995-2023)
	Everything combined			
	BTS/COAST combined (1991-2018)	BSAS/BTS/COAST combined (2019-2023)		
	BTS/COAST combined (1991-2018)	BSAS/BTS/COAST combined (2019-2023)	LPUE (1995-2023)	
	Combine BTS and COAST and have BSAS separate			
	BTS/COAST combined (1991-2023)	BSAS (1991-2023)		
	BTS/COAST combined (1991-2023)	BSAS (1991-2023)	LPUE (1995-2023)	

Information on some of the additional options for combined indices are provided in **Annex 5**. These additional indices include:

1. Combined BSAS+BTS+COAST indices for 2019 – 2023 (ages 0 – 8)
2. Combined BSAS+BTS indices for 2019 – 2023 (ages 1 – 7)
3. Combined BTS + COAST indices for 1991 – 2023 (ages 0 – 7)

Commercial index: NL LPUE biomass index

The Dutch landings per unit effort (LPUE) biomass index is currently the only commercial index used for North Sea turbot. Despite concerns about its relatively high weighting in the assessment, it may need to remain as part of the stock assessment indices until the BSAS survey has accumulated sufficient data over enough years to contribute meaningfully to the model results. This survey uses a combination of LPUE data from several Dutch metiers. As each metier is characterized by different catchabilities and fishing grounds, the modeled index needs to correct for gear and area when standardizing the LPUE. The LPUE statistical model includes interactions in space, time and gear. Raw LPUE's are calculated per trip and per ICES rectangle. The fishing effort per rectangle is then taken as a weighting factor in the analysis.

$$\text{LPUE} = \text{te}(\text{Longitude}, \text{Latitude}, \text{by} = \text{as.factor}(\text{year}), k = 5) + \text{as.factor}(\text{year}, k = 10) + \text{gear}$$

While the index shows a general downtrend in recent years after peaking in 2016, data from 2023 suggests in increase in exploitable biomass, potentially due to reduced fishing pressure (**Figs. 16 and 17**).

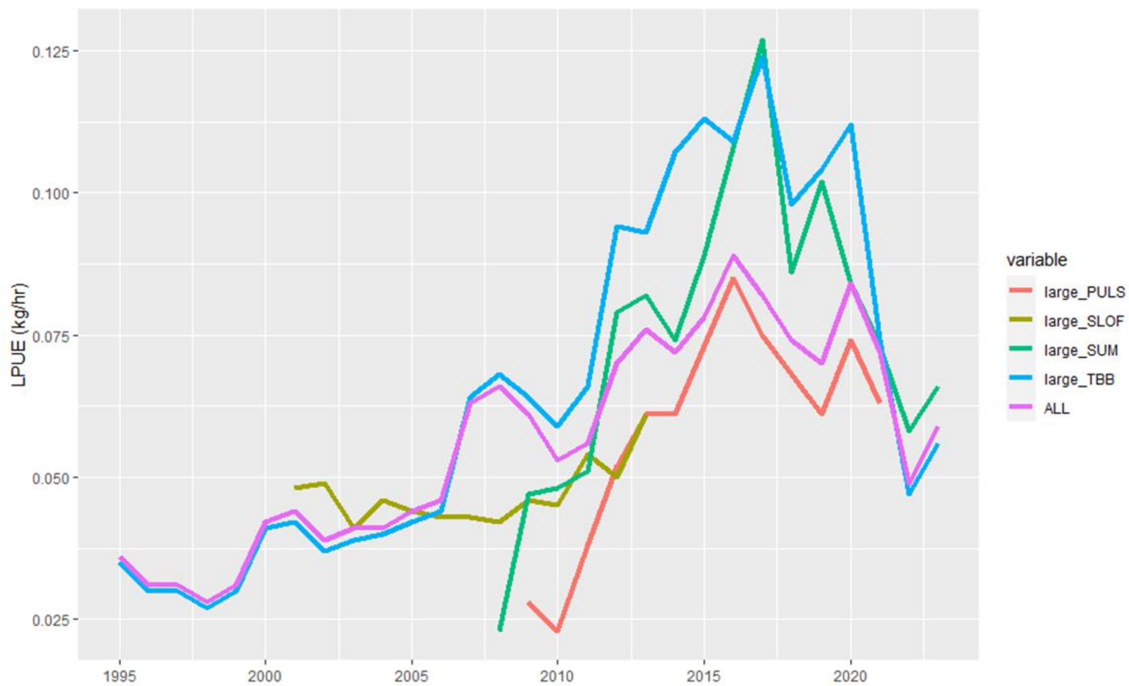


Fig. 16. Turbot LPUE by fleet segment over time (1995 – 2023)

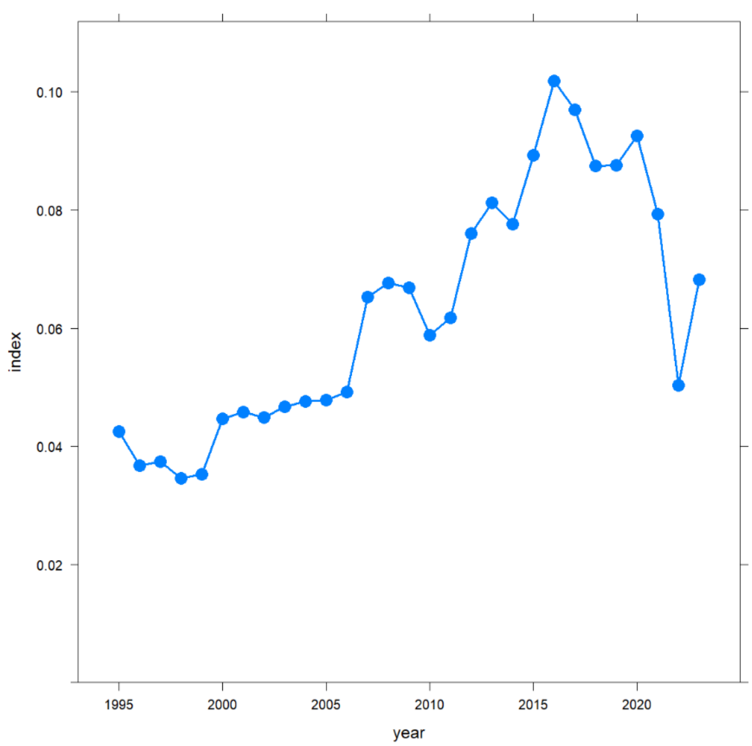


Fig. 17. LPUE exploitable biomass index results from 1995 – 2023

Conclusions

The new indices show improvements compared to previous indices used and will likely be more robust options for the turbot stock assessment moving forward. Nevertheless, the new modelled BTS and COAST indices only show a modest improvement in internal consistencies and cohort tracking ability, especially compared to similar indices used for other North Sea flatfish stocks such as sole and plaice. Despite the more robust modelled indices, these methods are still limited due to the low catchabilities of turbot in most North Sea scientific surveys. A potential remedy to this problem might be the inclusion of BSAS as an index in the North Sea turbot stock assessment.

Perhaps the greatest advantage of BSAS is its ability to catch and track older age groups. Uncertainty amongst older ages has been a point of criticism for the North Sea turbot stock assessment which currently estimates a large proportion of biomass within the 8+ age group (ICES, 2024). This estimated biomass relies the constant assumption of natural mortality coupled with lower fishing pressure in recent years.

One of the biggest limitations of BSAS is the fact that it is only able to provide information from 2019 onwards, however, if it is maintained as an important survey for the turbot and potentially brill assessment moving forward, this issue is expected to resolve itself as the years pass. Additionally, better cohort tracking within the BTS and COAST indices for more recent years may also improve their weighting in the assessment as time goes on.

While experts have advised the replacement of the Dutch LPUE index with a survey such as BSAS (ICES, 2018), the limited time series from BSAS coupled with only modest cohort tracking abilities from the other surveys may not be sufficient to justify the complete removal of the LPUE index. To account for this, several runs with and without the LPUE index are planned for the benchmark. A potential improvement in the assessment, however, was suggested in the 2018 turbot inter-benchmark by extracting the CV's (scaled variance) from the LPUE index and incorporating these explicitly within the state space stock assessment model used for turbot (ICES, 2018). Now that all indices to be tested at the benchmark come from statistical models, we are able to extract the CV at age for all indices and implement them directly into the turbot stock assessment.

References

ICES. 2018. Report of the Inter-benchmark Protocol for Turbot in 27.4 (IBP Turbot), June–September 2017, By correspondence. ICES CM 2017/ACOM:50. 116 pp.

ICES. 2024. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 6:38. 1659 pp. https://doi.org/10.17895/ices.pub.2560563

Annex 1: Supplementary Information for all surveys

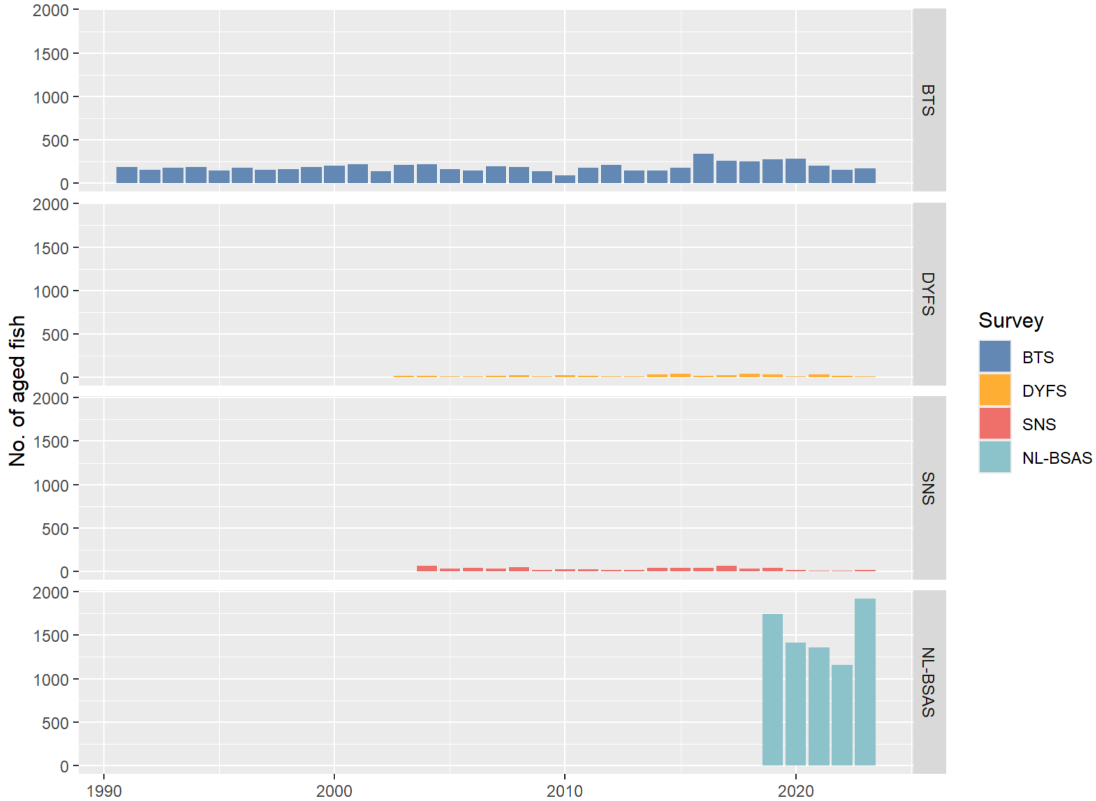


Fig. S1. Number of aged fish in the surveys

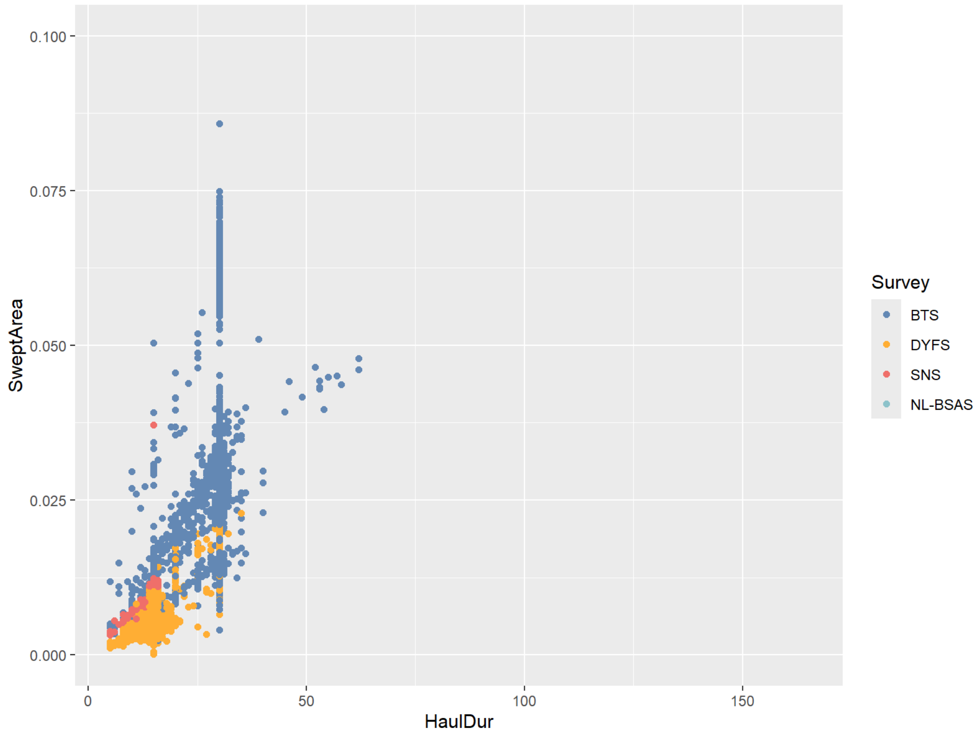


Fig. S2. Comparison of swept area per km² vs. haul duration (minutes) between surveys.

Annex 2: Supplementary Information for the BTS index

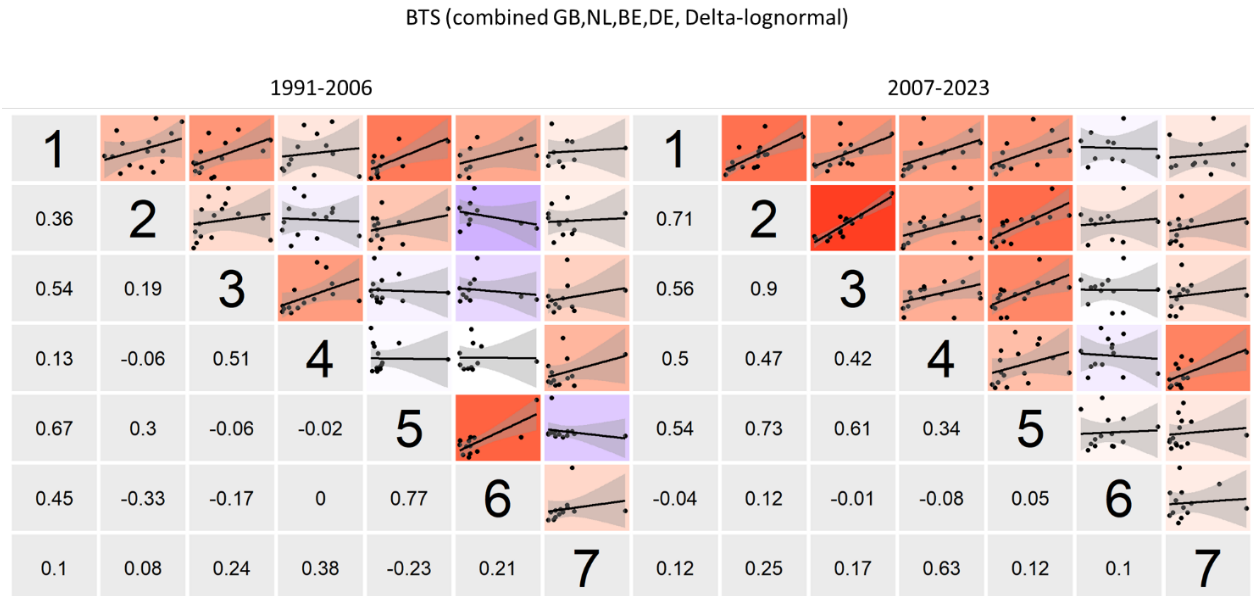


Fig. S3. Age correlation plots comparing the years 1991-2006 and 2007-2023 data in the delta-lognormal BTS index.

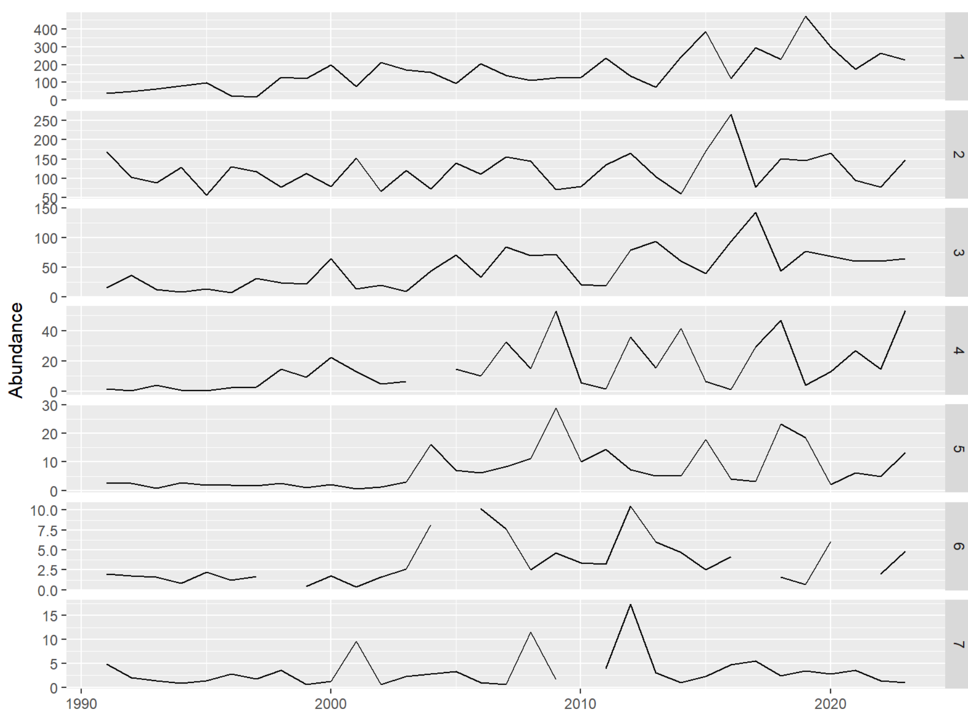


Fig. S4. Modelled index of abundance-at-age from the BTS.

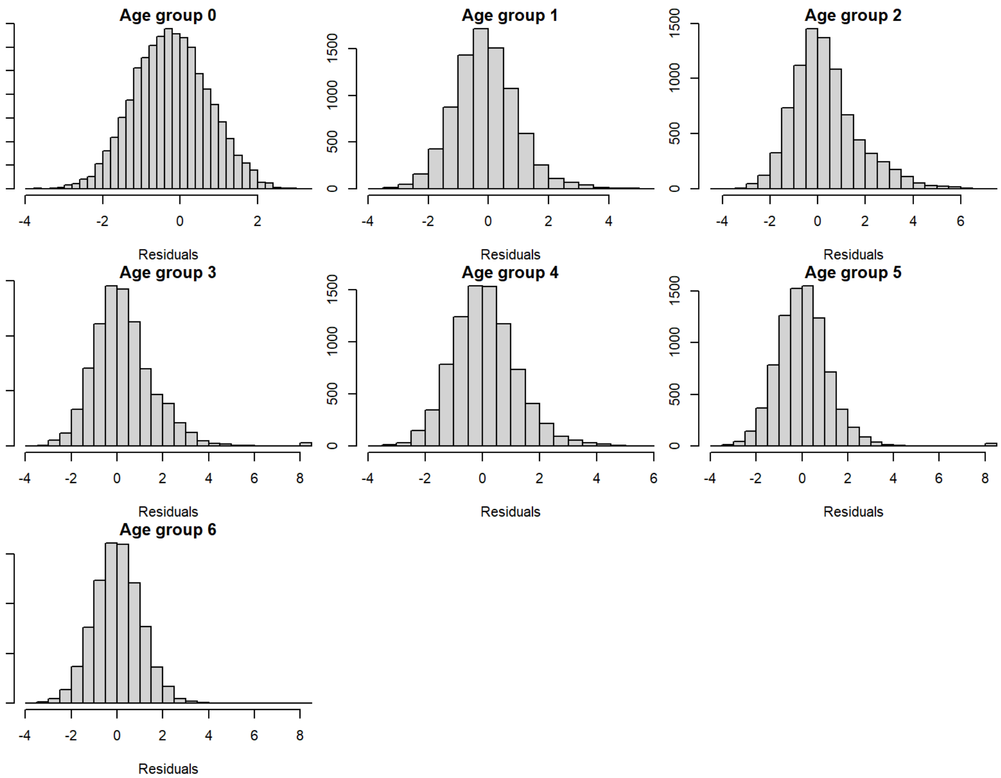


Fig. S5. Distribution of model residuals-at-age for the BTS.

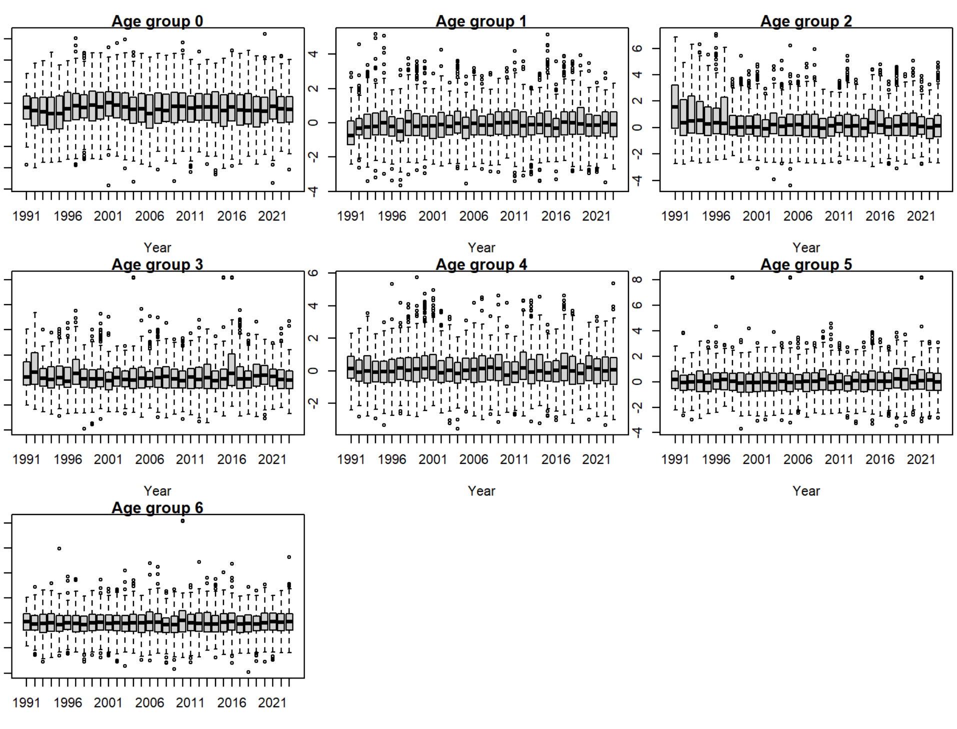


Fig. S6. Distribution of model residuals-at-age per year for the BTS.

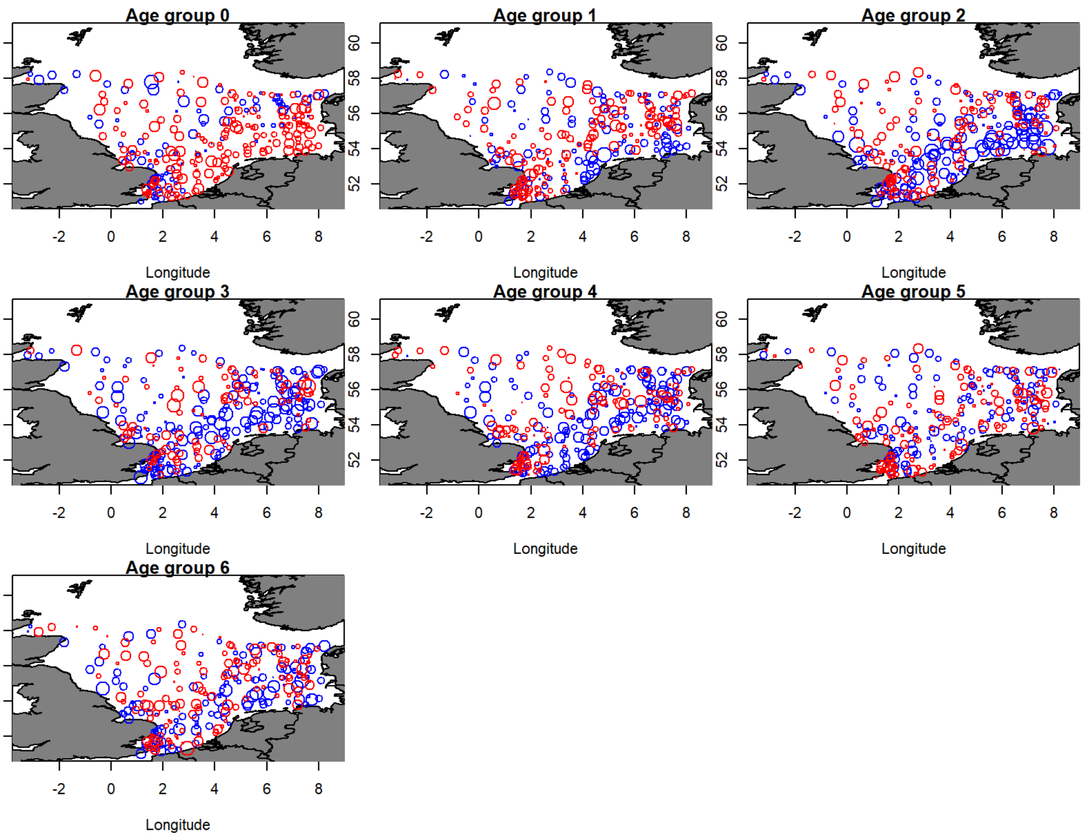


Fig. S7. Spatial residuals from the BTS index in 2020.

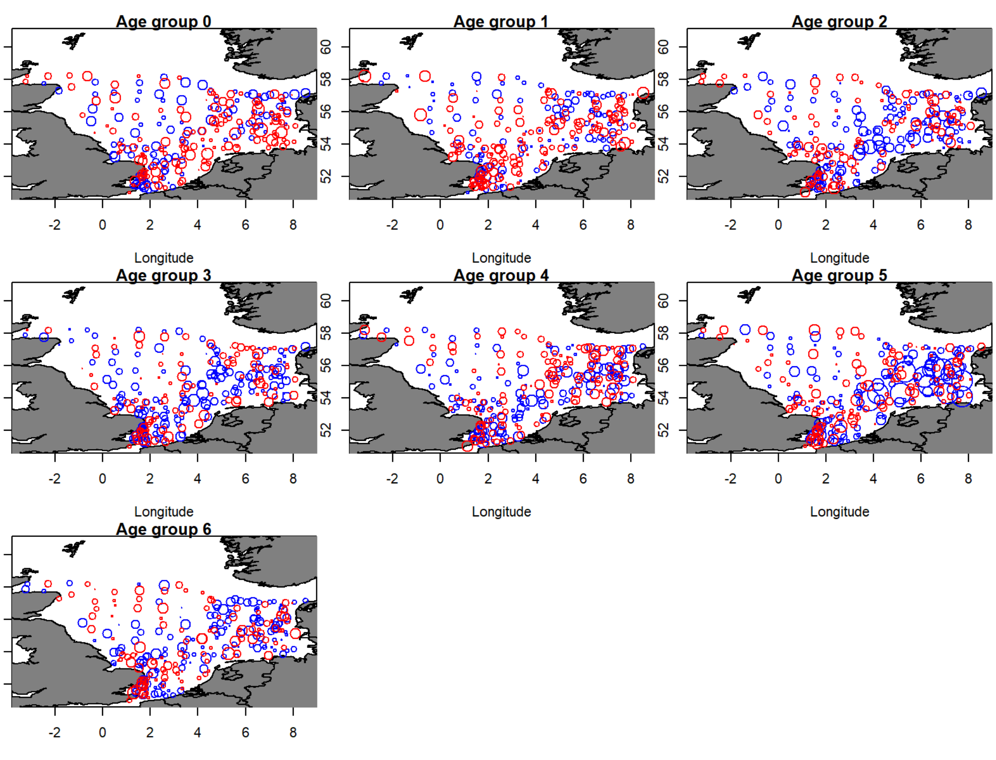


Fig. S8. Spatial residuals from the BTS index in 2021.

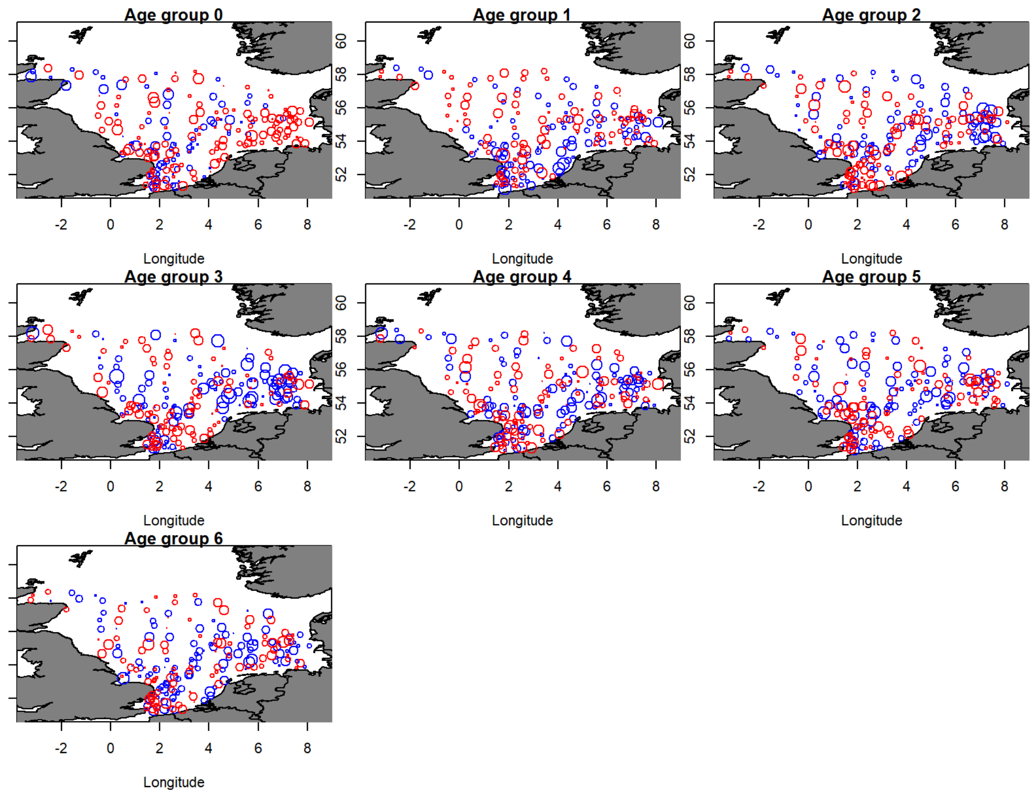


Fig. S9. Spatial residuals from the BTS index in 2022.

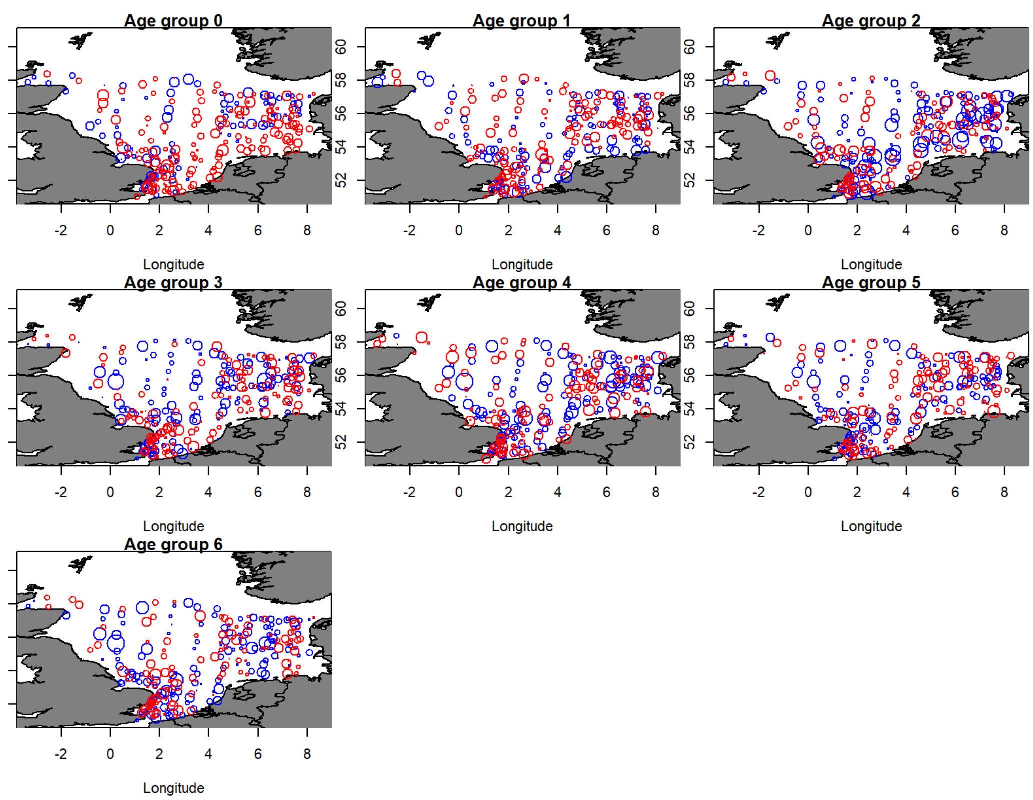


Fig. S10. Spatial residuals from the BTS index in 2023.

Annex 3: Supplementary Information for the COAST (SNS+DYFS) index

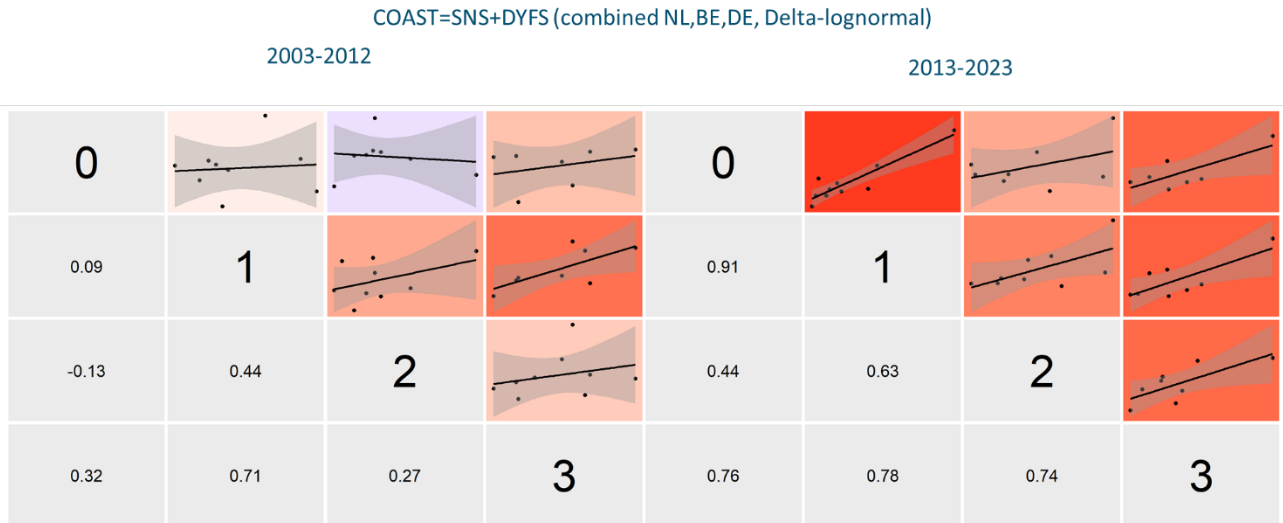


Fig. S11. Age correlation plots comparing the years 2003-2023 and 2013-2023 data in the delta-lognormal COAST index.

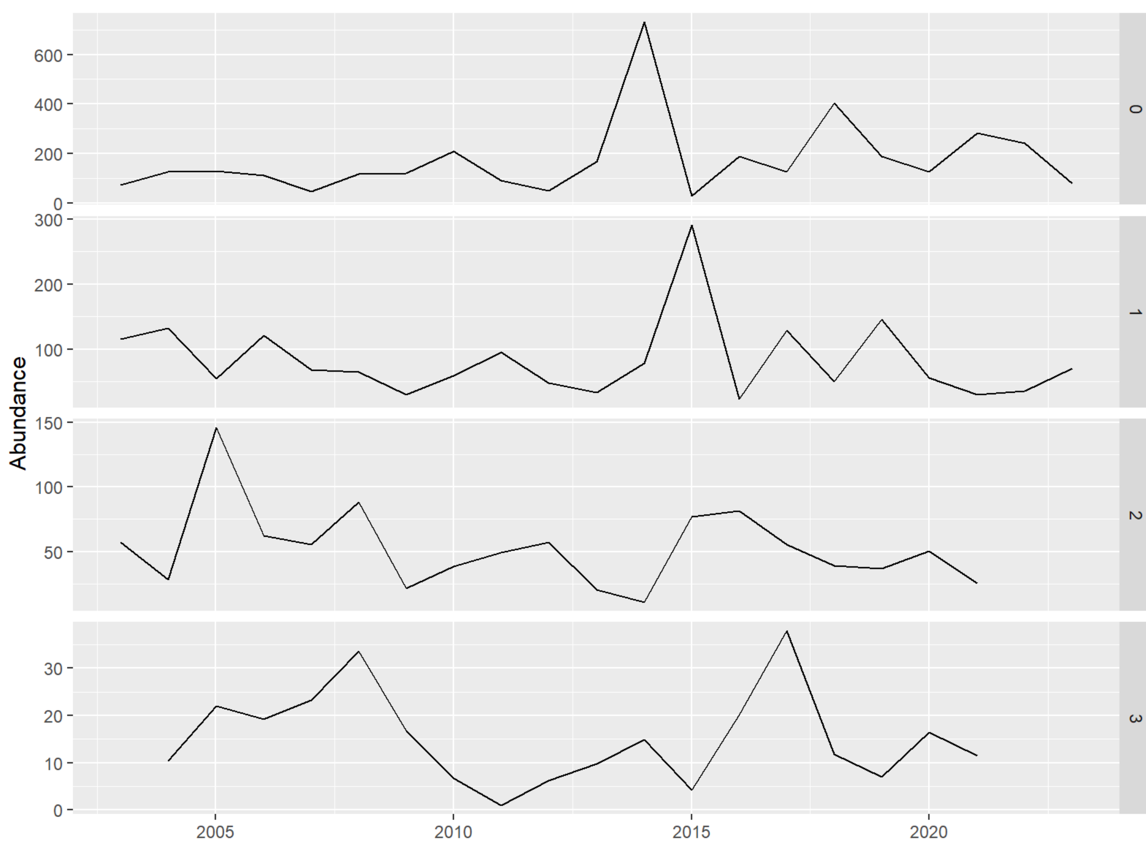


Fig. S12. Modelled index of abundance-at-age from the COAST (DYFS+BTS).

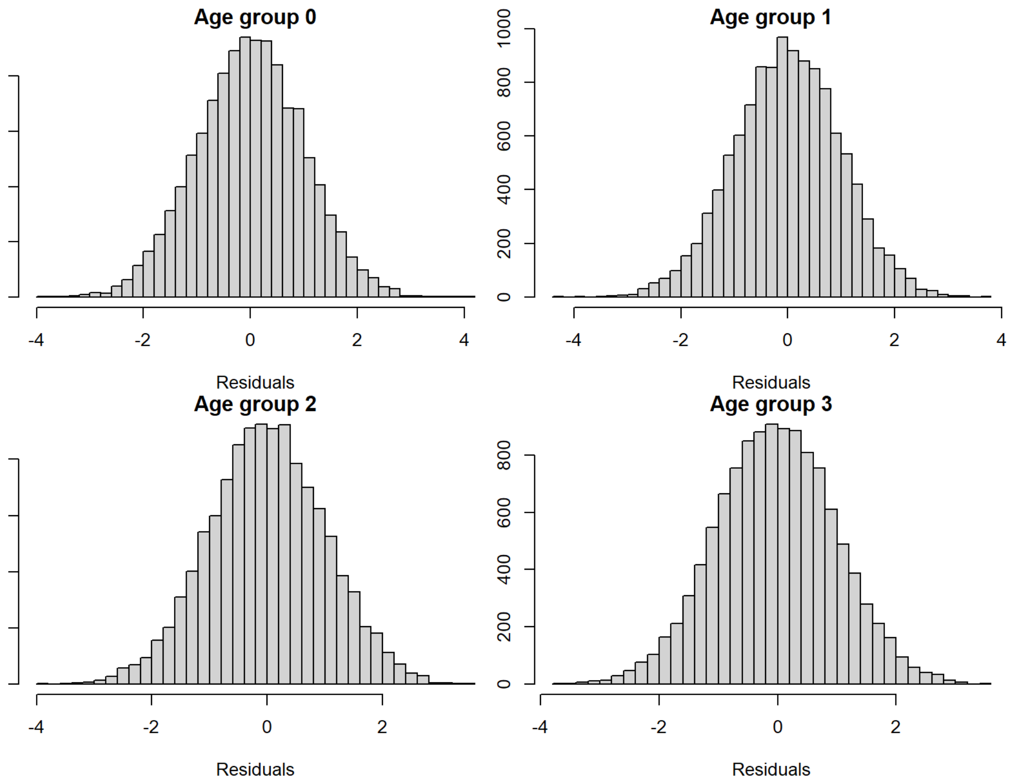


Fig. S13. Distribution of model residuals-at-age for the COAST (DYFS+SNS) index.

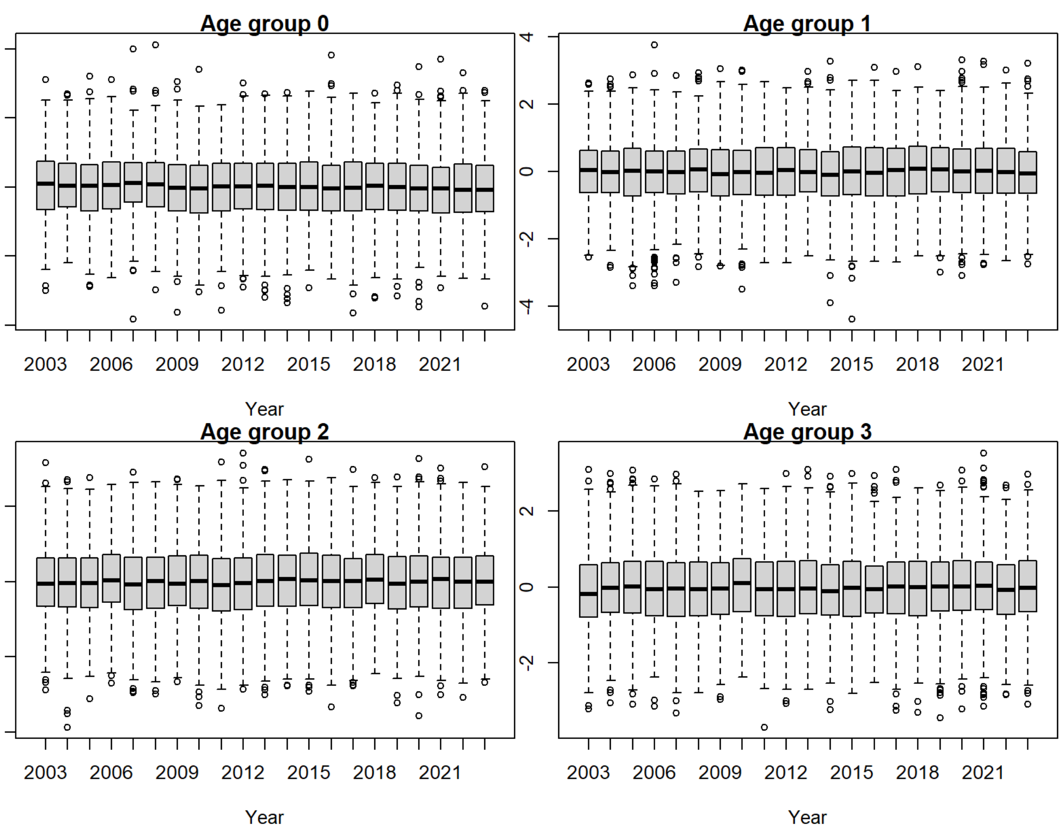


Fig. S14. Distribution of model residuals-at-age per year for the COAST (DYFS+SNS) index.

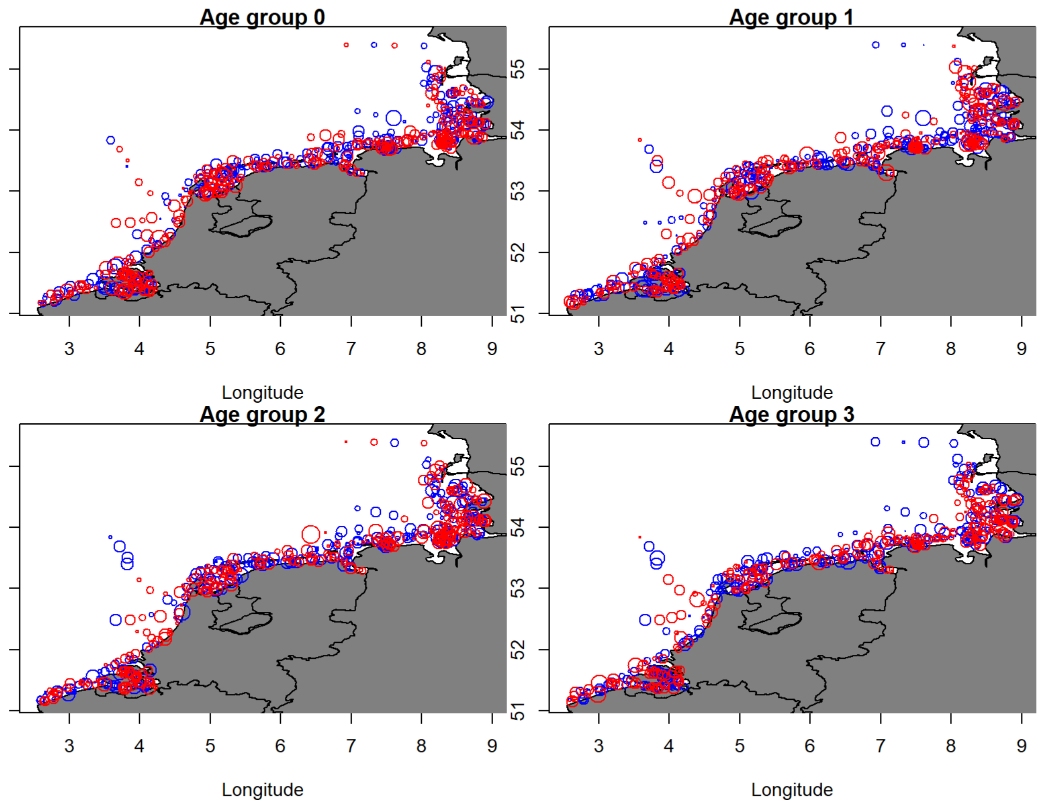


Fig. S15. Spatial residuals from the COAST index in 2020.

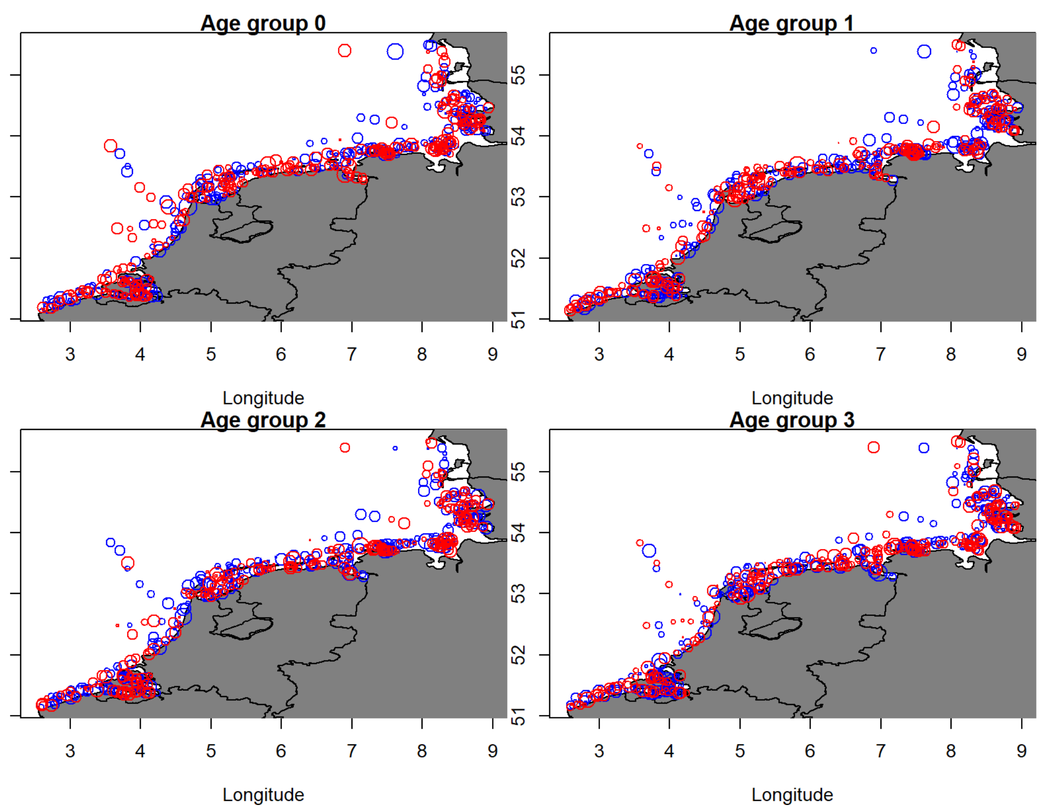


Fig. S16. Spatial residuals from the COAST index in 2021.

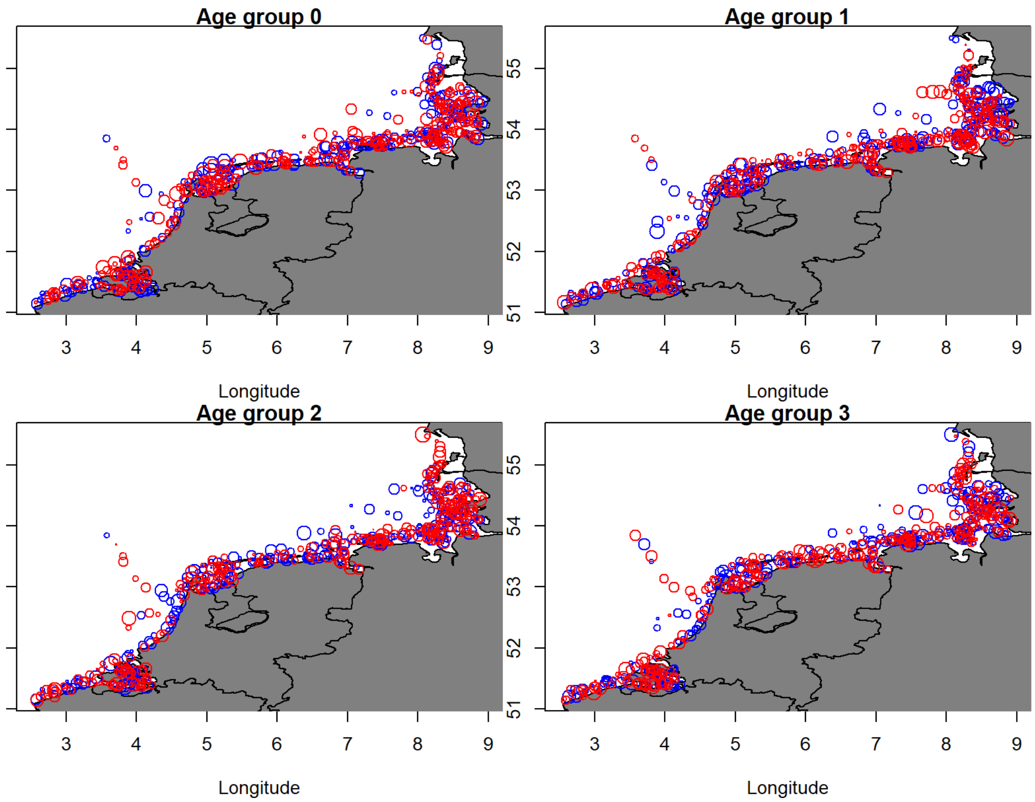


Fig. S17. Spatial residuals from the COAST index in 2022.

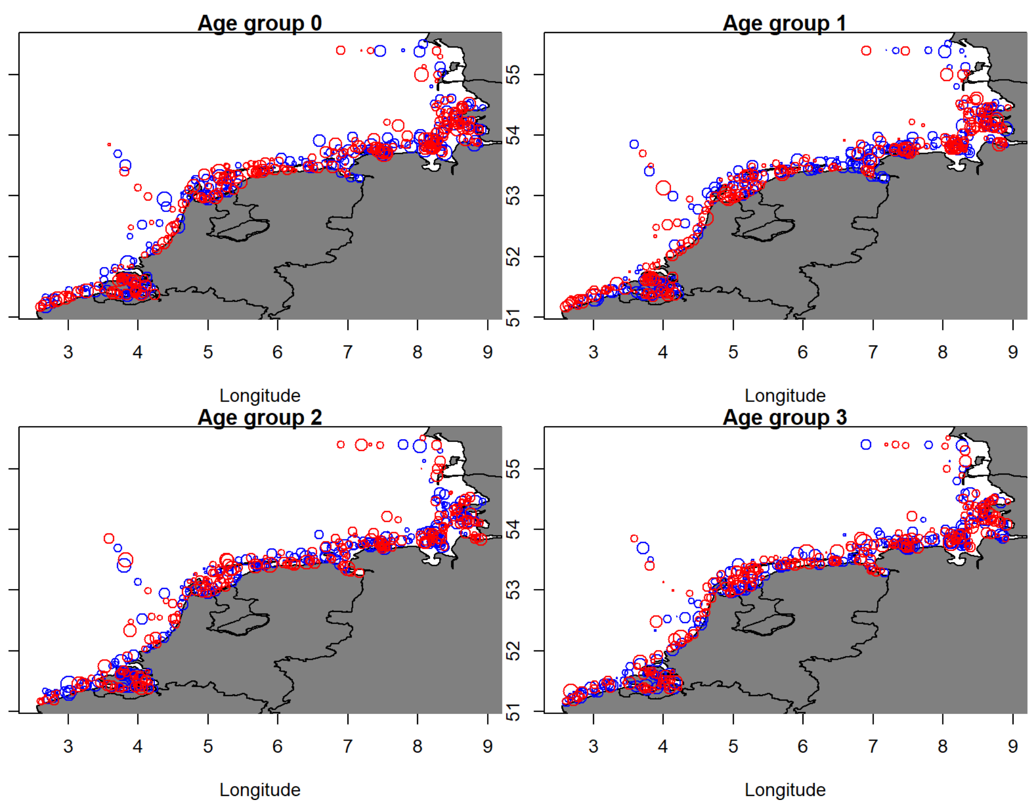


Fig. S18. Spatial residuals from the COAST index in 2023.

Annex 4: Supplementary Information for the BSAS index

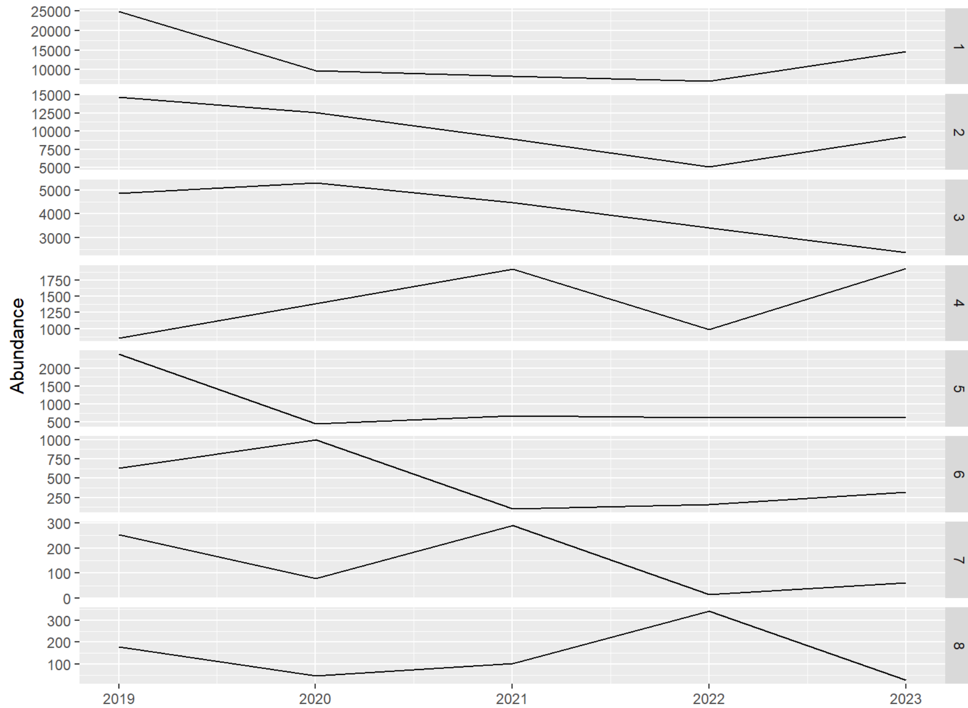


Fig. S19. Modelled index of abundance-at-age from the BSAS survey.

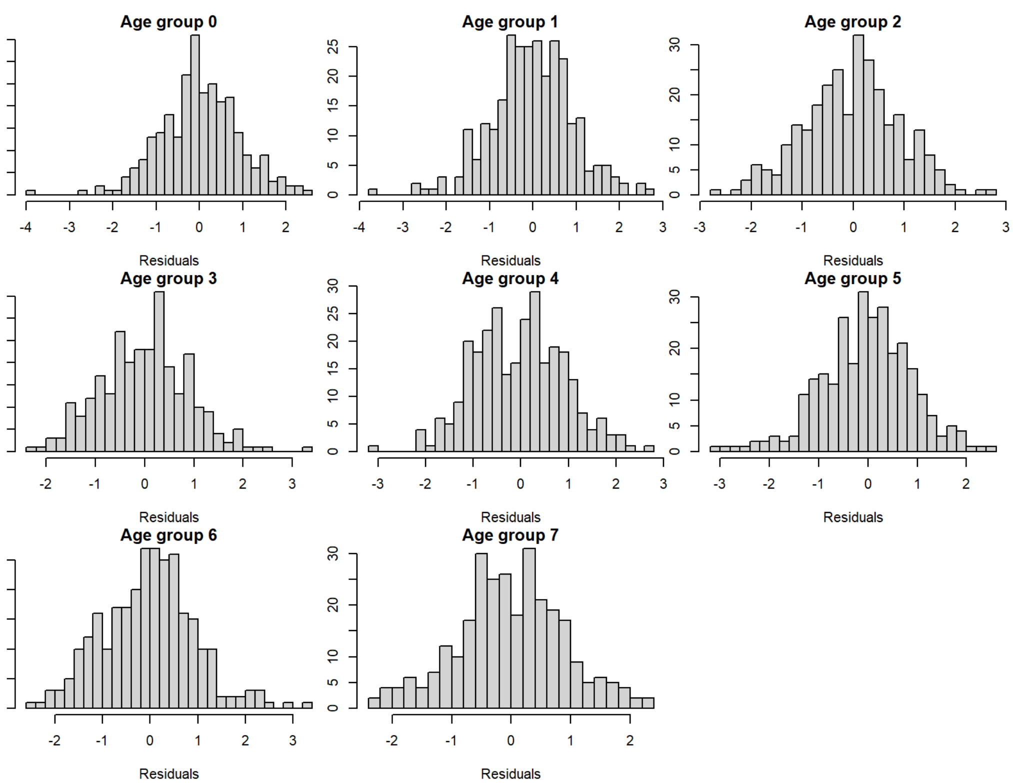


Fig. S20. Distribution of model residuals-at-age for the BSAS index.

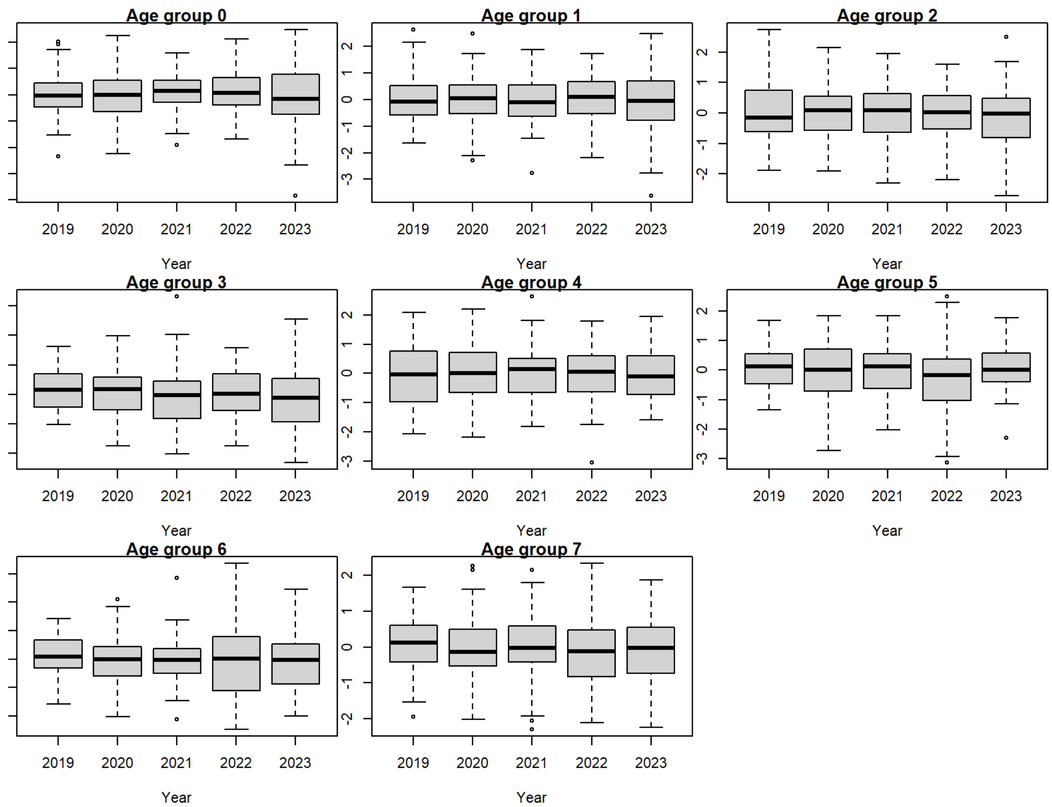


Fig. S21. Distribution of model residuals-at-age per year for the BSAS index.

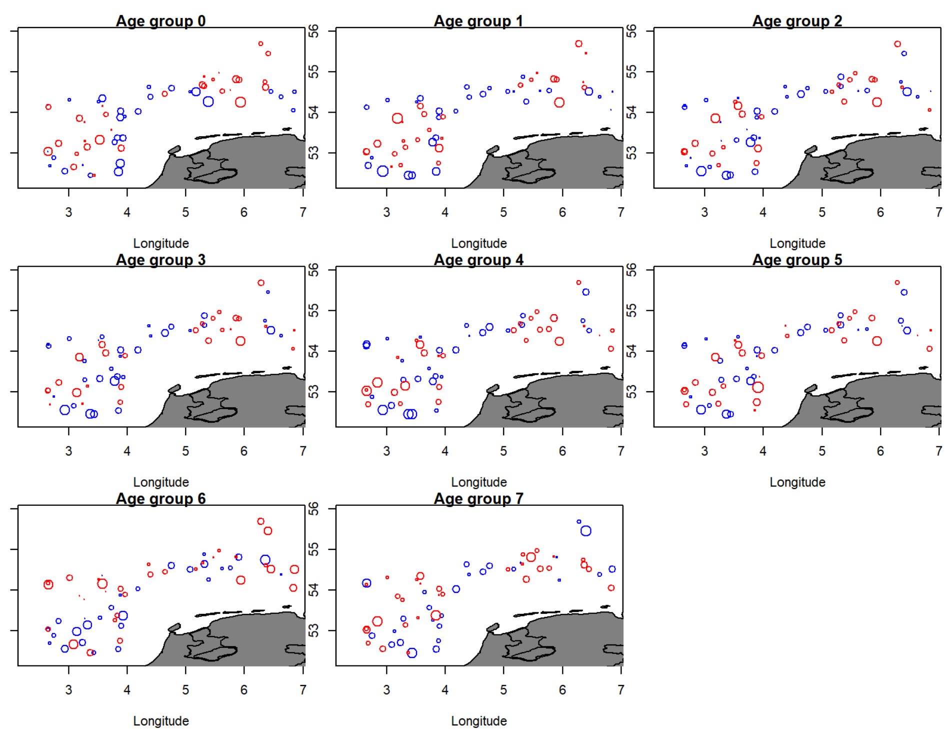


Fig. S22. Spatial residuals from the BSAS modelled index in 2020.

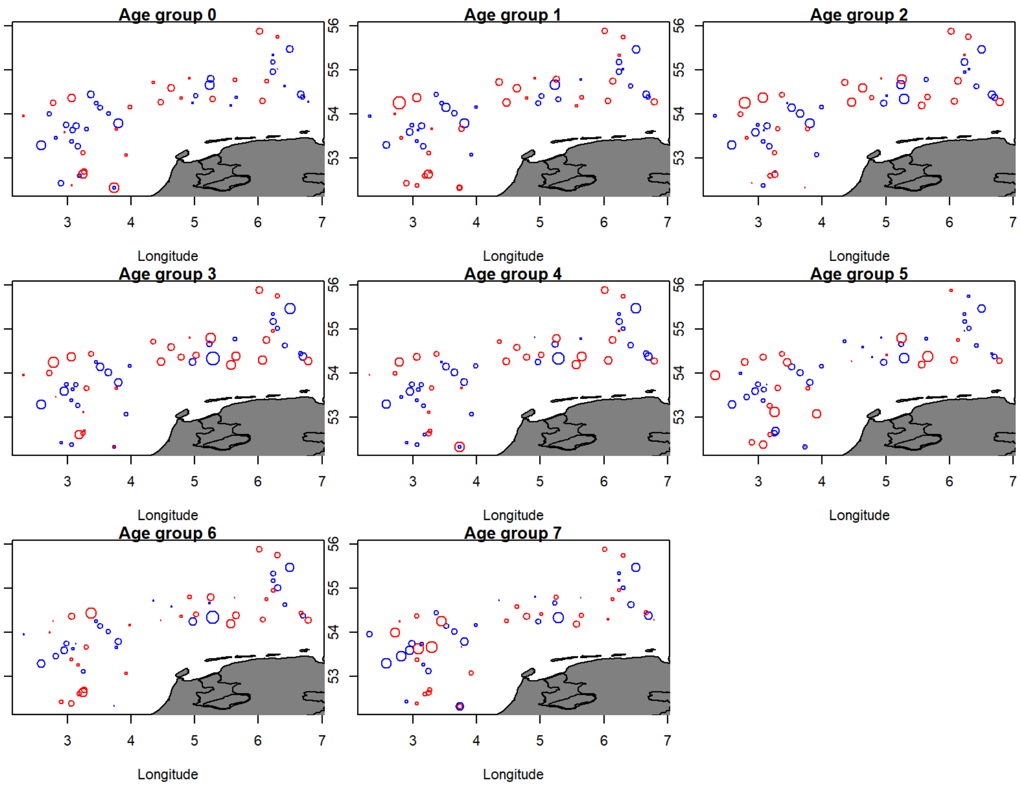


Fig. S23. Spatial residuals from the BSAS modelled index in 2021.

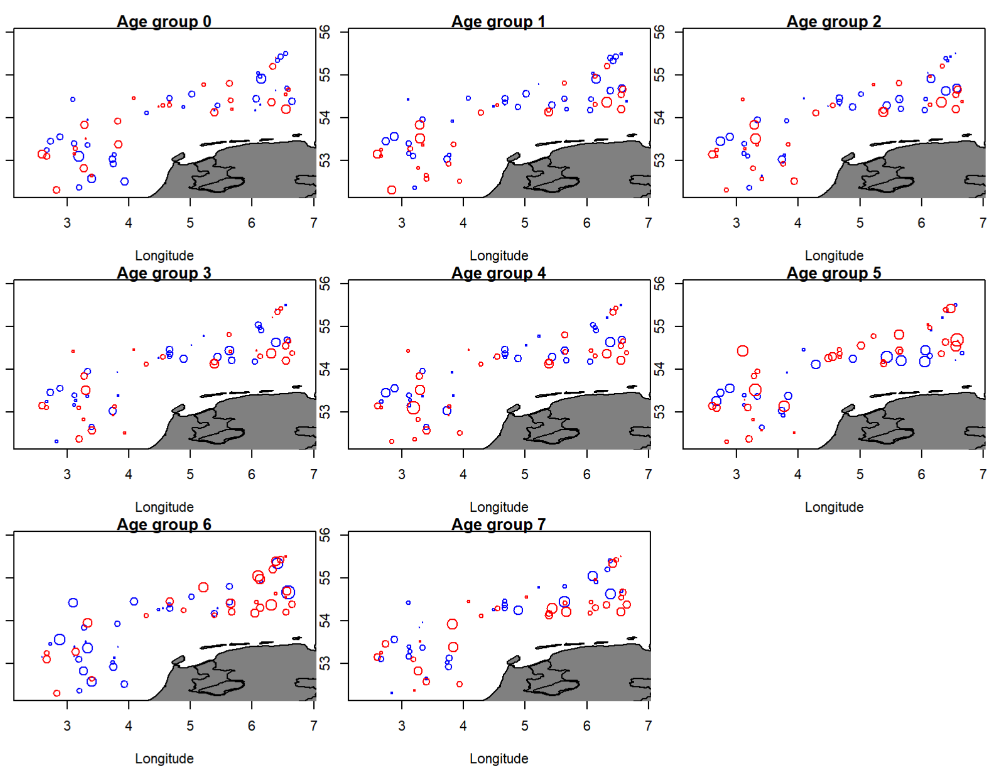


Fig. S24. Spatial residuals from the BSAS modelled index in 2022.

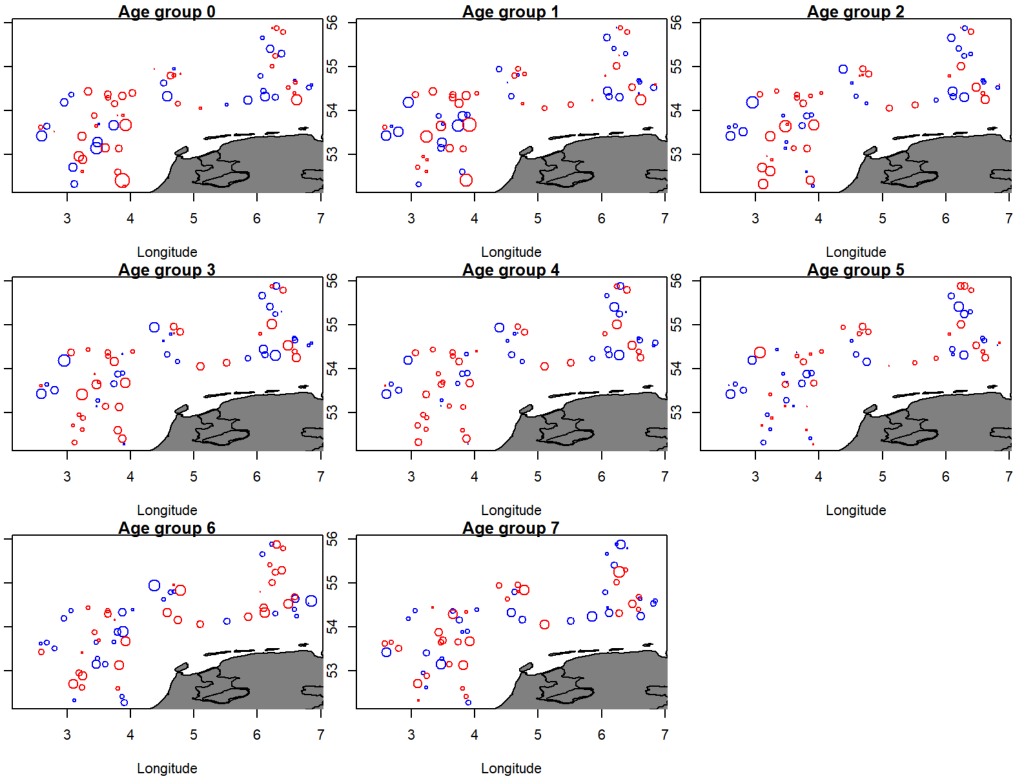


Fig. S25. Spatial residuals from the BSAS modelled index in 2023.

Annex 5: Supplementary Information for options for combined indices

Combined BSAS+BTS+COAST indices for 2019 – 2023 (ages 0 – 8)

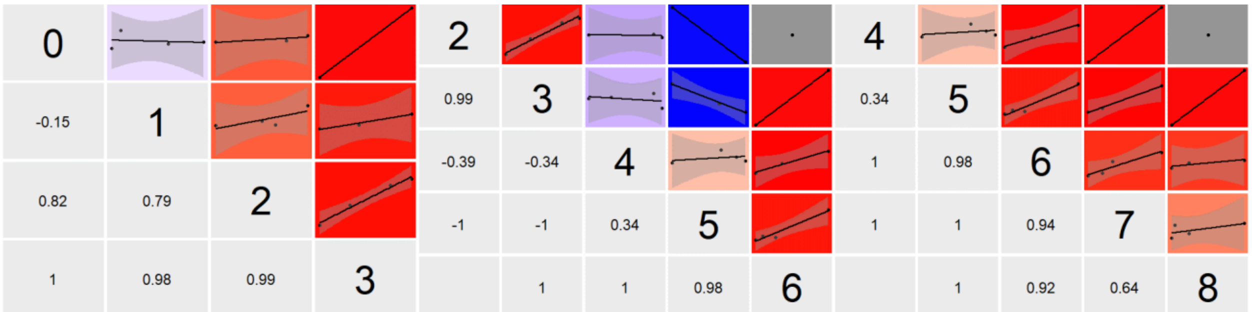


Fig. S26. Age correlation plots for the Tweedie BSAS+BTS+COAST index showing correlations between ages 1-4 (left), 3-7 (middle), and 5-8 (right).

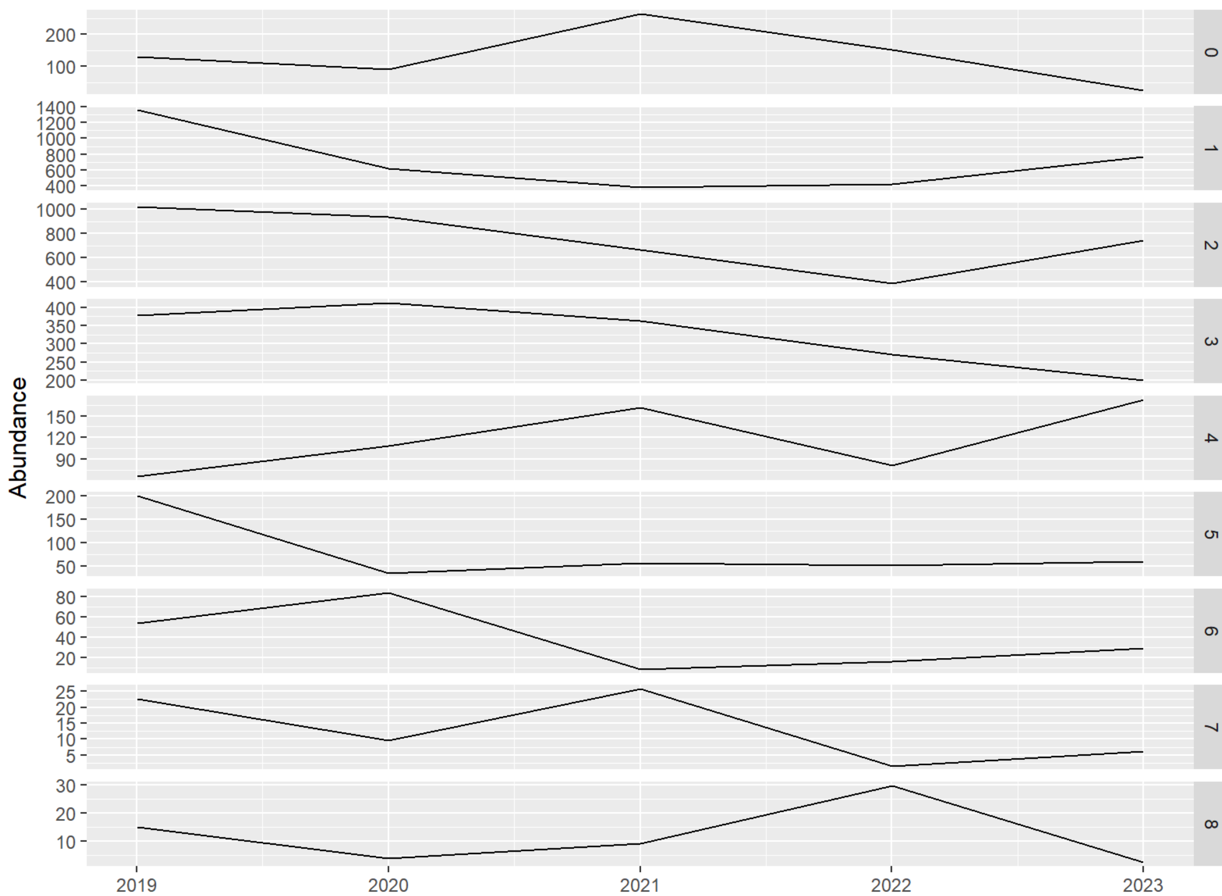


Fig. S27. Modelled index of abundance-at-age from the BSAS+BTS+COAST index.

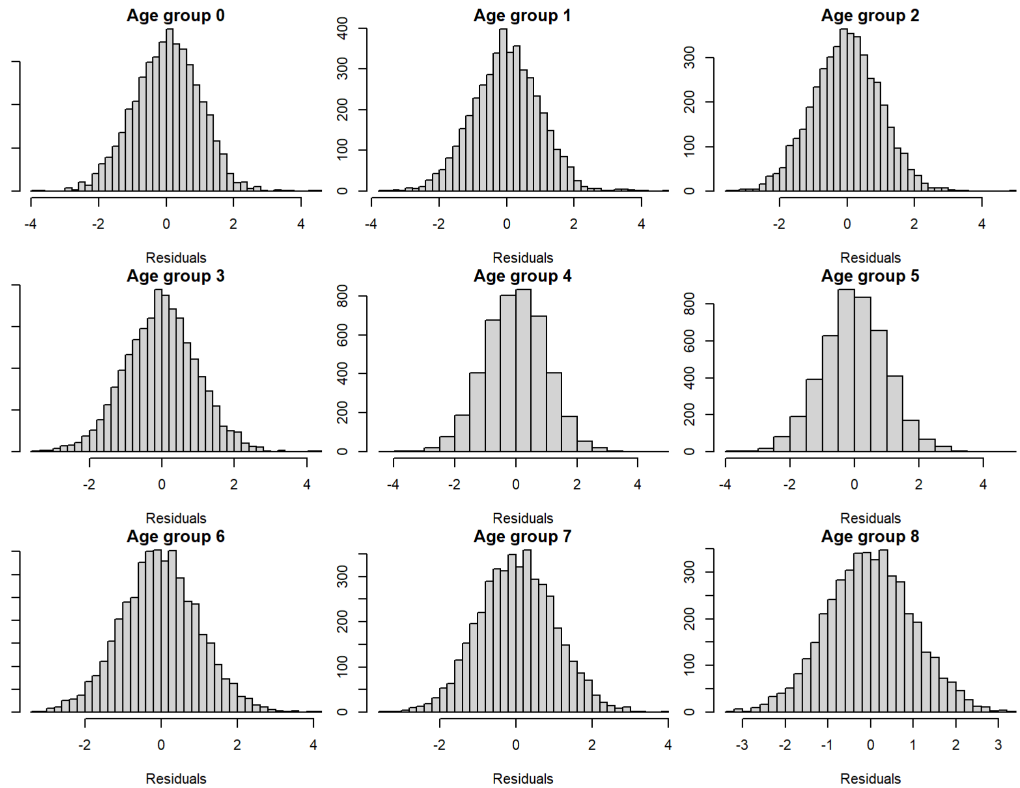


Fig. S28. Distribution of model residuals-at-age for the BSAS+BTS+COAST index.

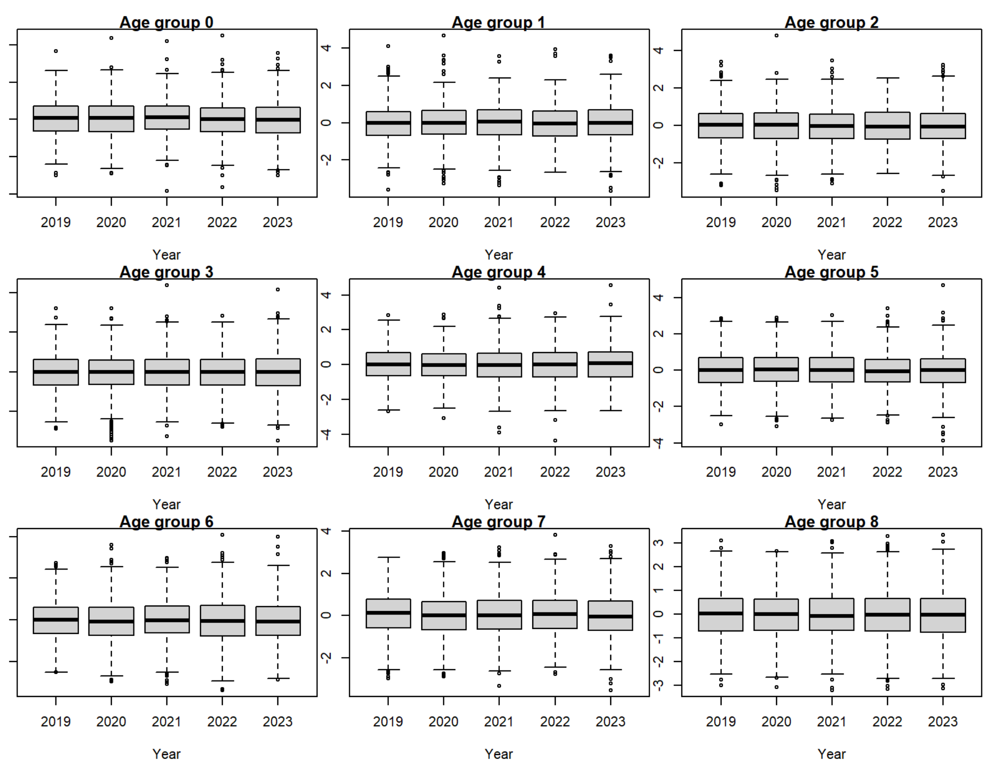


Fig. S29. Distribution of model residuals-at-age per year for the BSAS+BTS+COAST index.

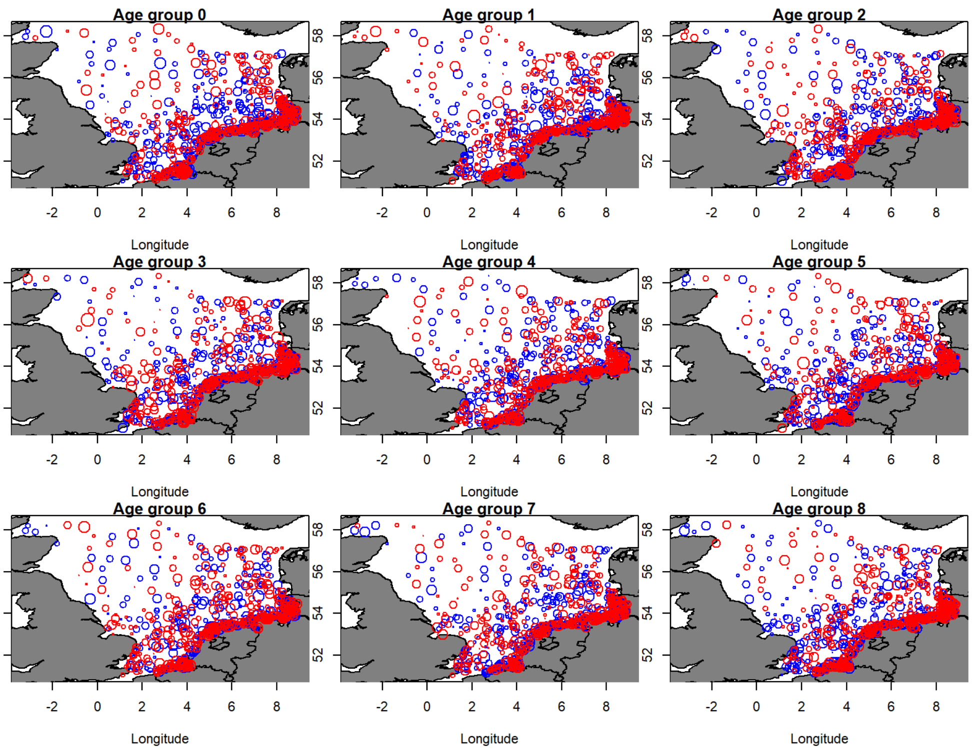


Fig. S30. Spatial residuals from the BTS+BSAS+COAST modelled index in 2020.

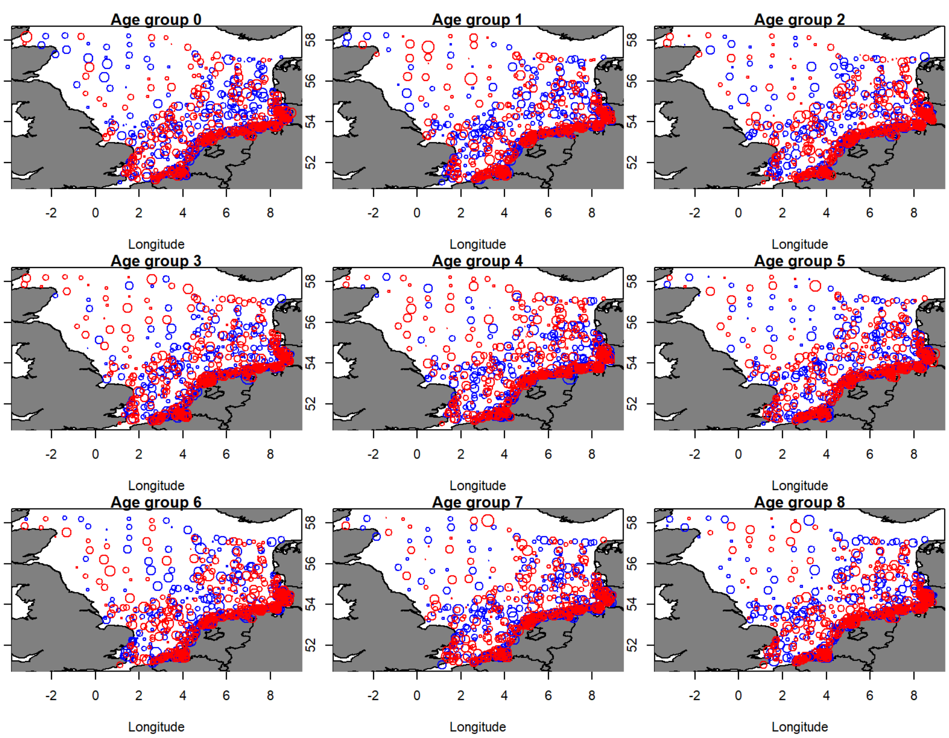


Fig. S31. Spatial residuals from the BTS+BSAS+COAST modelled index in 2021.

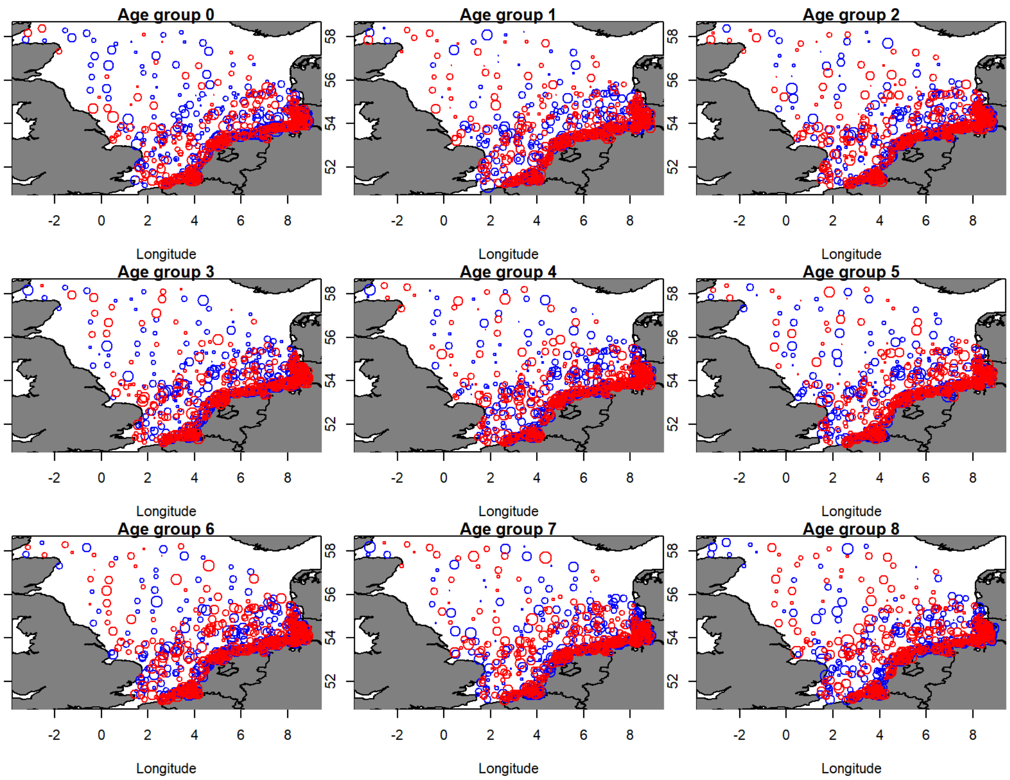


Fig. S32. Spatial residuals from the BTS+BSAS+COAST modelled index in 2022.

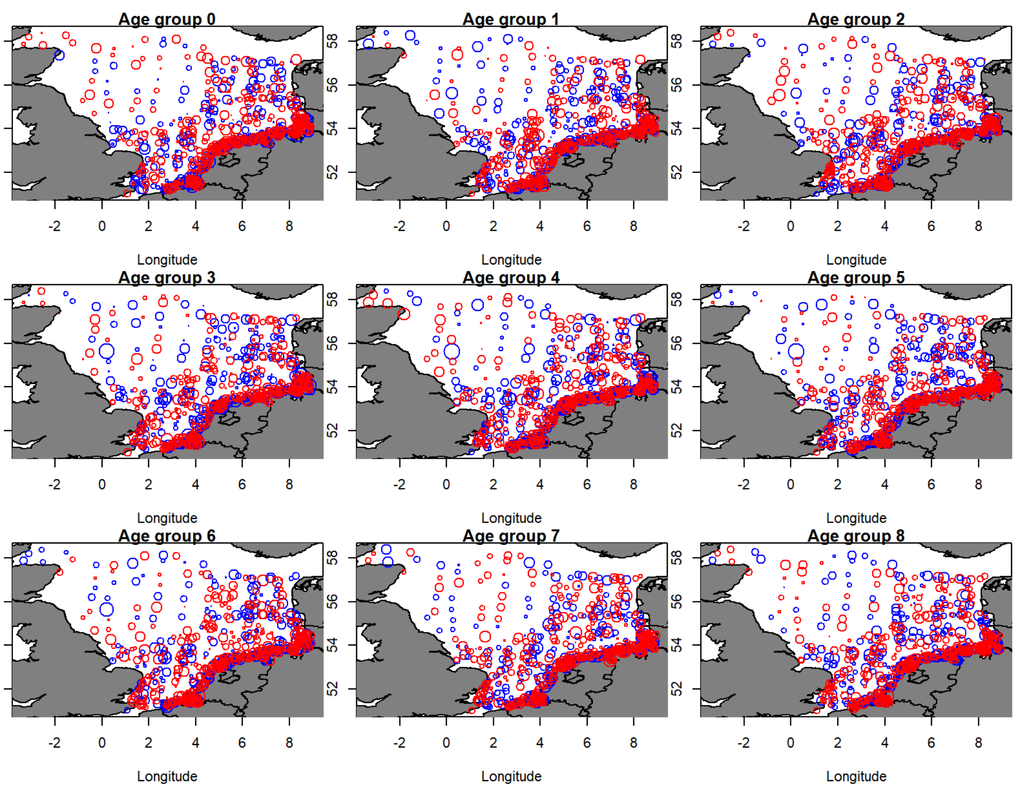


Fig. S33. Spatial residuals from the BTS+BSAS+COAST modelled index in 2023.

Combined BSAS+BTS indices for 2019 – 2023 (ages 1 – 7)

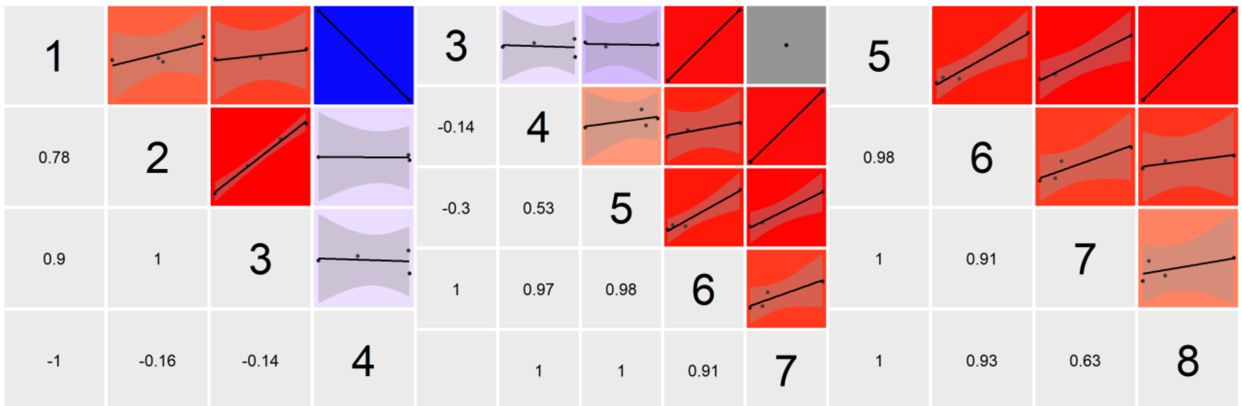


Fig. S34. Age correlation plots for the Tweedie BSAS+BTS index showing correlations between ages 1-4 (left), 3-7 (middle), and 5-8 (right).

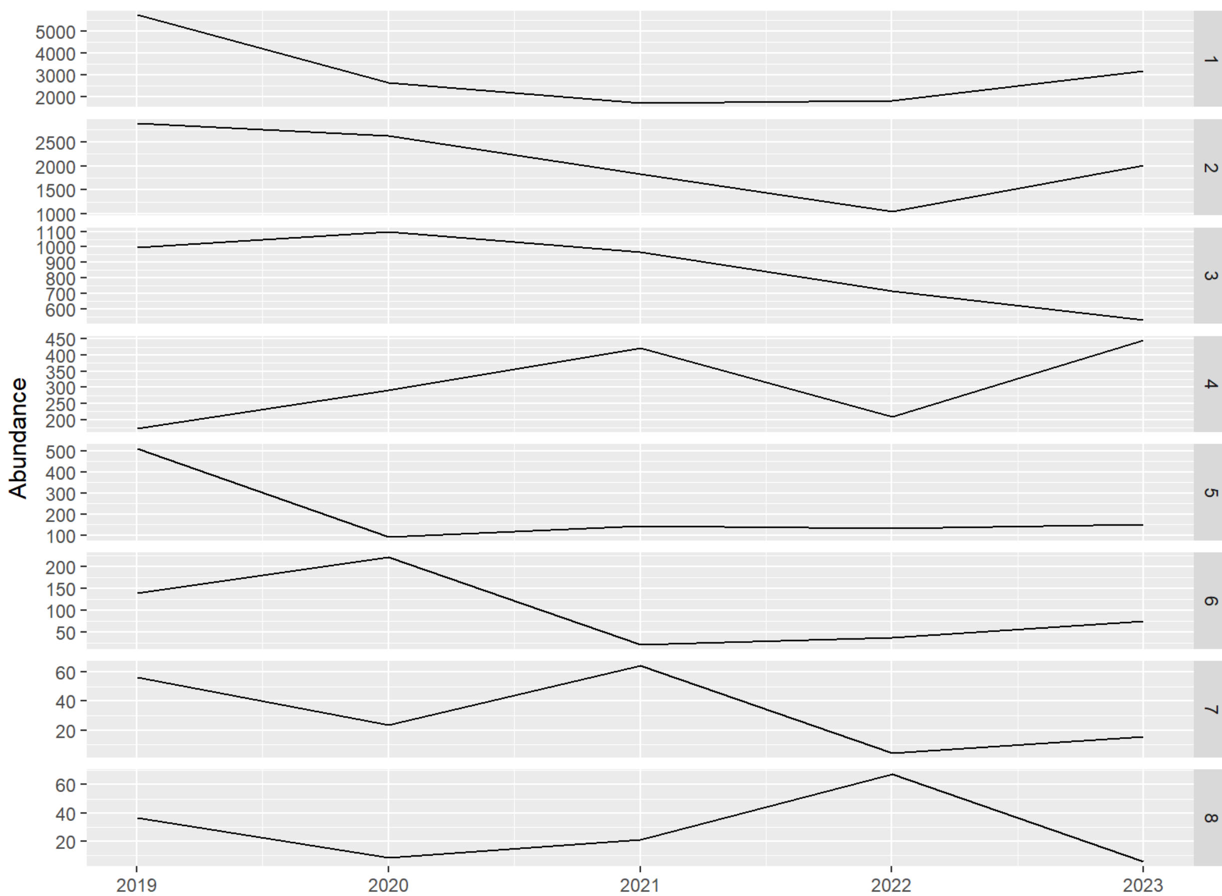


Fig. S35. Modelled index of abundance-at-age from the BSAS+BTS index.

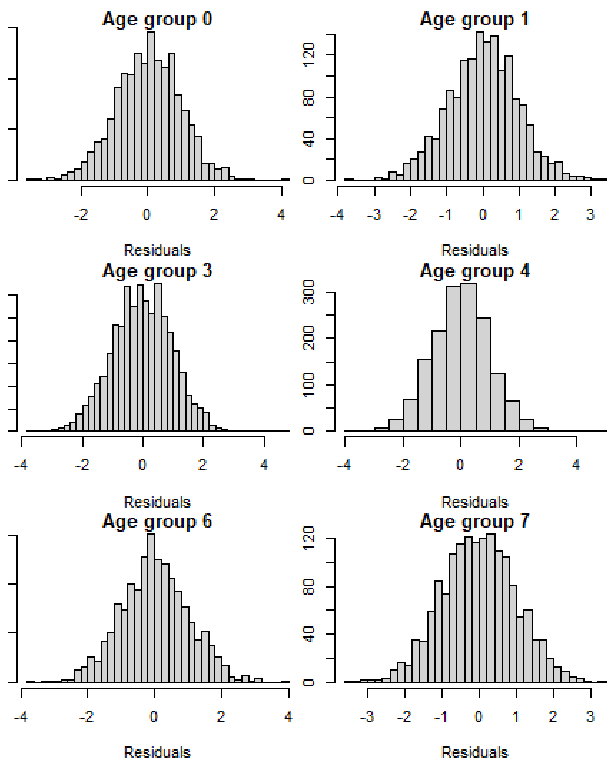


Fig. S36. Distribution of model residuals-at-age per year for the BSAS+BTS index.

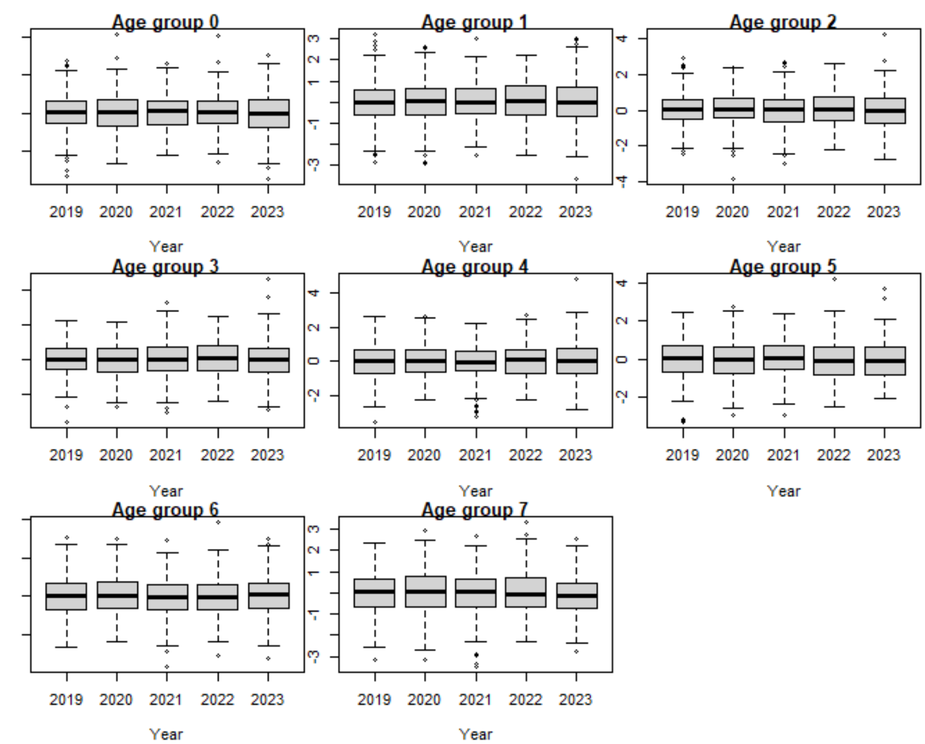


Fig. S37. Distribution of model residuals-at-age per year for the BSAS+BTS index.

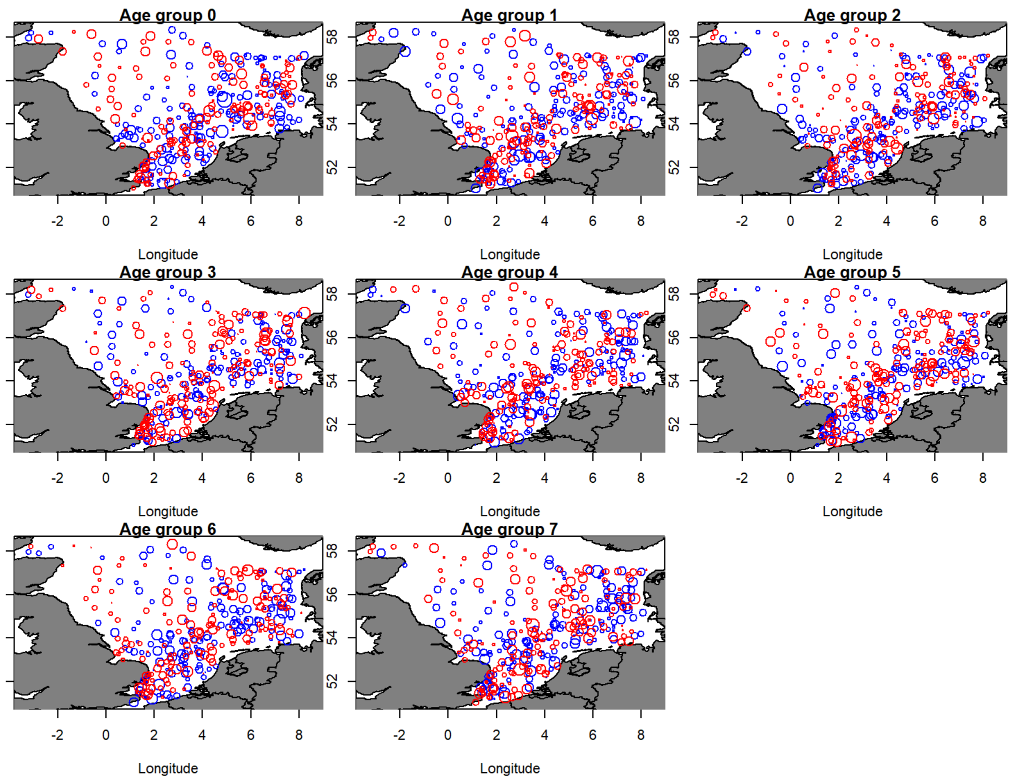


Fig. S38. Spatial residuals from the BTS+BSAS modelled index in 2020.

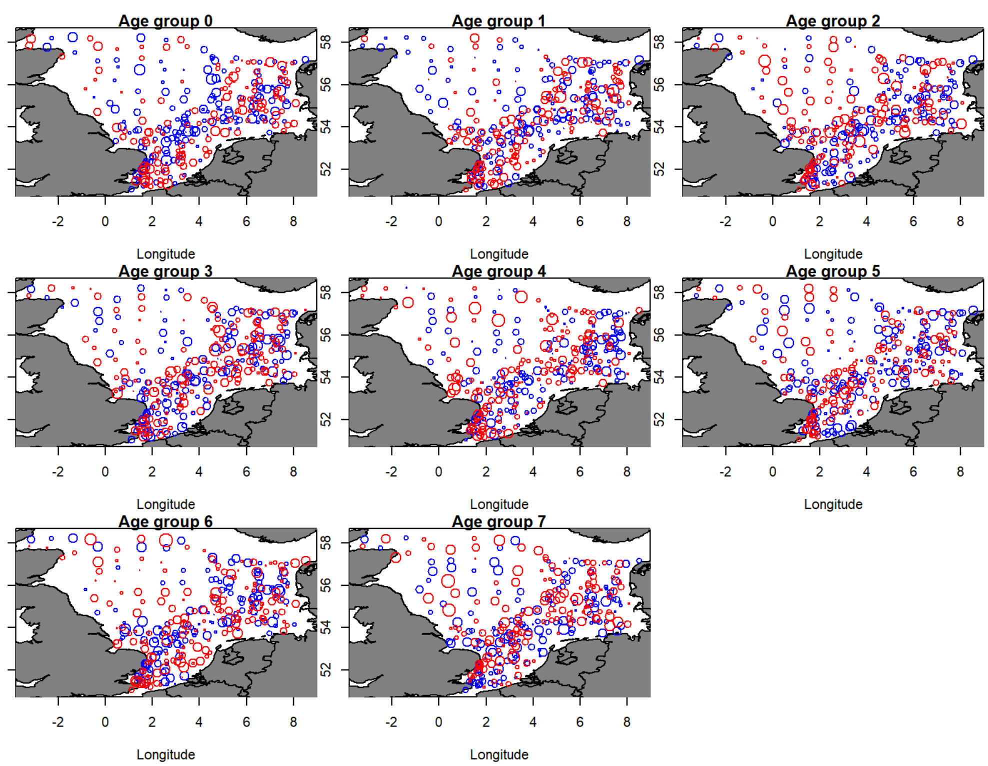


Fig. S39. Spatial residuals from the BTS+BSAS modelled index in 2021.

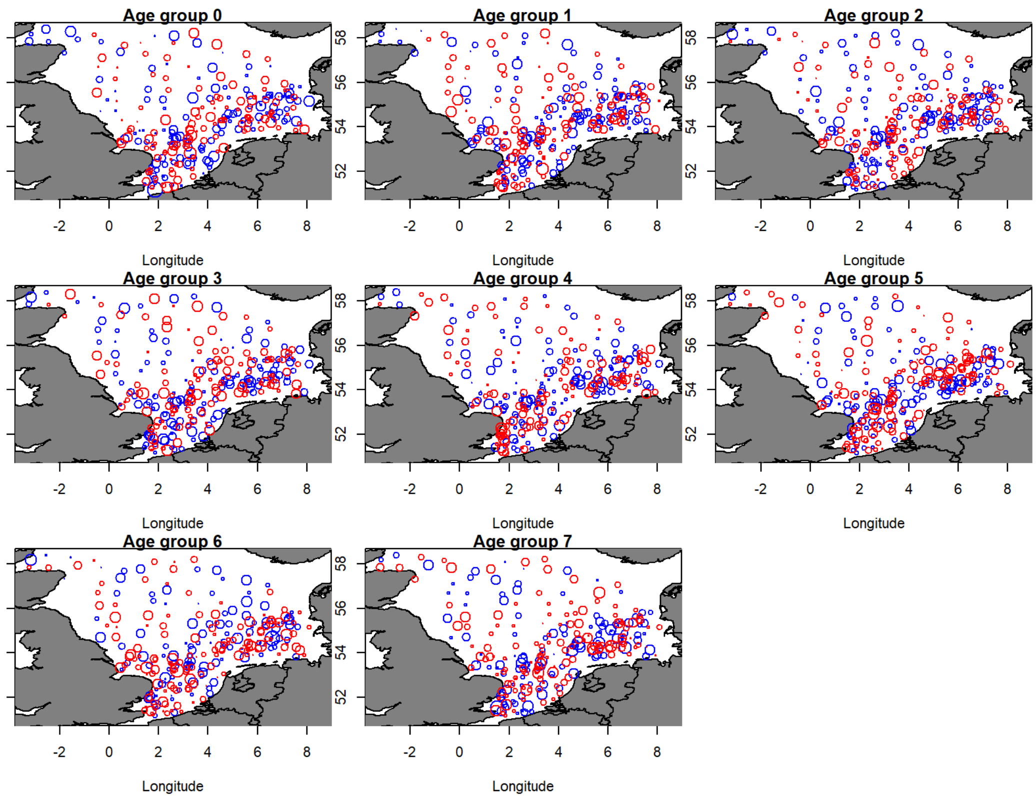


Fig. S40. Spatial residuals from the BTS+BSAS modelled index in 2022.

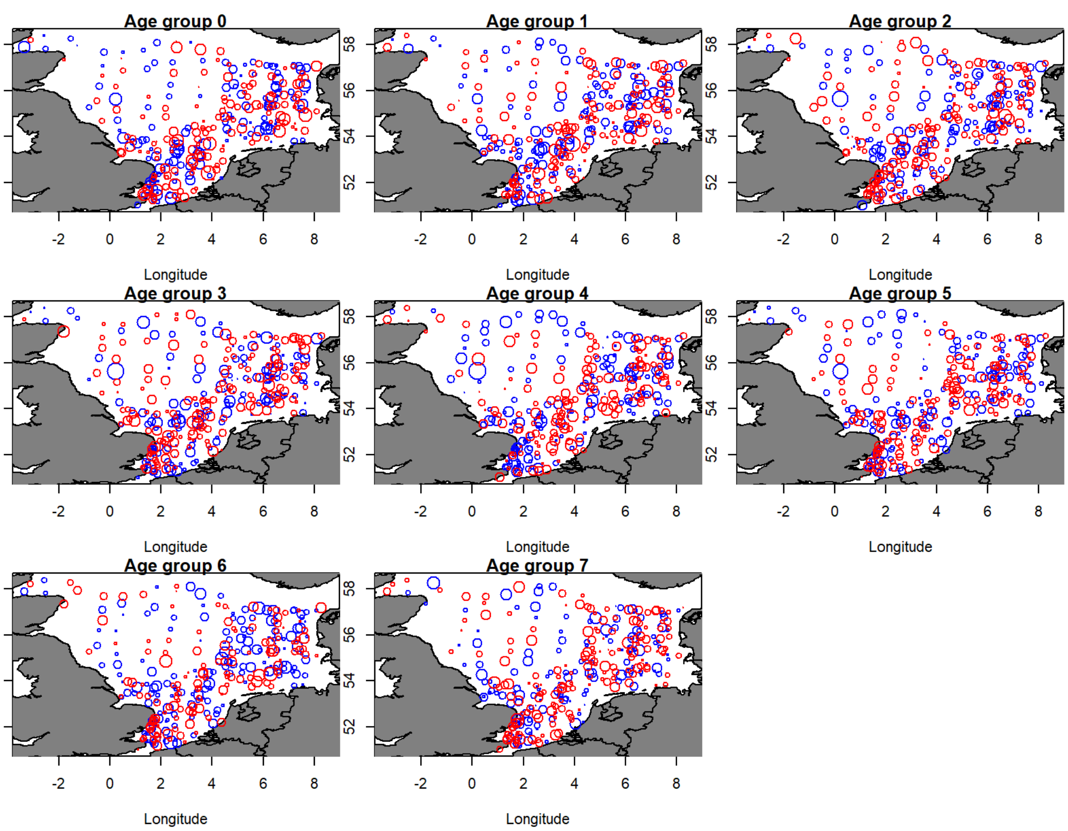


Fig. S41. Spatial residuals from the BTS+BSAS modelled index in 2023.

Combined BTS + COAST indices for 1991 – 2023 (ages 0 – 7)

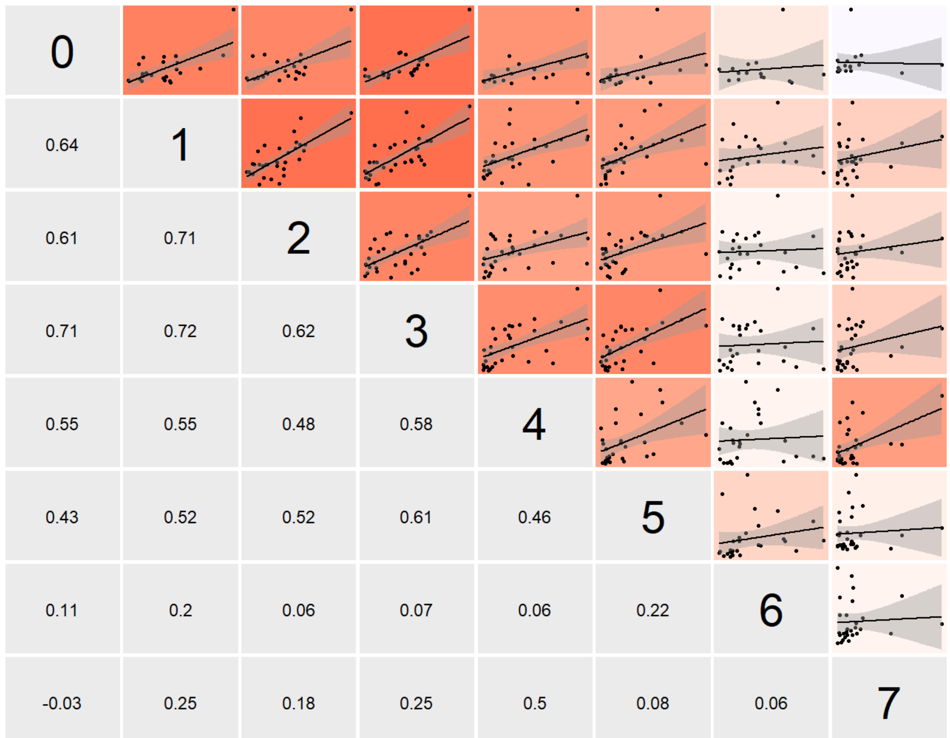


Fig. S42. Age correlation plot for the combined BTS+COAST index.

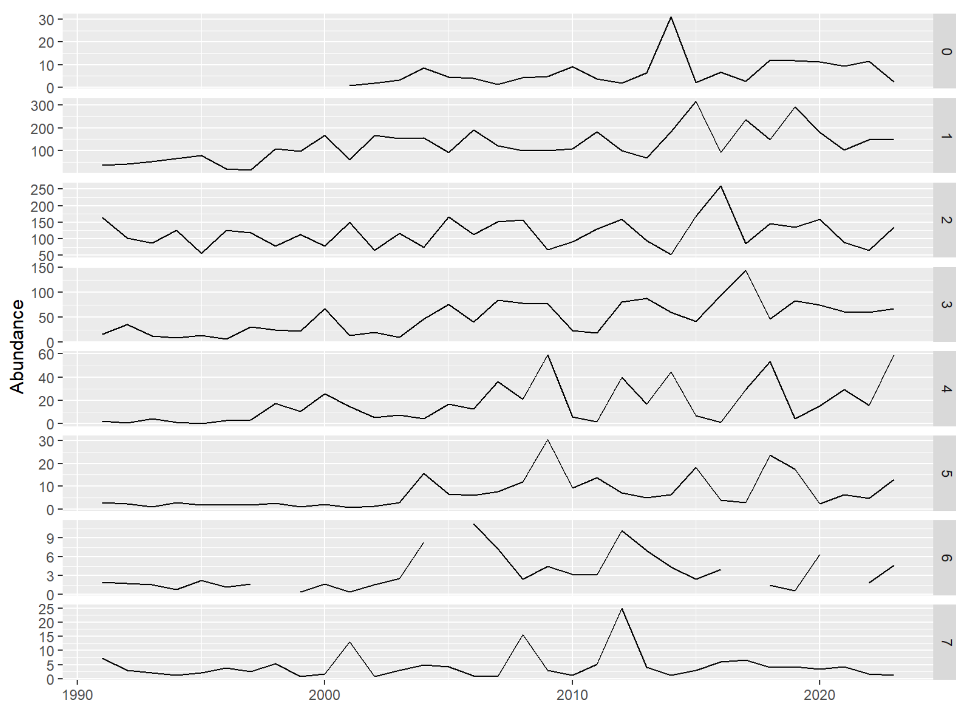


Fig. S43. Modelled index of abundance-at-age from the BTS+COAST index.

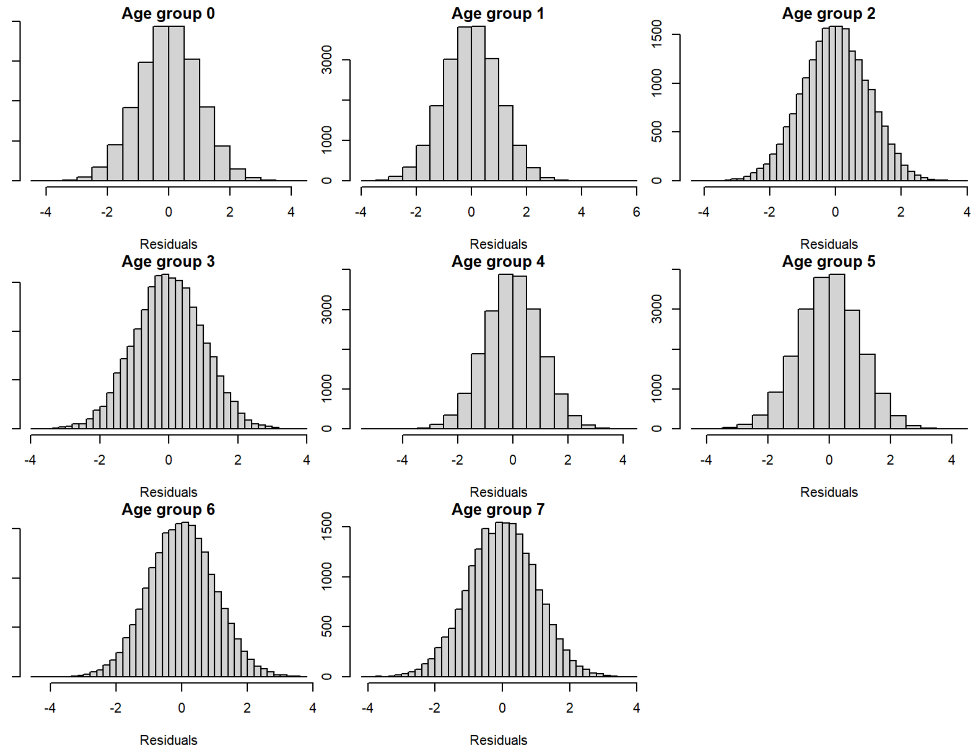


Fig. S44. Distribution of model residuals-at-age per year for the BTS+COAST index.

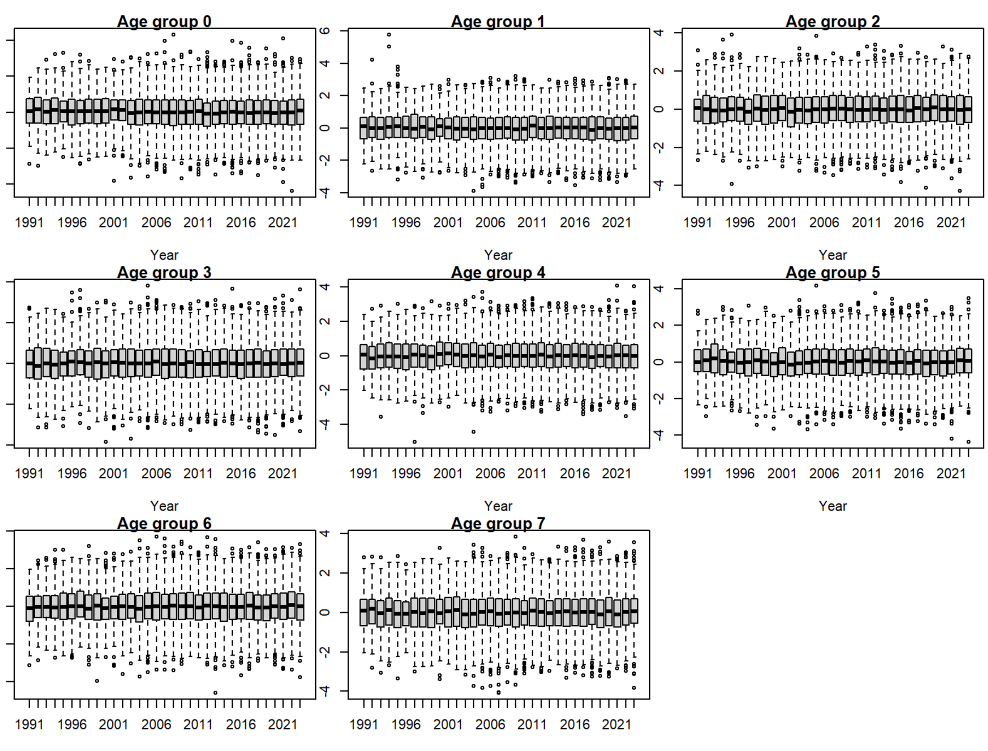


Fig. S45. Distribution of model residuals-at-age per year for the BTS+COAST index.

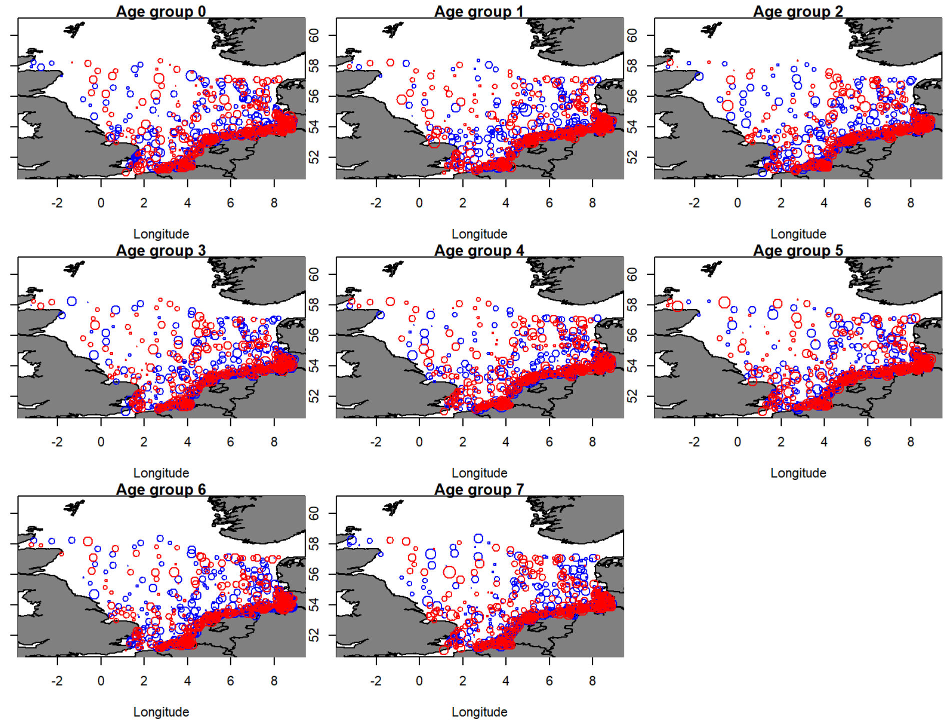


Fig. S46. Spatial residuals from the BTS+COAST modelled index in 2020.

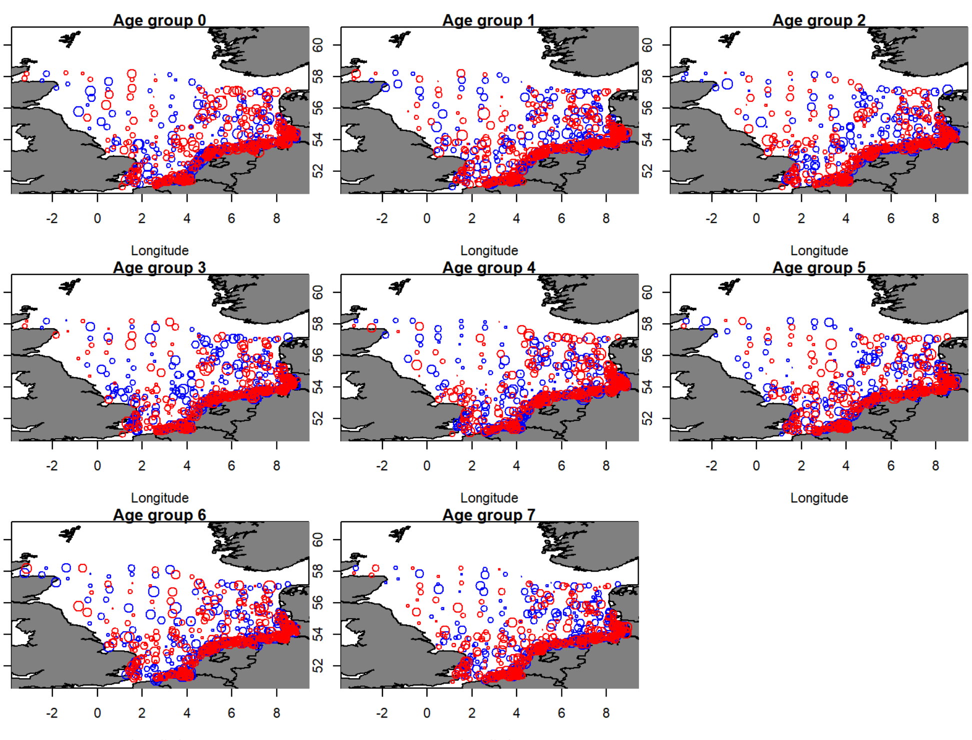


Fig. S47. Spatial residuals from the BTS+COAST modelled index in 2021.

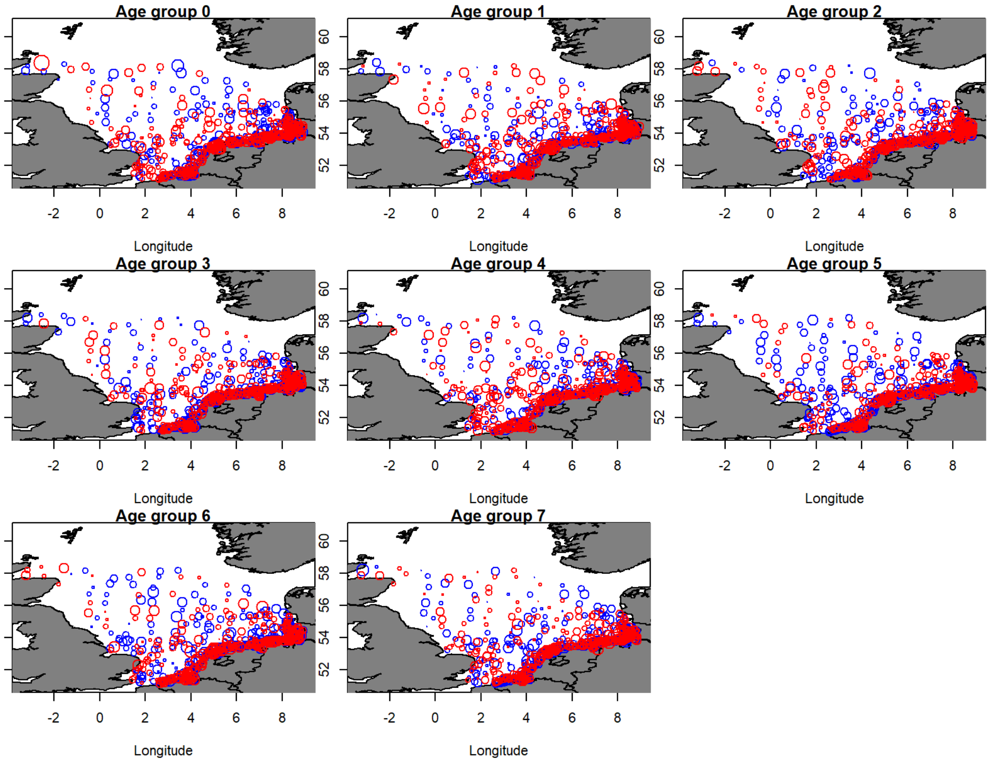


Fig. S48. Spatial residuals from the BTS+COAST modelled index in 2022.

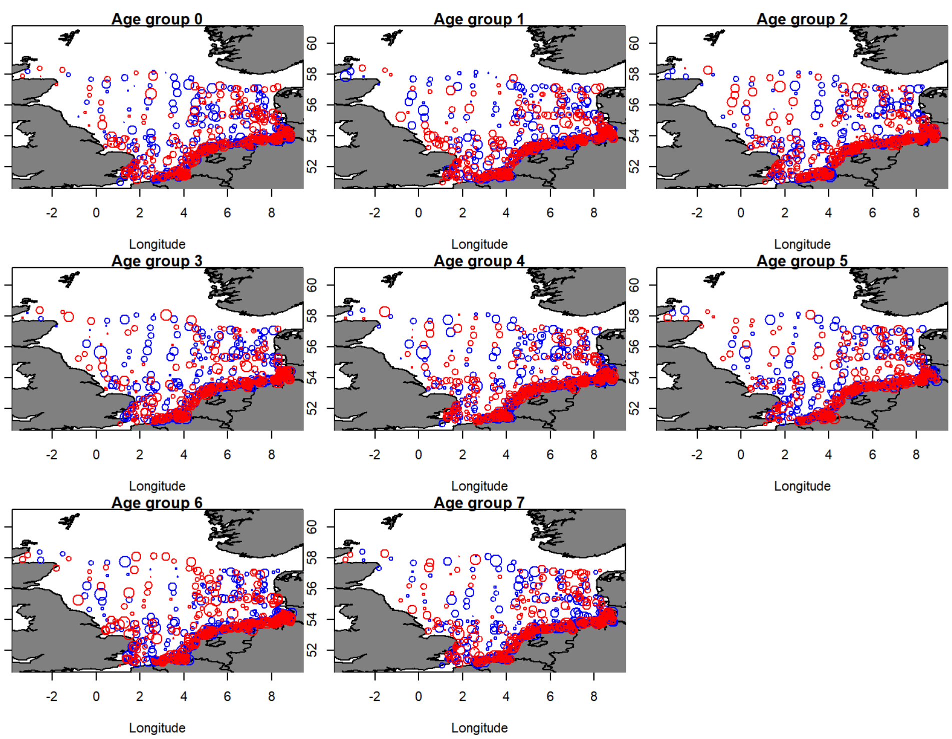


Fig. S49. Spatial residuals from the BTS+COAST modelled index in 2023.

WD Update to natural mortality for turbot (*Scophthalmus maximus*) in the Subarea 274.4 (North Sea)

Authors: Lennert van de Pol

Wageningen Marine Research, Wageningen University and Research, IJmuiden, The Netherlands

WKNSCS Turbot 27.4

Although age-varying natural mortality for turbot (TUR.27.4) was investigated during IBPNEW in 2012, high variability in von Bertalanffy growth parameter K made it difficult to reconcile the results. As a result, a constant natural mortality rate of M=0.2 has been used for all ages and years in North Sea turbot assessments (ICES, 2012; ICES, 2017). This value is double the constant mortality rates used for North Sea plaice and sole, reflecting the relatively fast growth rate of North Sea turbot.

During a data evaluation meeting, an age-varying natural mortality option was presented, following the relationship between body size and natural mortality proposed by Lorenzen (2022):

$$M(a) = M_{L_\infty} \cdot (1 - e^{-K\cdot(a-a_0)})^c$$

Where a is the age, a_0 is the age at length L=0, M_{L_∞} is the natural mortality at asymptotic length L_{inf}, K is the von Bertalanffy growth rate, and c is the allometric scaling factor.

Parameters a_0 and K were calculated using length and age data from combined quarter 3-4 North Sea survey data (IBTS, BTS, SNS, DYFS, BSAS) from 1991 – 2023, commercial catches from the Belgian sea sampling program from 2017-2023, and market sampling data from the Netherlands from 2003 to 2023, and a typical assumption of -1 was used for the allometric scaling factor (Lorenzen, 2022). To obtain an estimate of the natural mortality at asymptotic length (M_{L_∞}), several methods were compared. First, a value was extracted from literature. Hulak et al. (2021) found a value of 0.16 for M in the final age class (10 years) for Black Sea turbot. However, given the differences between the North Sea and Black Sea ecosystems, mainly in terms of the presence of apex predators such as seals, this value was not seen as representative for M_{L_∞} for North Sea Turbot.

Lorenzen (1996) propose a relationship between body weight and natural mortality. For natural ecosystems, the relationship between body weight at age (W_a) and natural mortality at age (M_a) is given as:

$$M_a = 3.00 \cdot W_a{}^{-0.288}$$

Here, we calculated the mean weight-at-age from samples in the survey data, commercial catches and market sampling to calculate M_a.

Then et al. (2015) propose a relationship between the maximum age (T_{max}) and natural mortality, where:

$$\acute{M} = 4.899 \cdot T_{max}{}^{-0.916}$$

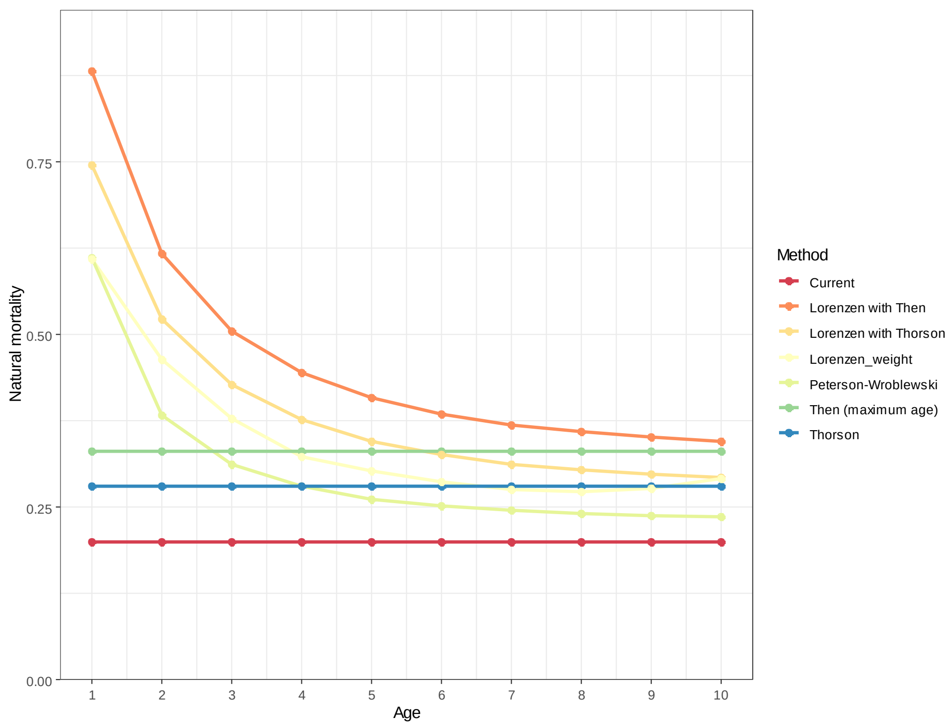
The maximum age of turbot found in the survey data, commercial catch sampling and market sampling was 19, resulting in a natural mortality estimate of 0.33.

Thorson et al. (2023) computed natural mortality estimates for all fishes worldwide based on relationships between several life history parameters as well as the effect of taxonomic structure. Their estimate of natural mortality for turbot is 0.27. This was also used as the scaling factor for the Lorenzen method of estimating natural mortality at age.

Peterson & Wroblewski (1984) propose a size-dependent equation for mortality between weight and natural mortality, based on known relationships between the distribution of biomass and size, where:

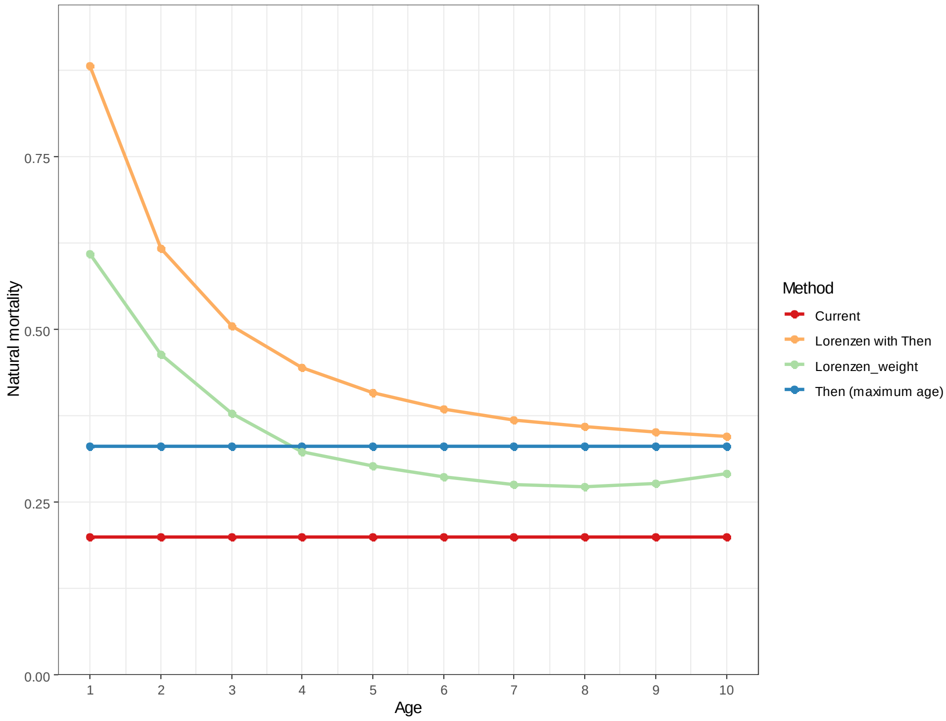
$$M_a = 1.92 \cdot W_a^{-0.25}$$

This method was developed for the dry weights of pelagic fish species.



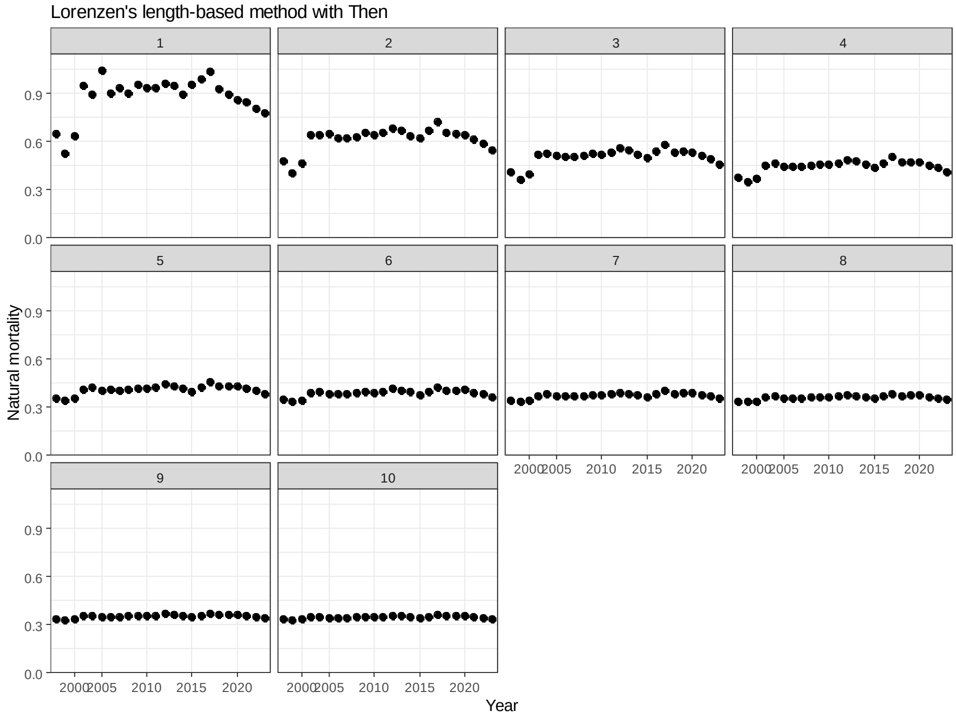
Results for several of the methods are relatively similar. The following approaches for computing natural mortalities at age were explored further:

1. Lorenzen's length-based method scaled to Then's maximum age-based natural mortality;
2. Lorenzen's weight-based method
3. The current assumption of constant natural mortality at age of 0.2

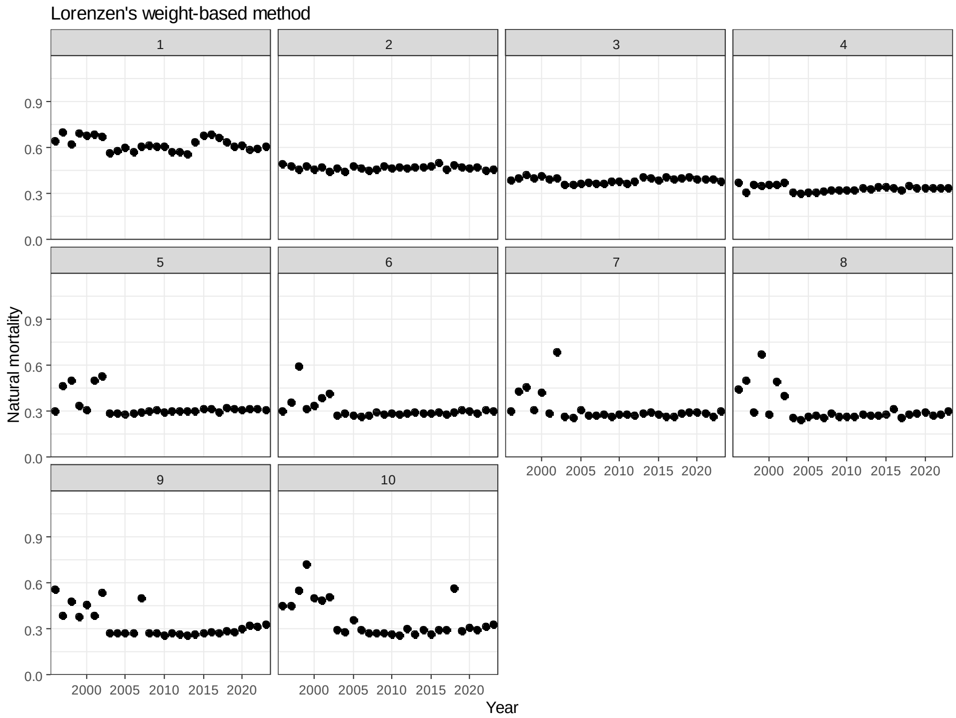


Note that natural mortality estimates using Lorenzen's weight-based method for ages 9 and 10 shows a slight increase compared to ages 7 and 8, likely due to the small sample size for these ages. Given that the plus group in the assessment model is age 8 and over, this is not relevant.

We also applied methods Lorenzen's length-based method and Lorenzen's weight-based method on the yearly length, weight and age data to see if estimates of natural mortality would differ strongly between years. For Lorenzen's length-based method, where M approaches the 0.33 value from Then, the results were as follows:



For Lorenzen's weight-based method, the result was:



Because of the small sample size per year, and limited variation between years, these approaches were not seen as appropriate.

Proposed scenarios for benchmark

We propose to compare three model runs with varying natural mortalities:

1. Constant M of 0.2, base case;
2. Weight-based method (Lorenzen's weight-based method);
3. Length-based method (Lorenzen's length-based method scaled to Then's maximum age-based method)

The preferred method is Lorenzen's weight-based assessment. This is mainly due to the fact that the outcome for this method is not dependent on any scaling to terminal M values, or on the selection of the final age group.

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Working Document: Weight-at-age for North Sea turbot (tur.27.4)

Author: Justin C. Tiano (WMR, The Netherlands)

Introduction

This working document describes the changes made for the stock and landings weight-at-age used in the North Sea turbot (tur.27.4) stock assessment. Landings weight-at-age data is available from 1981 - 1990 from the DATUBRAS database (Boon and Delbare, 2000) and also in 1998, and 2004 to 2023 from Dutch market samples. Stock weights are estimated as the catch weights in Q2, coinciding with peak spawning of the stock. Hence, stock weights estimates are available for the same time period as catch weights, but excluding the years 2005 and 2006 where no samples were available in the second quarter. In addition to this, average weights-at-age for the stock during the period 1976–1979 are available from Weber (1979; **Figure 1**).

***Figure 1**. Raw landings weight-at-age data (left). Raw stock weight-at-age data (right).*

Similar to other North Sea flatfish stocks, turbot exhibited larger sizes in the 1980's and 1990s. In 2015, during the interbenchmark on North Sea turbot, it was decided to use estimates for the weights at age in missing years to account for this change (ICES, 2018). With no data except a single year available in the 1990s (1998) modelling was required to infer the trend in weight-at-age over the period 1991 to 2003. Since 2018 (ICES, 2018), a time varying growth model has been used to estimate the weights at age in years when data has not been available. This is a two step process which where time varying length at age is first estimated using a von Bertalanffy growth model where length-at-age *a* (in mm) in a given year t is calculated:

$$L_{a,t} = L_{\infty,t}(1\text{-}\exp(-K(a - a_0)))$$

where $L\infty,t$ is the asymptotic length in year t, K is a curvature parameter, and $a0$ deter-mines the point in time when the fish has zero length. Stock weights-at-age in a given year Wa,tS (in kg) are calculated using an allometric growth model:

$$W^{S}{}_{a,t} = \alpha\ L_{a,t}{}^{\beta}$$

With parameters α= 0.00001508 and β=3.090, as estimated by Bedford *et al.* (1986). Catch weights-at-age $W^{C}{}_{a,t}$ are linked to stock weights-at-age by a simple age-independent scaling factor such that $W^{C}{}_{a,t}=\gamma W^{S}{}_{a,t}$.

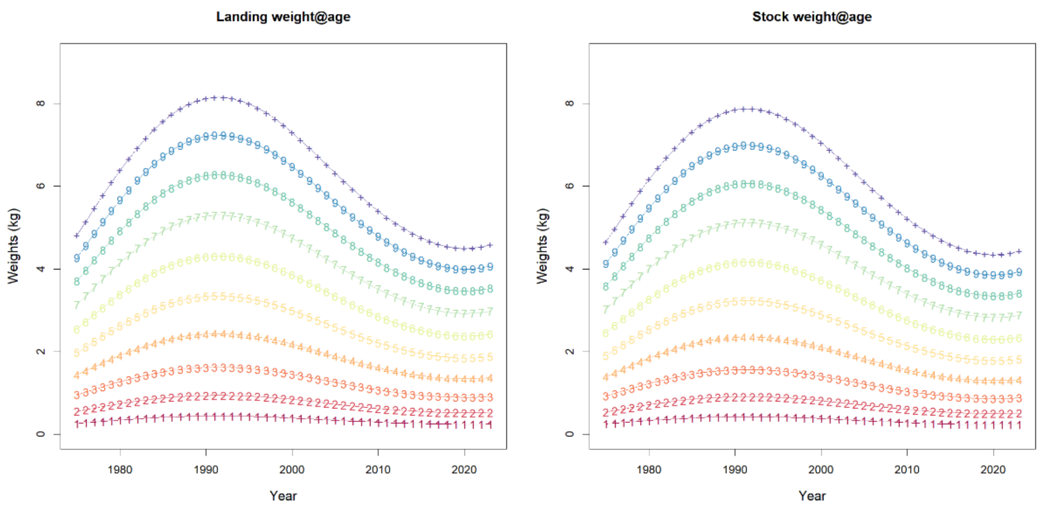

Figure 2. *Landings weight-at-age assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (left). Stock weights (Q2 catch weights) assuming gradually changing weights-at-age, following a von Bertalanffy growth curve (right). Linf$_t$ is a 5 parameter/knot spline in this example.*

A potential drawback of this method is that the entire weight-at-age dataset needs to be updated and changed every year. The turbot stock currently shows a growing retrospective pattern in SSB which might be alleviated if a more stable method for estimating weights-at-age is adopted.

In preparation for the 2025 benchmark workshop WKBNSCS, new methods will be tested to improve upon the modelled weights-at-age used in the North Sea turbot assessment and some data year gaps some data year gaps were filled following new data available from InterCatch.

Adding new information to the catch-at-age matrix

The turbot stock assessment model does not include discard data therefore the weight-at-age matrices consist of only landings weight-at-age and stock weight-at-age.

Biological data for weights from catch data were made available for 2003 (NL), 2005 (DK,BE), and 2006 (DK, BE) from the benchmark datacall. This allowed the estimation of stock weights at age and landings weights at age for these years through InterCatch. The raising procedure followed the annual raising procedure conducted for each new year of data for the turbot stock assessment. Allocations to calculate the age structure were conducted within métier per quarter where possible. If by quarter was not possible, available quarters were grouped (**Table 1**).

__Table 1.__ Age allocation for weight-at-age estimates conducted in InterCatch

Group	Allocation
TBB < 100mm	Within metier, all quarter
TBB > 100mm	Within metier, all quarter
OTB < 100mm	Within metier, all quarter
OTB > 100mm	Within metier, all quarter
OTB/TBB < 70mm	All, all quarter
SSC > 100mm	All, all quarter
SSC < 100mm	All, all quarter
GNS/GTR	All, all quarter
Rest	All, all quarter

Weight-at-age smoothened with rolling weighted averages

A simple weighted average procedure for both stock and landings weight at age may provide a more stable approach to the weight at age estimations where yearly updates would only result in changes to the final two years of data. This is the same approach used for Whiting in the Irish Sea (whg.27.7a) and smooths other the raw data using a 3 year window with more weight being given to the current years rather than the previous and following year: sum($\frac{1}{4}W_{y-1}$ + $\frac{1}{2}W_y$ + $\frac{1}{4}W_{y+1}$).

Years where no information is available were filled in using the mean of the closest years between the years with missing data is used. This results in a relatively flat pattern observed when multiple consecutive missing data years are present, however, the rolling average smoothing mitigates some of this effect (**Figure 3**). Older ages in particular show much variability in weight-at-age. This can occur due to natural factors, as rapidly growing flatfish like turbot can be strongly influenced by various environmental and biological conditions that impact their growth rates. Concurrently, this species displays low catchabilities for older ages in North Sea fisheries and surveys, limiting available samples sizes for older fish. The assessment currently sets its plus group at age 8+

Figure 3. *Landings and stock weights-at-age smoothened using a rolling weighted average with a three-year window.*

Increasing model flexibility to account for additional years

If it is decided to continue using the current time varying von Bertalanffy models to estimate weight-at-age for turbot, it is likely in need of some adjustment before continued use. There have been no changes to the number of knots used in the smoothing functions and adding additional knots will be necessary to ensure the model can adapt to changing growth patterns.

Model runs were tested using smoothing functions with 5 – 7 knots (**Figure 4**). Weight-at-age using the standard 5 knots as well as with 7 knots leads to a slight increase in growth rates in recent years while growth models using 6 knots suggest a continued downward trend for all ages.

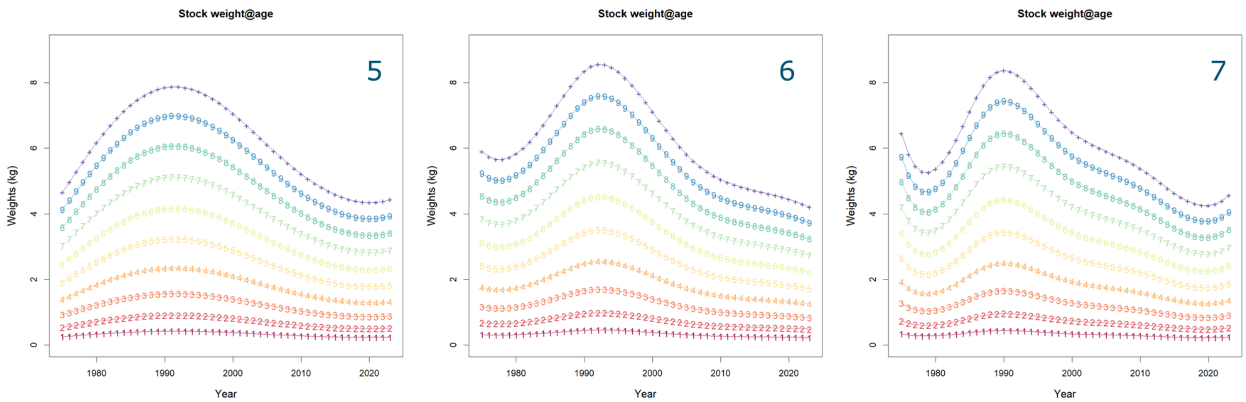

Figure 4. *Stock weight-at-age when using time varying von Bertalanffy growth models with 5 to 7 knots.*

One of the main considerations to account for will be how these methods (adding knots or using a weighted rolling average) will any retrospective patterns. Between model runs using 5-7 knots for weight-at-age smoothing functions, the assessment using 6 knots appears to show the lowest mohns-rho value (-10.32) when evaluation the retrospective pattern in SSB though using 7 knots (-10.4) also appears to improve upon the original 5 knots (-11.66; **Figure 5**).

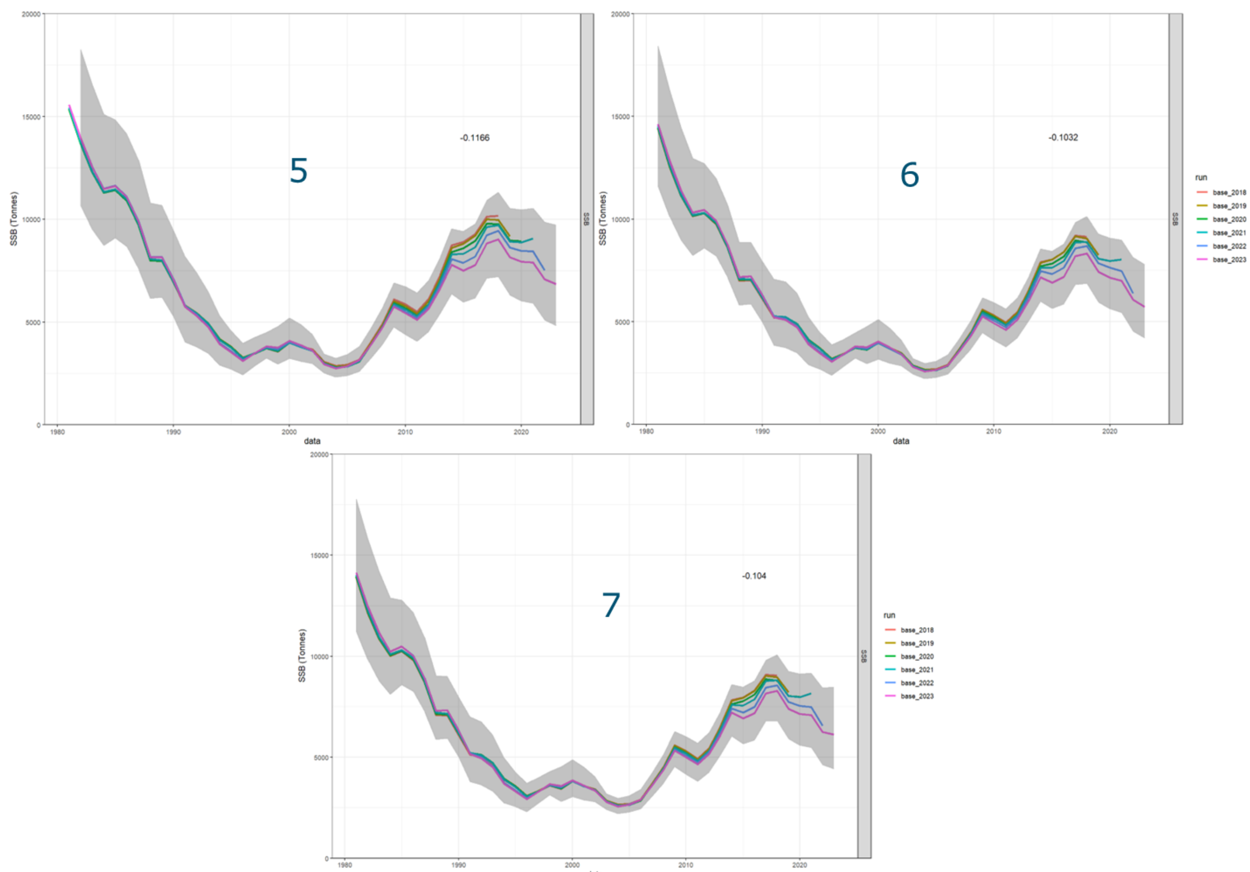

Figure 5. *Retrospective analysis using weight-at-age models with smoothing functions using between 5-7 knots.*

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Working document: Development modelled combined survey exploitable biomass index for turbot in the North Sea (ICES divisions 27.4 a-c) using scientific and industry based surveys.

Authors: Damian Villagra (ILVO, Belgium)

1. Introduction and objective

This document describes how combined (modelled) survey exploitable biomass indices were derived for the turbot (Scophthalmus maximus) in Subarea 4 (North Sea) stock (tur.27.4) using survey data available from DATRAS. The main objective of this index was to obtain a unique exploitable biomass index for the entire stock's distribution and move away from regionally-limited survey indices (NS [B3499], BTS-Isis [B2453]) and commercial indices (NL_BT2).

For this purpose: (1)the survey data (datras) was explored to identify spatial-temporal and gear-specific data gaps, (2) survey and commercial length frequency distribution were compared to identify match/missmatch and to determine an appropiate cut-off length to represent accuratly the stock's exploitable biomass; (3) models were built and fitted to the data to predict turbot biomass over a spatiotemporal grid, and lastly (4) to provide annual exploitable biomass estimates for the stock over its entire distribution area.

2. Data exploration

2.1 Haul data (HH)

The HH data, comprising haul information, was filtered to the stock's area (ICES Subarea 4) (Figure 1). Hauls are homogeneously spread in space since the beginning of the time series (1999). A previous exploration of the available data (previous to 1999) revealed that in older data, haul sampling was more patchy, while simultaneously a lower degree of spatial and temporal overlap between hauls of different surveys occurred.

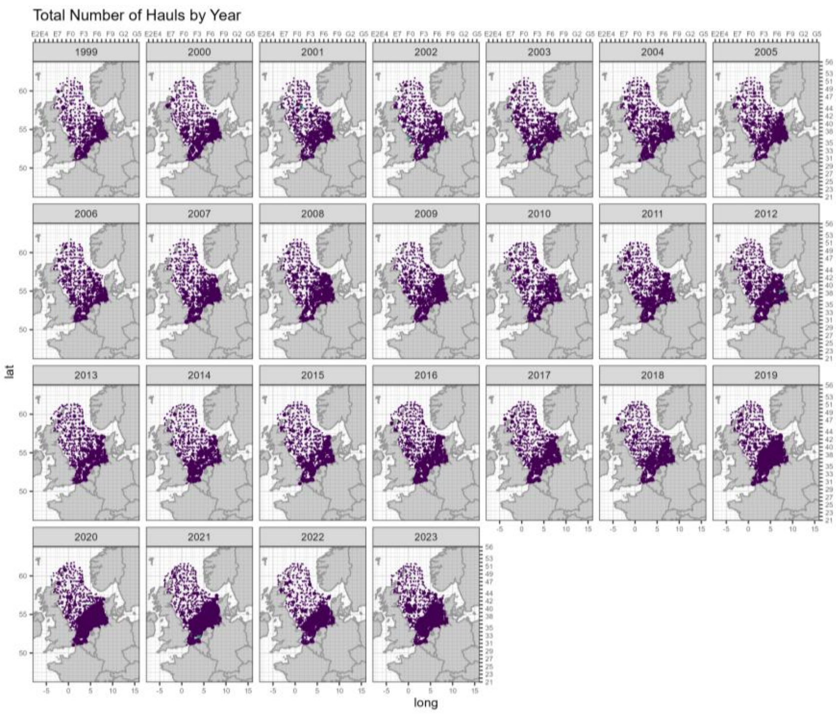


Figure 1: Number and haul position by year of all DATRAS survey from 1999 to 2023 in the stock area (ICES Subarea 4).

Throughout the time-series BT and GOV_CL are the most frequently (number of hauls) used gears for surveys in the stock area(Figure 2). Hauls using the BT_BSAS represent hauls performed during the Dutch Industry survey (NL-BSAS) and only contribute to the time-series between 2019-2023. Although also a beam trawl (BT), the commercial characteristics of this survey/gear (i.e. targeting behaviour, higher trawling speeds) were considered to assume a different catchability and therefore defining a new gear type (BT_BSAS). Although sampling seems, homogenous within the time-series, more surveys target the southern and central north sea. Herein only, the BTS and NS-IBTS sample the northern North Sea (Figure 3).

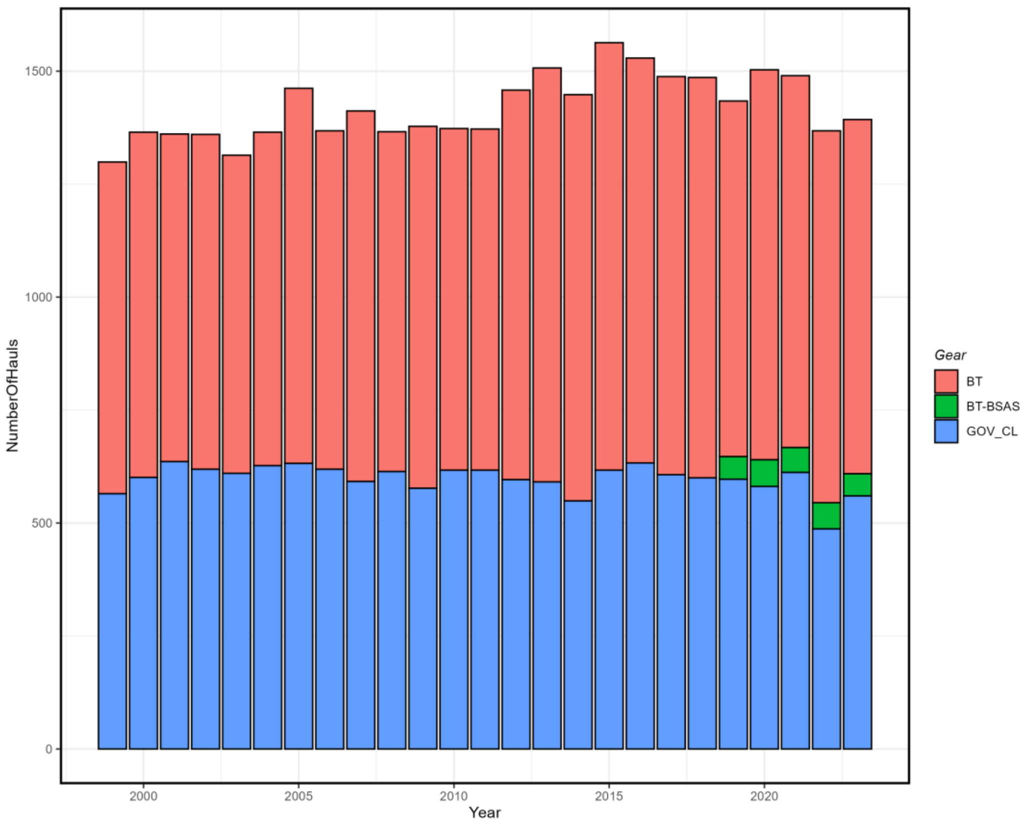


Figure 2: Haul count by gear from 1999 to 2023

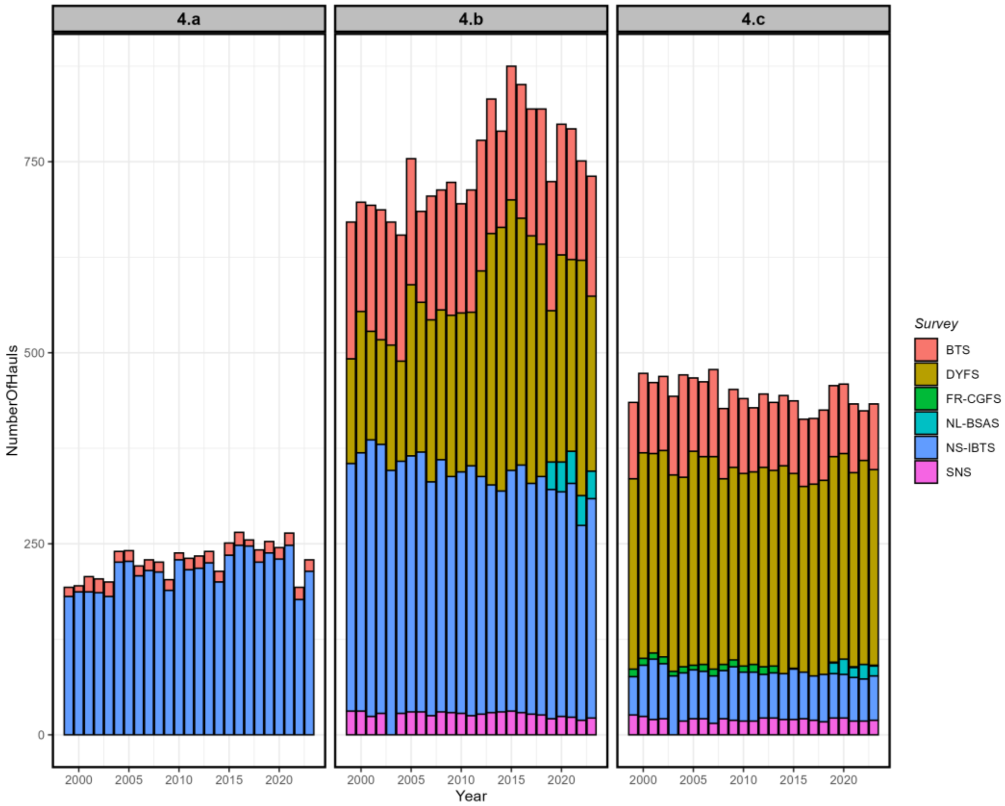


Figure 3: Haul count by gear from 1999 to 2023 for each ICES sub-area

Only the GOV_BL used during the NS-IBTS is used to sample the stock area during the first quarter of the year. Considering this, an annual modelling approach was preferred over a biannual (two semesters) or quarterly approach, as the absence of survey overlap in a part of the year was likely to lead to increased uncertainty for that semester/quarter (Figure 4).

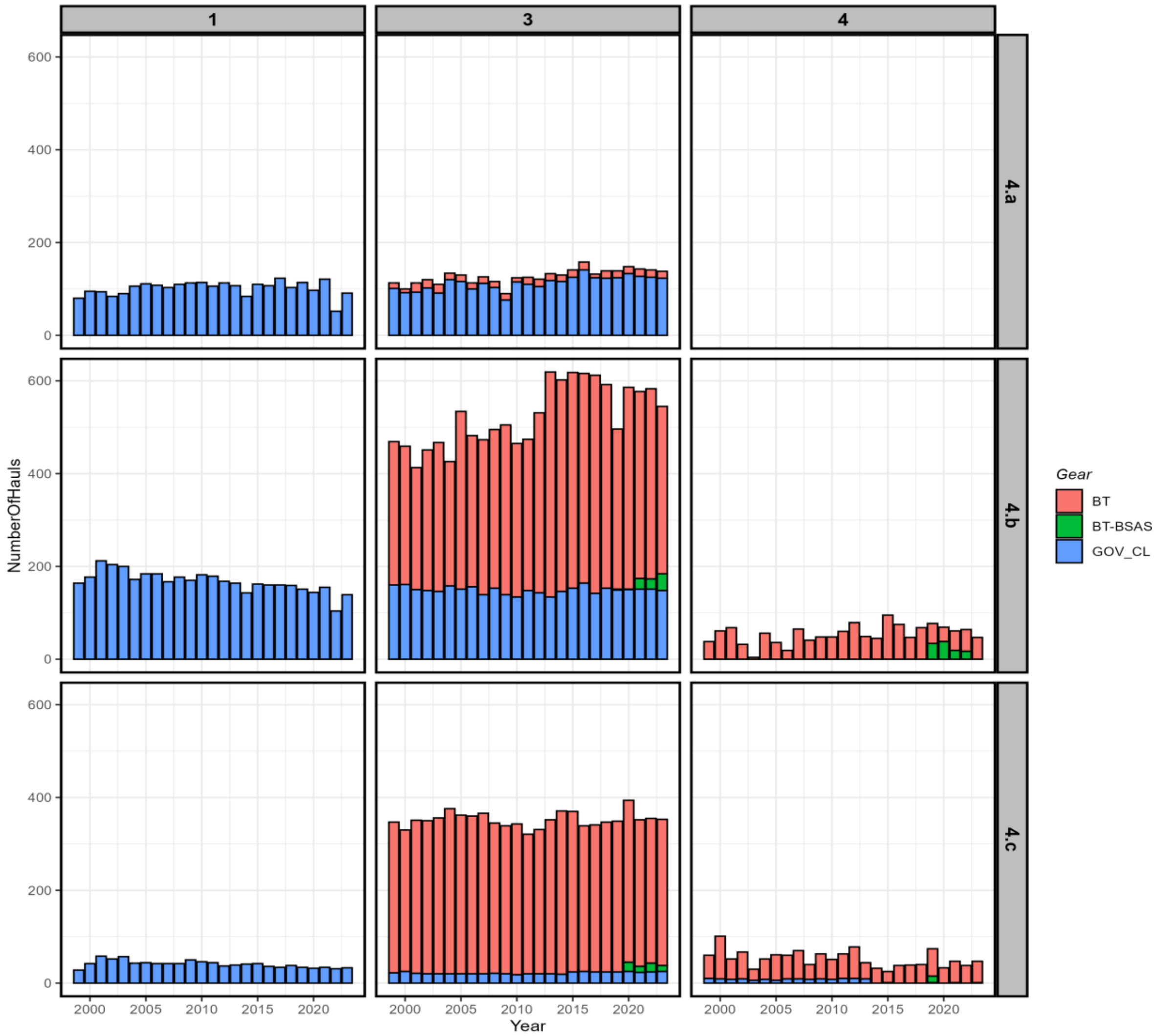


Figure 4: Haul count by gear from 1999 to 2023 for each ICES sub-area and quarter of the year

2.2 Length data (HH + HL)

Turbot lengths caught in surveys range from 3 to 88 cm and seemed to reflect a similar distribution as the one observed in commercial catches of the Belgian TBB fleet (seagoing observer program) (Figure 5). It however seems that a larger proportion of small (<30cm) fish are general caught during survey hauls compared to the commercial catches. This situation is significantly more present in the last five years of data, as the NL-BSAS industry survey provide a significant increase in the number of fish caught.

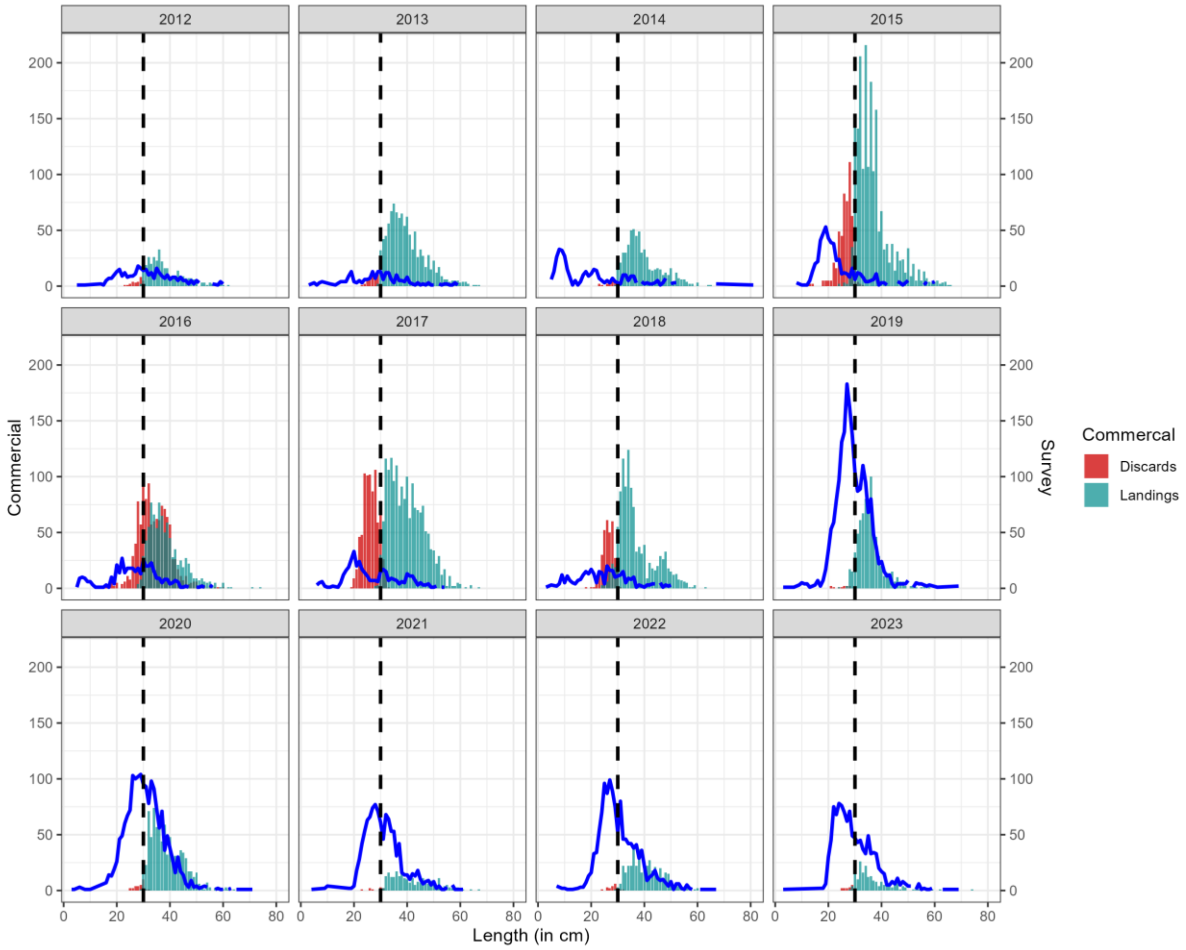


Figure 5: Length frequency distribution comparison between survey and commercial data. The black dotted line represents a theoretical cut-off length ant 25 and 30cm respectively.

Although there is no Minimum Conservation Reference Size (MCRS) for turbot in the stock area commercial landings seem to more or less consistently start at a minimum size of 30cm with the exception of year 2016 were larger fish were also discarded. This is likely due to the reach of the quota as 2016 is one of the few years for which the combined turbot and turbot TAC was overshot. Based on this, an ideal cut-off point (length) to provide an exploitable biomass index using the survey data was chosen at 30cm. This would also cope with the high proportion of small fish (<30cm) present in the survey data, while providing a representative sample (i.e. similar length distribution trend) of the commercial catch and therefore exploitable biomass (Figure 6).

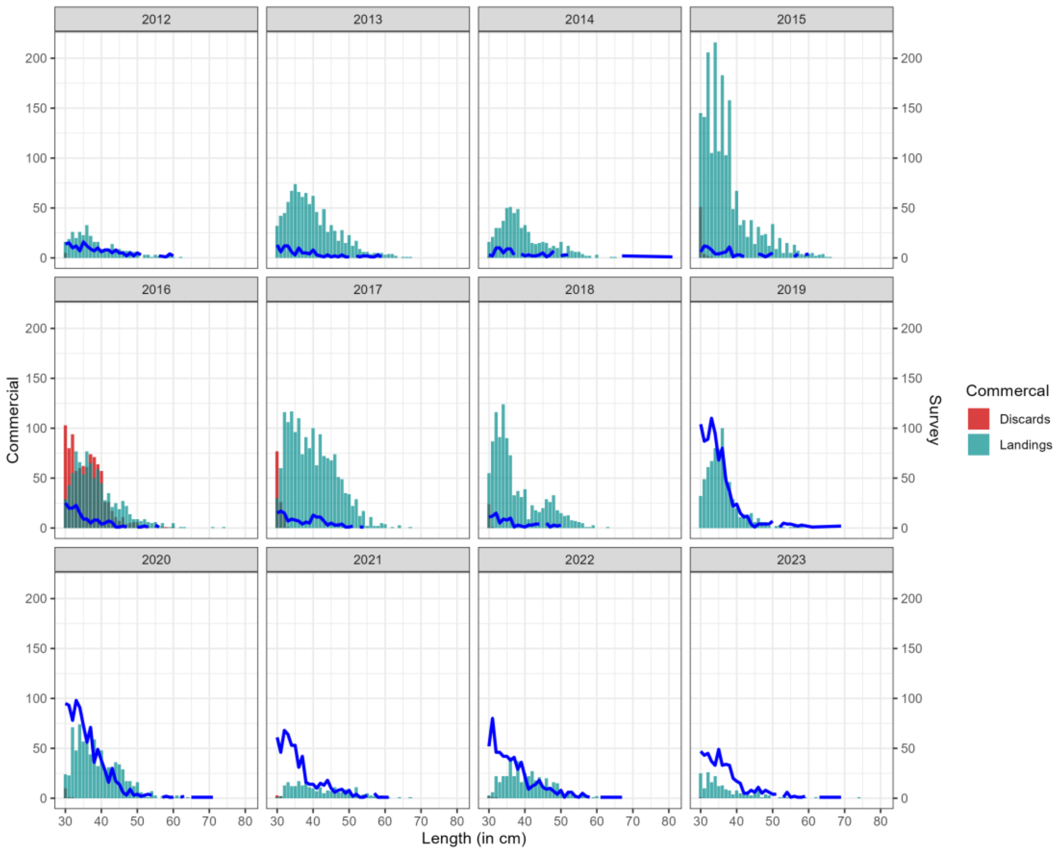


Figure 6: Length frequency distribution comparison between survey and commercial data cut-off at 25cm.

2.3 Catch data (HH+HL+CA)

2.3.1 Turbot presence absence

From 1999 to 2023 turbots were caught in 5 to 10% of the hauls performed. A slight increase is observed in the last five years, due to the inclusion of the NL-BSAS survey, which has a significantly higher catchability (Figure 7).

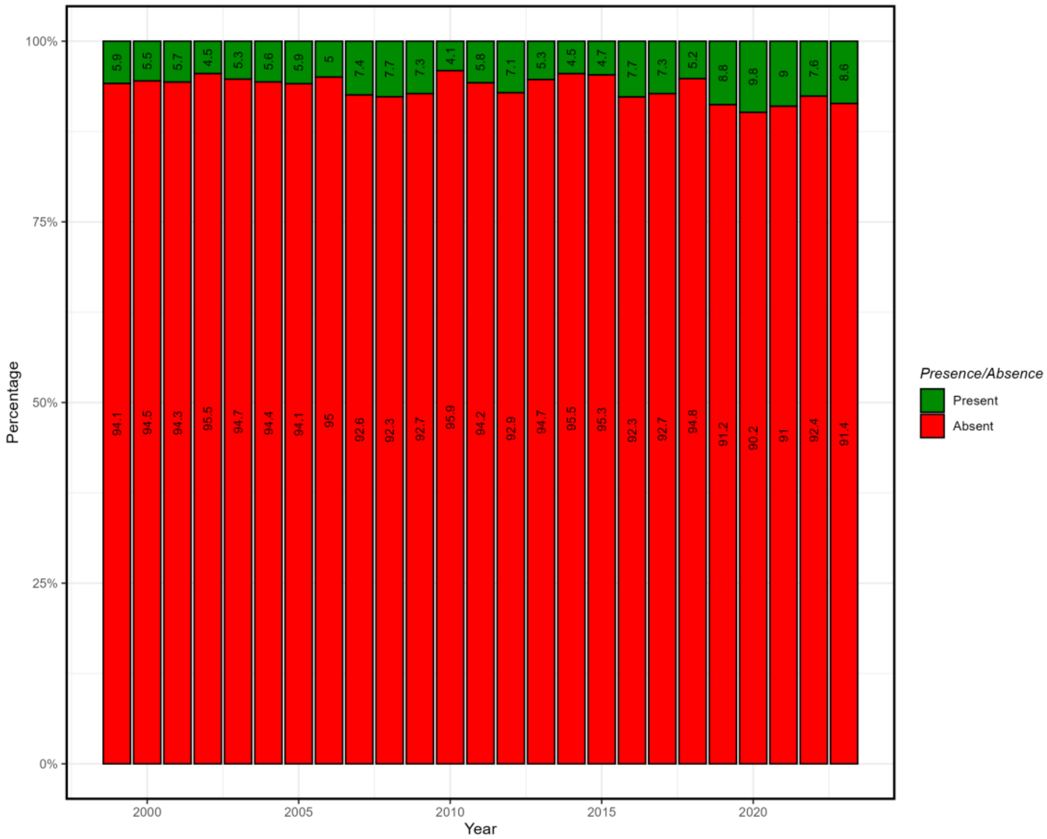


Figure 7: Percentage of presence/absence of exploitable turbot (>30cm) in survey hauls from 1999 to 2023.

As expected catchability was found significantly different between gears. BT and GOV_CL caught turbot with “similar” frequencies, while 90% hauls from the NL-BSAS were found to have caught turbot. (Figure 8).

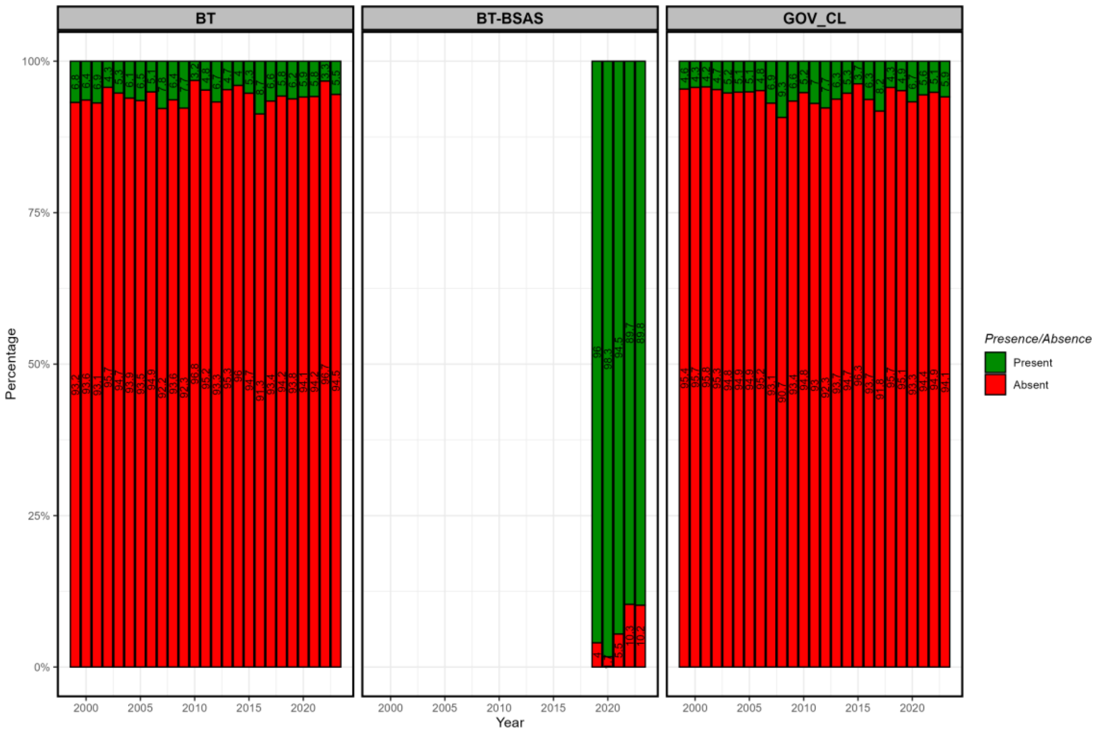


Figure 8: Percentage of presence/absence of exploitable turbot (>30cm) in survey hauls from 1999 to 2023 by gear.

2.3.2 Total catches

Throughout the time-series, spatial coverage is homogeneous and turbot catches are found to be higher in the central and southern north sea, with only low and sporicidal catches happening further north (Figure 9). Catches increase significantly in the period 2019-2023 as the data from the NL-BSAS survey are included in.

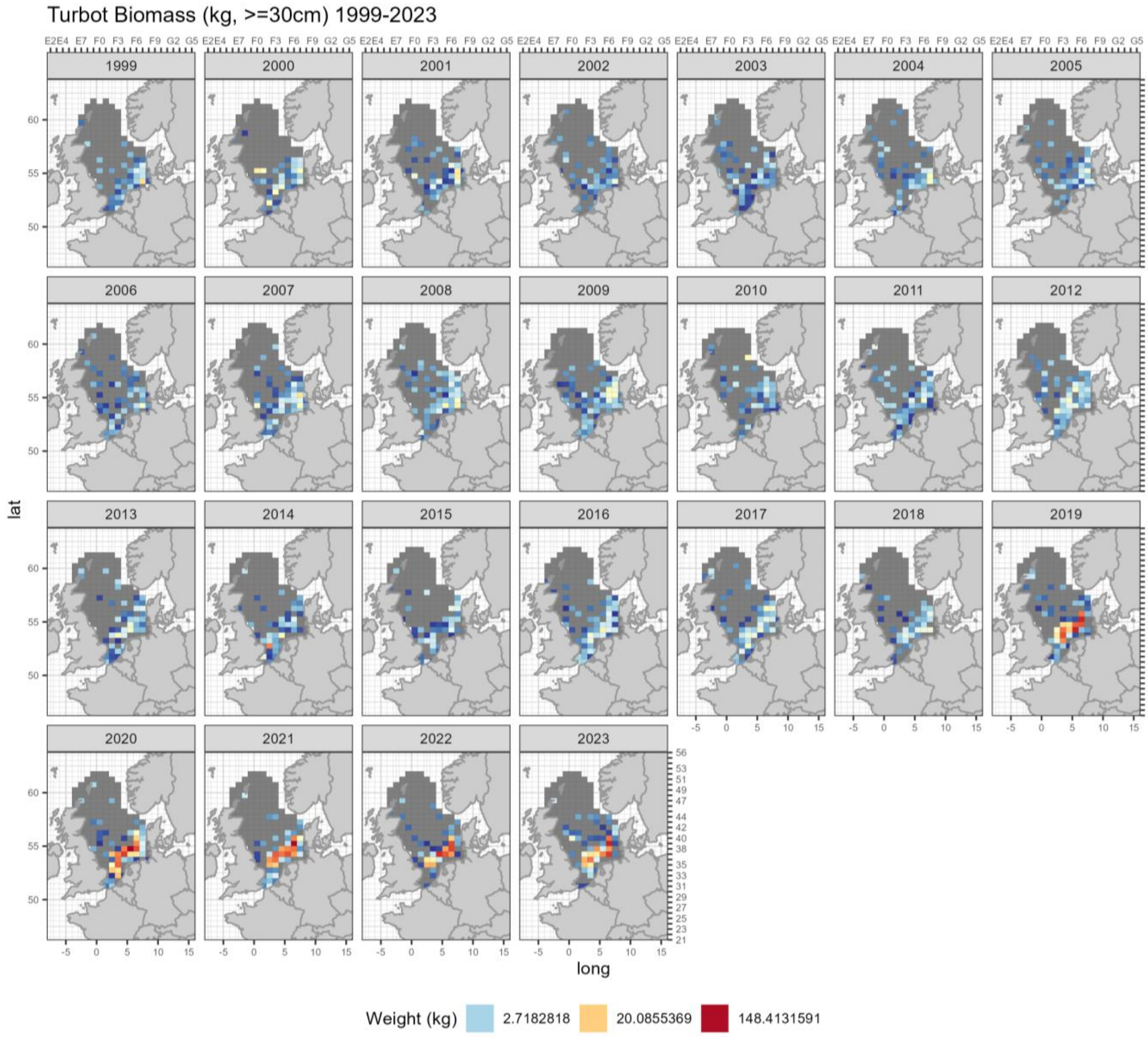


Figure 9: Total exploitable turbot (>30cm) survey catches (kg) per year in the stock area from 1999 to 2023.

Although sampling effort and catchability of turbot has significantly changed in the latest part of the time-series, due to the inclusion of the NL-BSAS, the CPUE seems to follow the same spatial distribution as observed in years previous to 2019 (Figure 10).

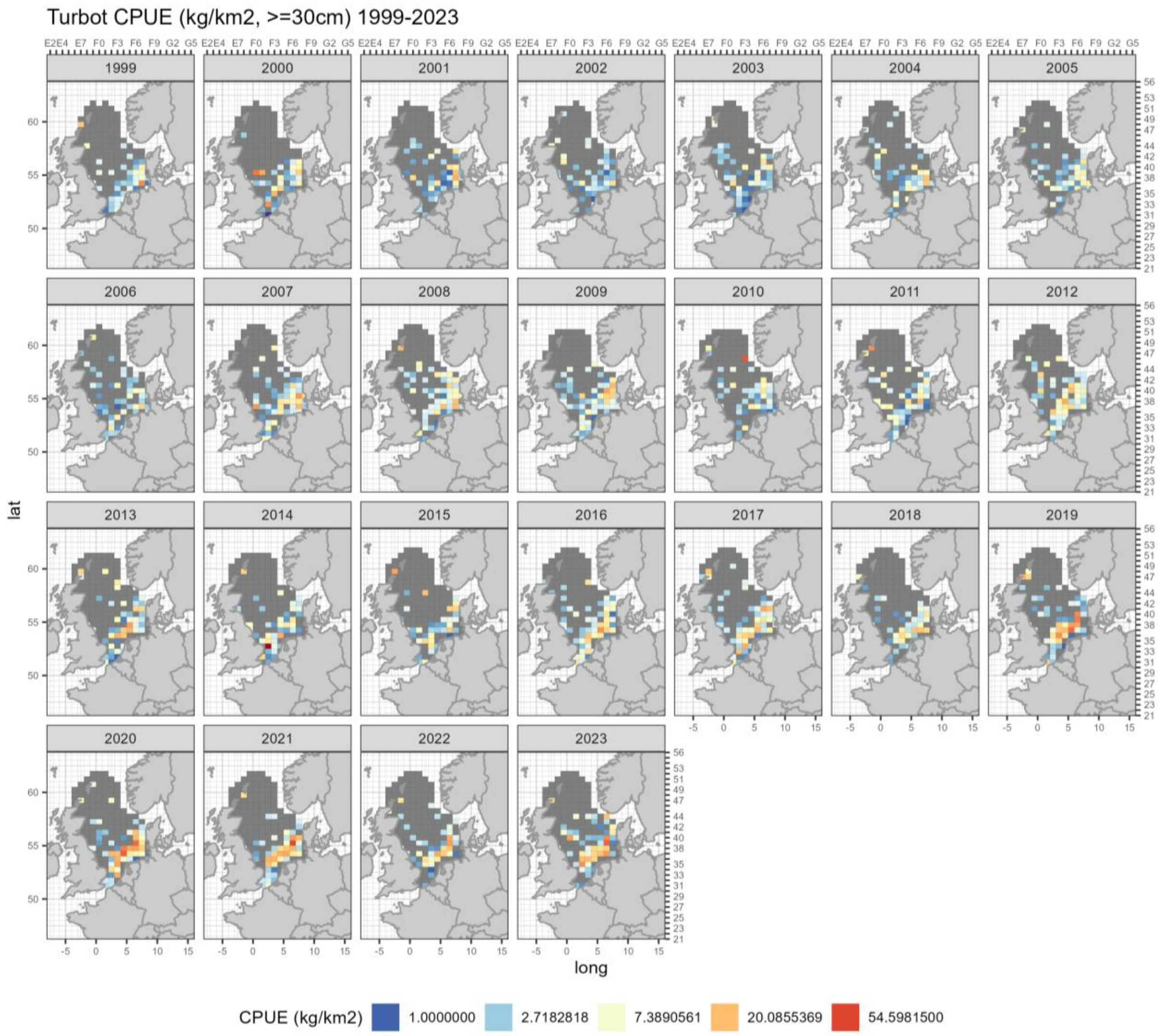


Figure 10: Total exploitable turbot (>30cm) survey catches (kg) per year in the stock area from 1999 to 2023.

2.4 Conclusions and decision

Conclusion	Decision
Data previous to 1999, do not provide sufficient coverage of the stock area or did not catch turbot	Exclude data previous to 1999.
BT_BSAS has a significantly different catchability	BT_BSAS, is included as a new gear, different from the rest of grouped BT used in scientific surveys.
Despite the absence of a MCRS, turbot tends to be discarded from 30cm	Exclude data of turbot <30cm, to represent the stock's exploitable biomass.
Survey data shows a significant peak of turbot of sizes <30cm, which differs from the catch data.	
Data for Q1 comes only from the NS-IBTS, with no survey overlap.	Use an annual approach, to increase certainty of estimates.
Differences in the spatial-temporal distribution and catchability of different gears/ surveys	Build annual models including a gear effect and linear offset considering the Swept area.

3. Modelling an survey index

Based on the data exploration conclusions and decision made, an annual model configuration was preferred over a biannual one using general additive models (GAM) to account for the spatial-temporal variation in data availability, different gears used and their catchability. As detailed before, the data was also trimmed to only include exclude data from 1999 onward and turbot larger than 30 cm, to accurately represent the stock's exploitable biomass, while also ensuring an homogeneous spatial sampling framework.

3.1 Model data

In order to assess the effect of the inclusion of the NL-BSAS data within the modelling framework, three different datasets were modeled following exactly the same approach:

- Data including available from all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) and the industry survey (NL-BSAS) between 1999 and 2023.
- Data including available from all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) between 1999 and 2023.
- Data including available from the industry survey (NL-BSAS) between 2019 and 2023.

3.2 Model framework

This model configuration included an interaction fixed effect for year , spatiotemporal effect (3 dimensional smoother), a fixed spatial effect, a depth effect (1 dimensional smoother), gear fixed effect, ship random effect and a linear offset based on the log of the swept area. Finally, the observational error was assumed to follow a Tweedie distribution (Figure 11).

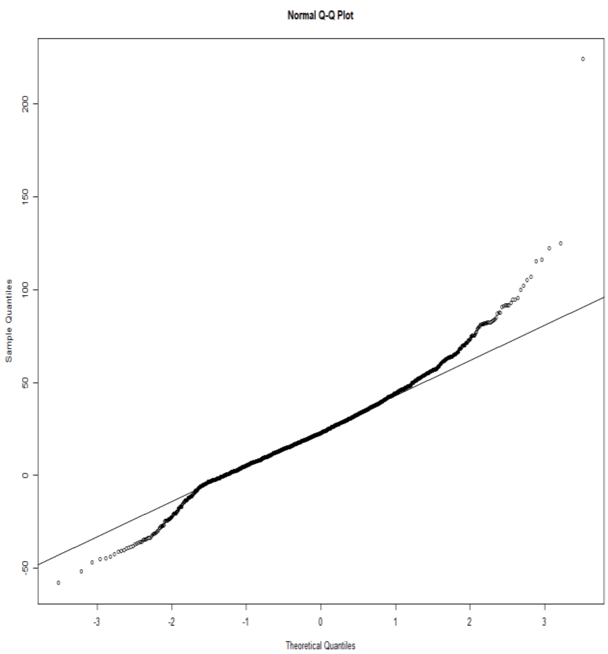
```
fit_model <- function(data) {
  gam(
    bio.adult ~
      s(lon, lat, bs=c('ds'), k=256, m=c(1,0.5)) +
      ti(ctime, lon, lat, d=c(1,2), bs=c('ds','ds'), k=c(10,40), m=list(c(1,0), c(1,0.5))) +
      as.character(Year) +
      s(Depth, bs='ds', k=5, m=c(1,0)) +
      Gear +
      s(Ship, bs = "re") +
      offset(log(SweptArea)),
    family = tw(),
    data = data)}
```

Figure 11: Model configuration

3.3 Model output

3.3.1 Full scientific and industry survey model (all scientific and NL-BSAS surveys)

The QQ plot shows some deviation from the assumed distribution, whilst 49.7% of the deviance is explained by the model.




```
Parametric coefficients:
                          Estimate Std. Error t value            Pr(>|t|)
(Intercept)                7.07041    0.17598  40.177 < 0.0000000000000002 ***
as.character(Year)2000  0.18001    0.16836   1.069            0.285002
as.character(Year)2001  0.03933    0.18358   0.214            0.830352
as.character(Year)2002 -0.26267    0.20555  -1.278            0.201292
as.character(Year)2003  0.14189    0.19827   0.716            0.474216
as.character(Year)2004  0.26408    0.19365   1.364            0.172666
as.character(Year)2005  0.31447    0.19134   1.644            0.100285
as.character(Year)2006  0.21177    0.19768   1.071            0.284068
as.character(Year)2007  0.63729    0.18556   3.434            0.000595 ***
as.character(Year)2008  0.54841    0.18720   2.930            0.003397 **
as.character(Year)2009  0.39147    0.18958   2.065            0.038932 *
as.character(Year)2010  0.02102    0.20395   0.103            0.917923
as.character(Year)2011  0.18777    0.19525   0.962            0.336210
as.character(Year)2012  0.31356    0.19239   1.630            0.103145
as.character(Year)2013  0.02294    0.19974   0.115            0.908582
as.character(Year)2014  0.06627    0.20041   0.331            0.740897
as.character(Year)2015 -0.23046    0.20682  -1.114            0.265158
as.character(Year)2016  0.20775    0.19310   1.076            0.282000
as.character(Year)2017  0.46499    0.19274   2.412            0.015849 *
as.character(Year)2018 -0.08988    0.20581  -0.437            0.662318
as.character(Year)2019 -0.03974    0.18841  -0.211            0.832931
as.character(Year)2020  0.06755    0.18381   0.368            0.713227
as.character(Year)2021 -0.12987    0.18100  -0.718            0.473062
as.character(Year)2022 -0.55305    0.19397  -2.851            0.004358 **
as.character(Year)2023 -0.09158    0.19841  -0.462            0.644410
GearBT-BSAS                0.42367    0.24364   1.739            0.082049 .
GearGOV_CL                -1.66115    0.10260 -16.191 < 0.0000000000000002 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                        edf Ref.df      F             p-value
s(lon,lat)          153.875    255  5.592 <0.0000000000000002 ***
ti(ctime,lon,lat)    85.041    351  1.020 <0.0000000000000002 ***
s(Depth)              3.705      4 20.210 <0.0000000000000002 ***
s(Ship)              17.702     39  3.921 <0.0000000000000002 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.754   Deviance explained = 49.6%
-REML =  24691  Scale est. = 559.64    n = 35462
```

Figure 12: QQplot (left) and summary of the model (right)

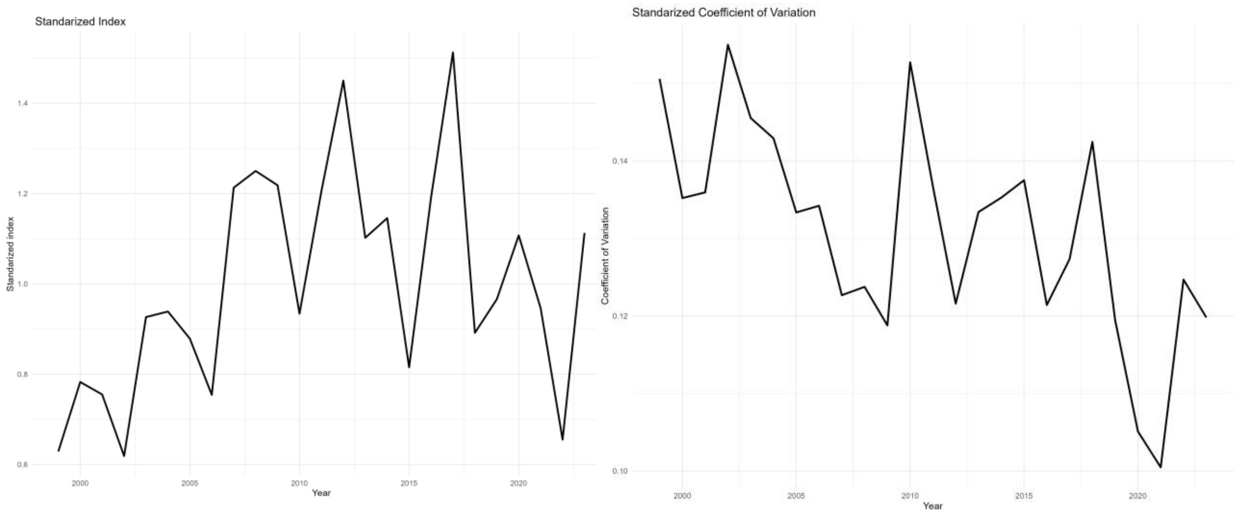


Figure 13. Standardized biomass exploitable (left) and coefficient of variation (right) for the model using data all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) and the industry survey (NL-BSAS) between 1999 and 2023.

The retrospective analysis highlights the absence of retrospective patterns for the index (Figure 14).

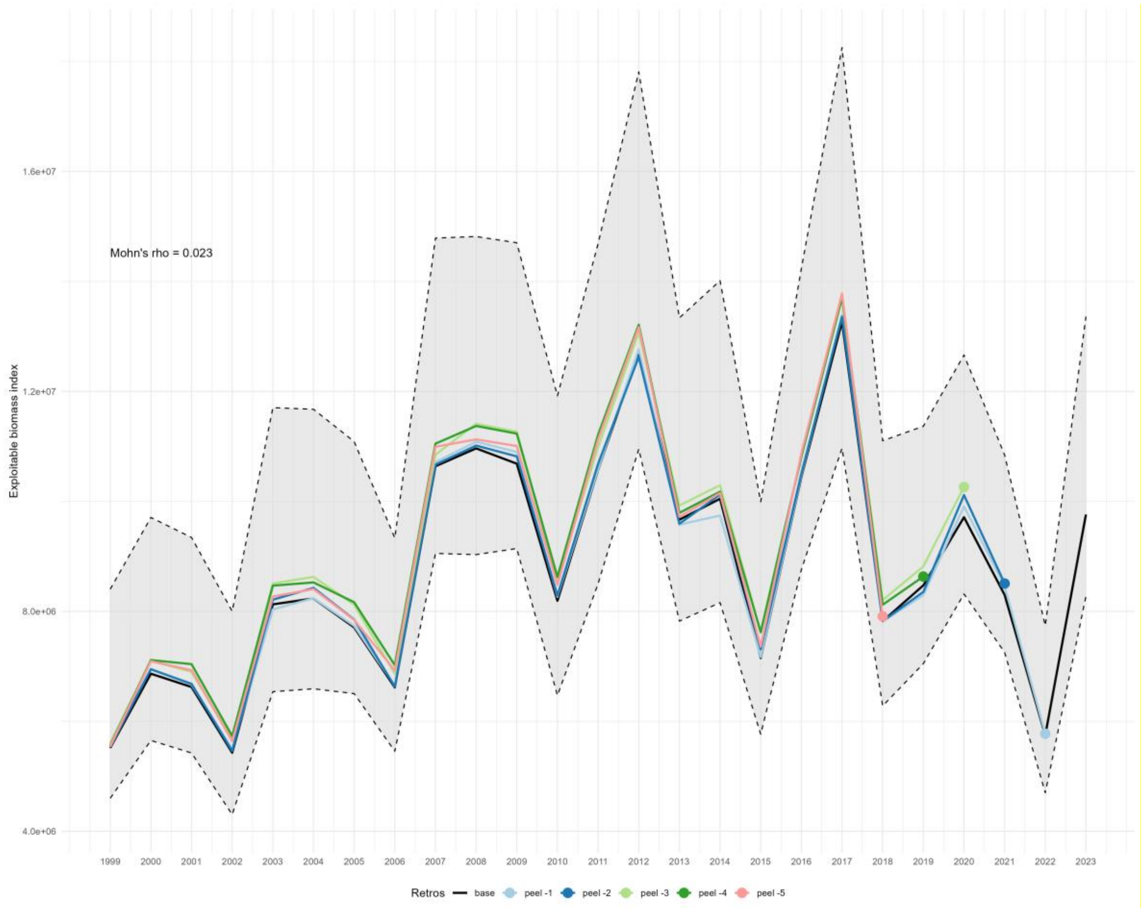


Figure 14: Retrospective analysis of the index using data all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) and the industry survey (NL-BSAS) with indication of calculated Mohn's rho considering 5 retrospective peels. Shaded area represents the 95% confidence interval of the base peel.

Model predictions highlight a generally low biomass of turbot across the stock area, with high density/biomass areas located close to the coast north coast of western Europe in the Southern and Central North Sea (Figure 15) .

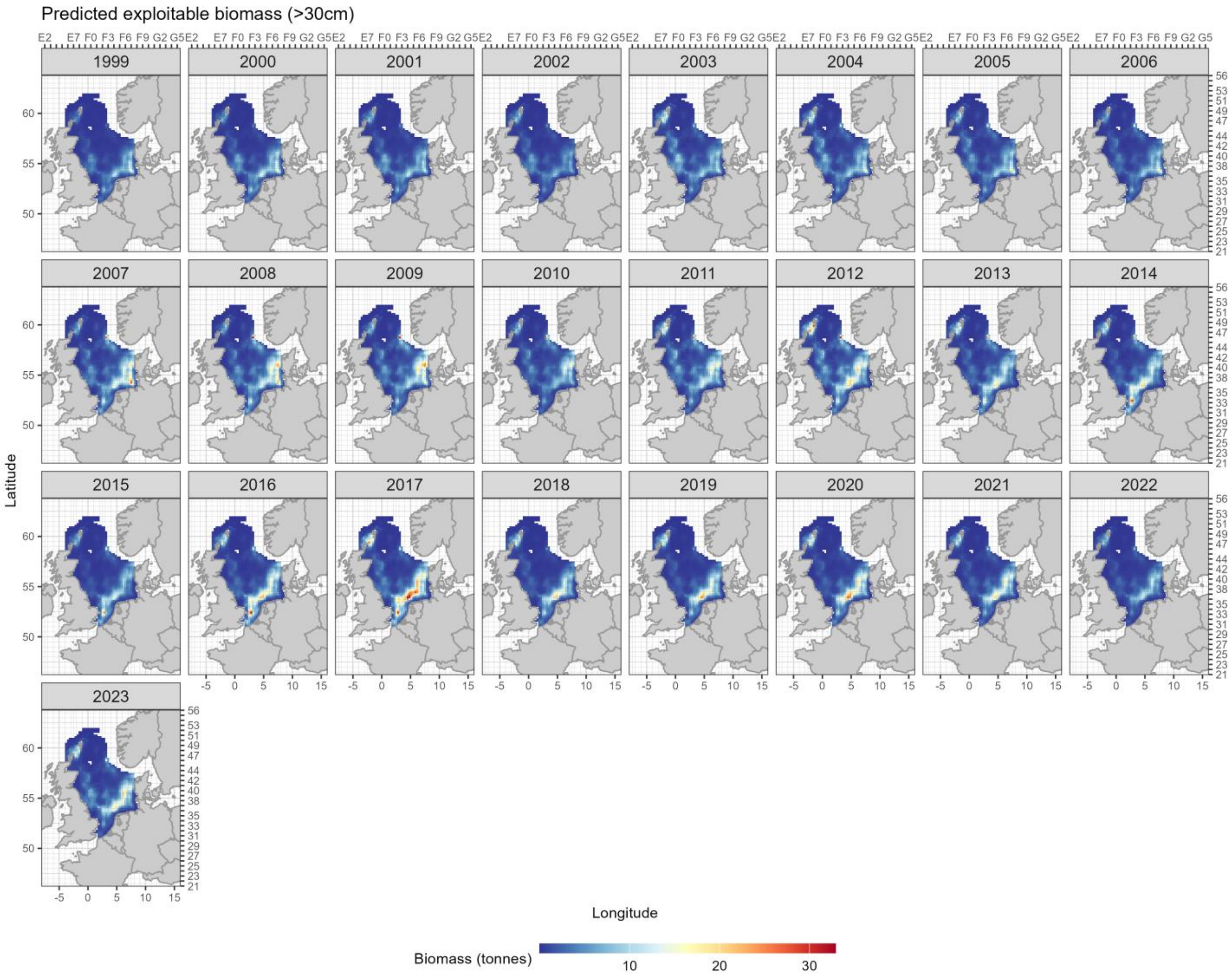
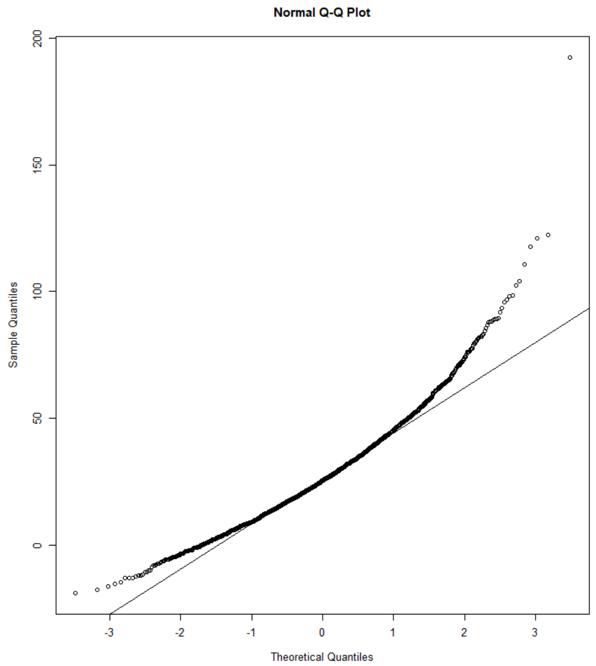


Figure 15: Predicted exploitable biomass (>30cm) for turbot in the North Sea for the model using data all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) and the industry survey (NL-BSAS).

3.3.1 Full scientific survey model (all scientific survey)

The QQ plot shows some deviation from the assumed distribution, whilst 37.6% of the deviance is explained by the model.




```
Parametric coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)               6.88802    0.17801  38.694  < 2e-16 ***
as.character(Year)2000  0.18934    0.16519   1.146 0.251705
as.character(Year)2001  0.06637    0.17951   0.370 0.711563
as.character(Year)2002 -0.23851    0.20167  -1.183 0.236946
as.character(Year)2003  0.15098    0.19499   0.774 0.438763
as.character(Year)2004  0.28813    0.19015   1.515 0.129718
as.character(Year)2005  0.32185    0.18824   1.710 0.087312 .
as.character(Year)2006  0.21315    0.19499   1.093 0.274339
as.character(Year)2007  0.63370    0.18266   3.469 0.000522 ***
as.character(Year)2008  0.55866    0.18438   3.030 0.002448 **
as.character(Year)2009  0.40670    0.18651   2.181 0.029218 *
as.character(Year)2010  0.01512    0.20152   0.075 0.940184
as.character(Year)2011  0.18588    0.19277   0.964 0.334907
as.character(Year)2012  0.32176    0.18918   1.701 0.088996 .
as.character(Year)2013  0.02129    0.19693   0.108 0.913892
as.character(Year)2014  0.05769    0.19832   0.291 0.771150
as.character(Year)2015 -0.24133    0.20423  -1.182 0.237343
as.character(Year)2016  0.21391    0.19050   1.123 0.261498
as.character(Year)2017  0.47205    0.19078   2.474 0.013355 *
as.character(Year)2018 -0.06962    0.20331  -0.342 0.732021
as.character(Year)2019 -0.10913    0.20383  -0.535 0.592377
as.character(Year)2020  0.10604    0.19885   0.533 0.593868
as.character(Year)2021 -0.06031    0.20128  -0.300 0.764448
as.character(Year)2022 -0.51538    0.22635  -2.277 0.022800 *
as.character(Year)2023 -0.02766    0.21686  -0.128 0.898507
GearGOV_CL               -1.69884    0.10329 -16.447  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                       edf Ref.df      F p-value
s(lon,lat)         153.306    255  4.949  <2e-16 ***
ti(ctime,lon,lat)   76.177    351  0.917  <2e-16 ***
s(Depth)             3.791      4 22.302  <2e-16 ***
s(Ship)             16.618     37  4.048  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.141   Deviance explained = 37.6%
-REML =  21754  Scale est. = 537.37    n = 35191
```

Figure 16: QQplot (left) and summary of the model

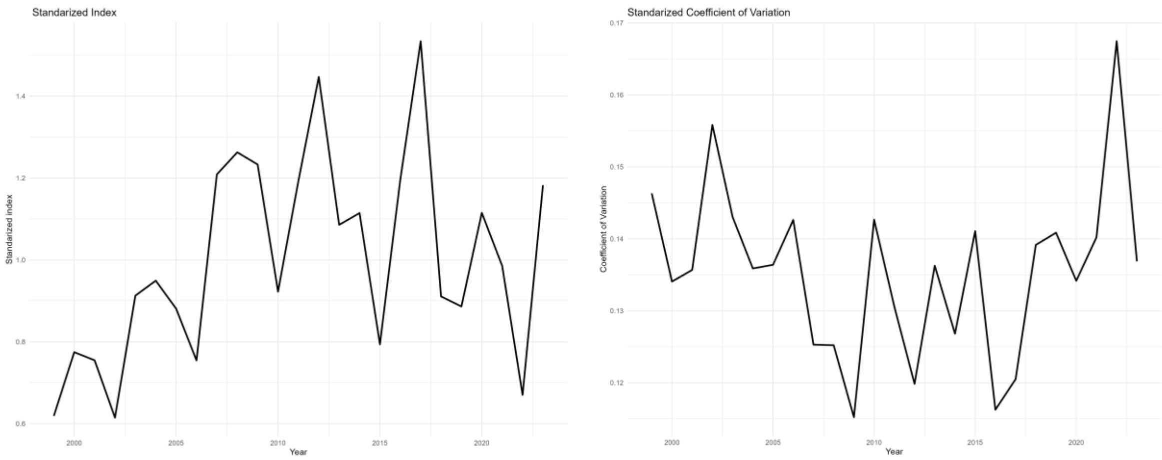


Figure 17: Standardized biomass exploitable index (left) and coefficient of variation (right) for the model using data all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS) only between 1999 and 2023.

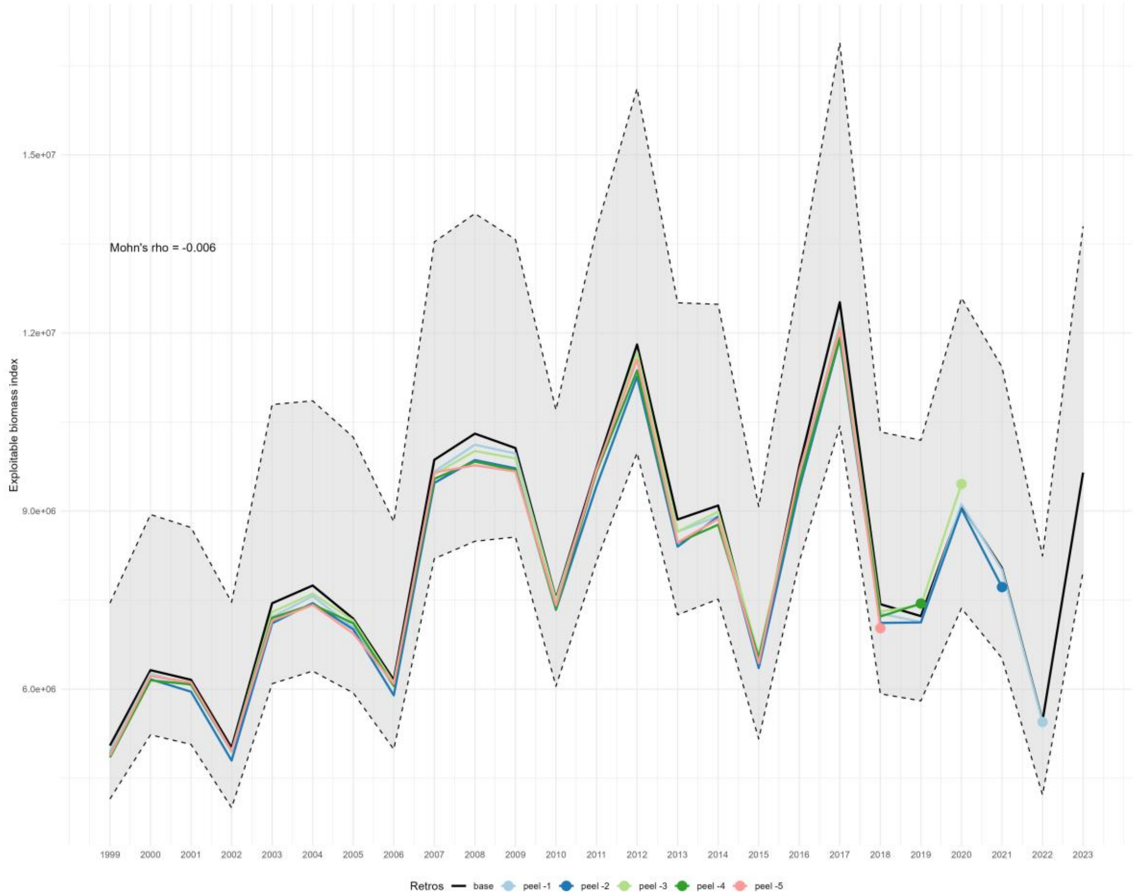


Figure 18: Retrospective analysis of the index with indication of calculated Mohn's rho.

Model predictions highlight a generally low biomass of turbot across the stock area, with high density/biomass areas located close to the coast north coast of western Europe in the Southern and Central North Sea (Figure 19).

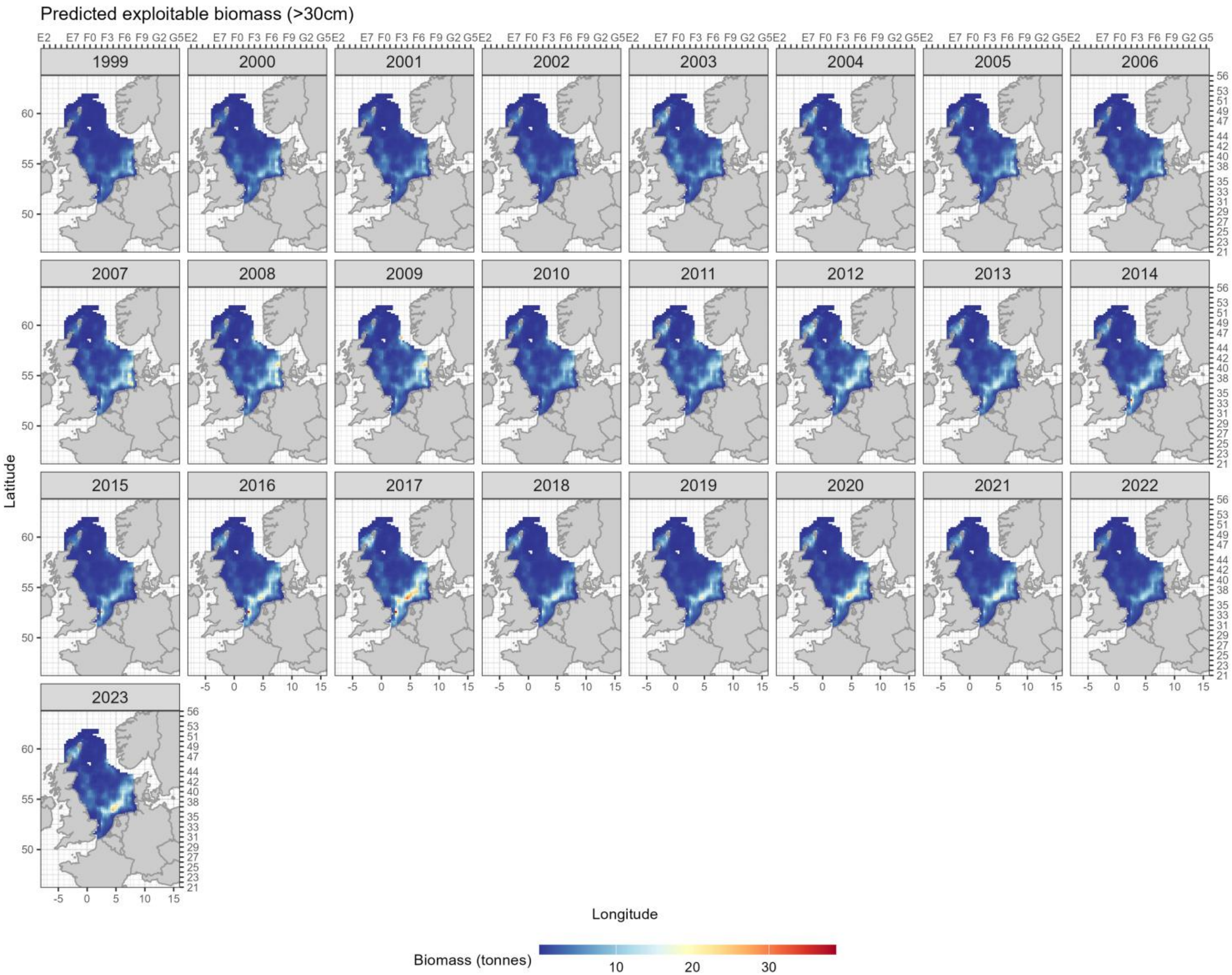
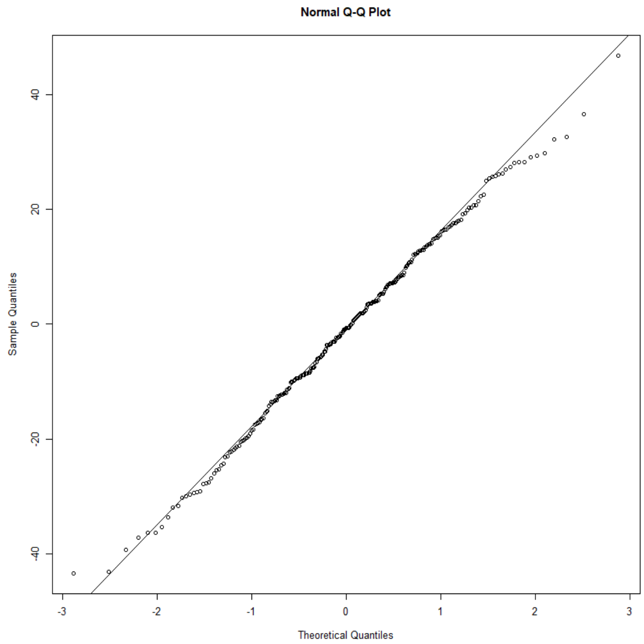


Figure 19: Predicted exploitable biomass (>30cm) for turbot in the North Sea for the model using data all scientific surveys (BTS,DYFS, FR-CGFS, NS-IBTS, and SNS).

3.3.2 Only industry survey (NL-BSAS)

The QQ plot shows little deviation from the assumed distribution, whilst 70.28% of the deviance is explained by the model.




```
Formula:
bio.adult ~ s(lon, lat, bs = c("ds"), k = 256, m = c(1, 0.5)) +
    ti(ctime, lon, lat, d = c(1, 2), bs = c("ds", "ds"), k = c(length(unique(data$Year)),
        40), m = list(c(1, 0), c(1, 0.5))) + as.character(Year) +
    s(Depth, bs = "ds", k = 5, m = c(1, 0)) + s(Ship, bs = "re") +
    offset(log(SweptArea))

Parametric coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            10.09594    0.08106 124.548  < 2e-16 ***
as.character(Year)2020  0.14763    0.11099   1.330    0.185
as.character(Year)2021 -0.17973    0.11550  -1.556    0.121
as.character(Year)2022 -0.56786    0.12332  -4.605 7.51e-06 ***
as.character(Year)2023 -0.21555    0.12247  -1.760    0.080 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                        edf Ref.df     F p-value
s(lon,lat)        61.952279    255 3.159   1.000
ti(ctime,lon,lat) 11.049331    156 0.177   0.927
s(Depth)           1.325056      4 0.557   0.570
s(Ship)            0.001322      2 0.000   0.608

R-sq.(adj) =  0.752   Deviance explained = 70.2%
-REML = 2613.1  Scale est. = 433.5     n = 271
```

Figure 20: QQplot (left) and summary of the model (right) for Quarter 1 (1.a)

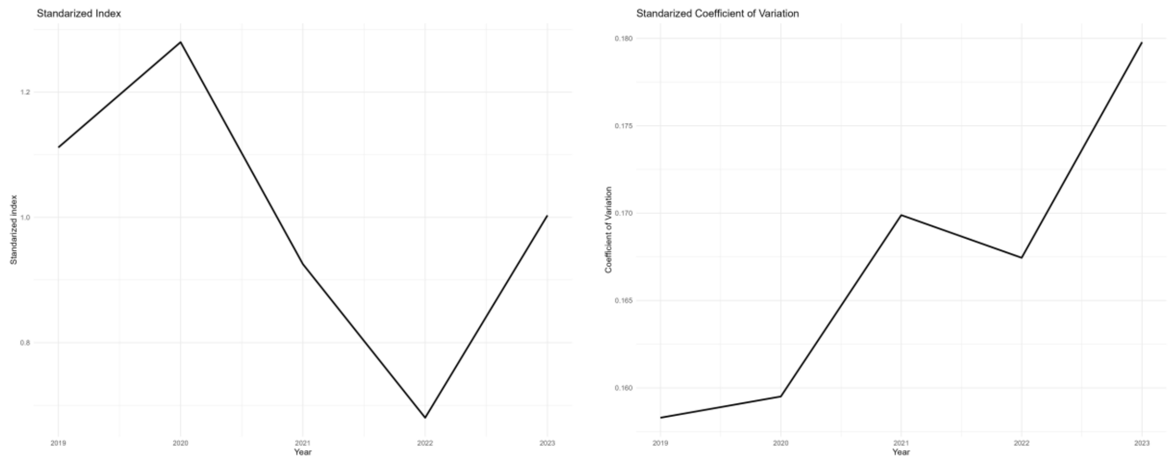


Figure 21: Standardized biomass exploitable index (left) and coefficient of variation (right) for the model using data from the industry survey (NL-BSAS) between 2019 and 2023.

Predictions for this model are limited to the central and southern North Sea,; as no sampling occurs in the northern North Sea and between years 2019 and 2023. Model predictions highlight a generally low biomass of turbot across the stock area, with high density/biomass areas located mostly off to the Dutch, German and Danish Coast (Figure 22).

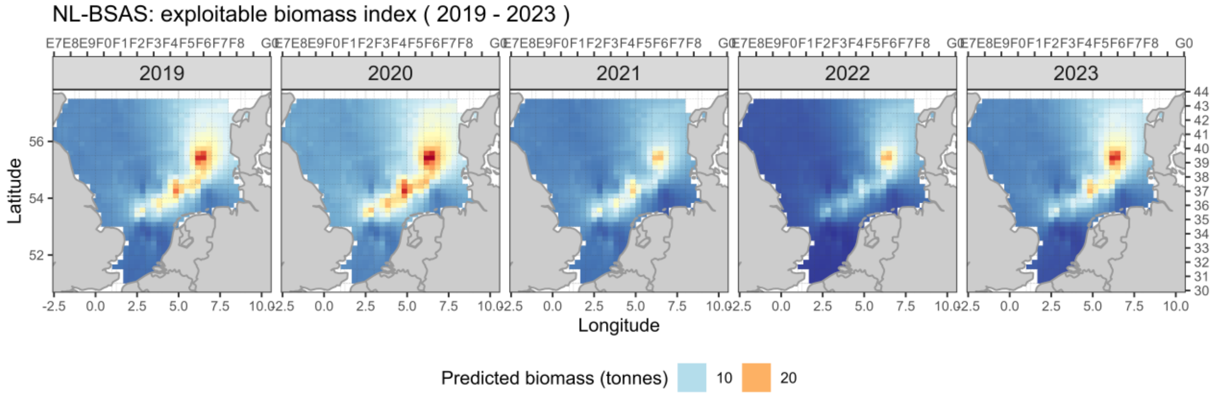


Figure 22: Predicted exploitable biomass (>30cm) for turbot in the North Sea.

3.4 Comparison of indices

No large trend differences are observed in the calculated exploitable biomass indices when including or excluding the data from the NL-BSAS. Furthermore, the inclusion of the NL-BSAS seems to slightly increase the certainty around the estimates. The index developed using only the NL-BSAS, shows a more optimistic vision of the exploitable biomass at the beginning of it's time series. This is likely to be caused by the index being heavily dominated by samples coming from specific ICES rectangles, while the other indices provide a broader

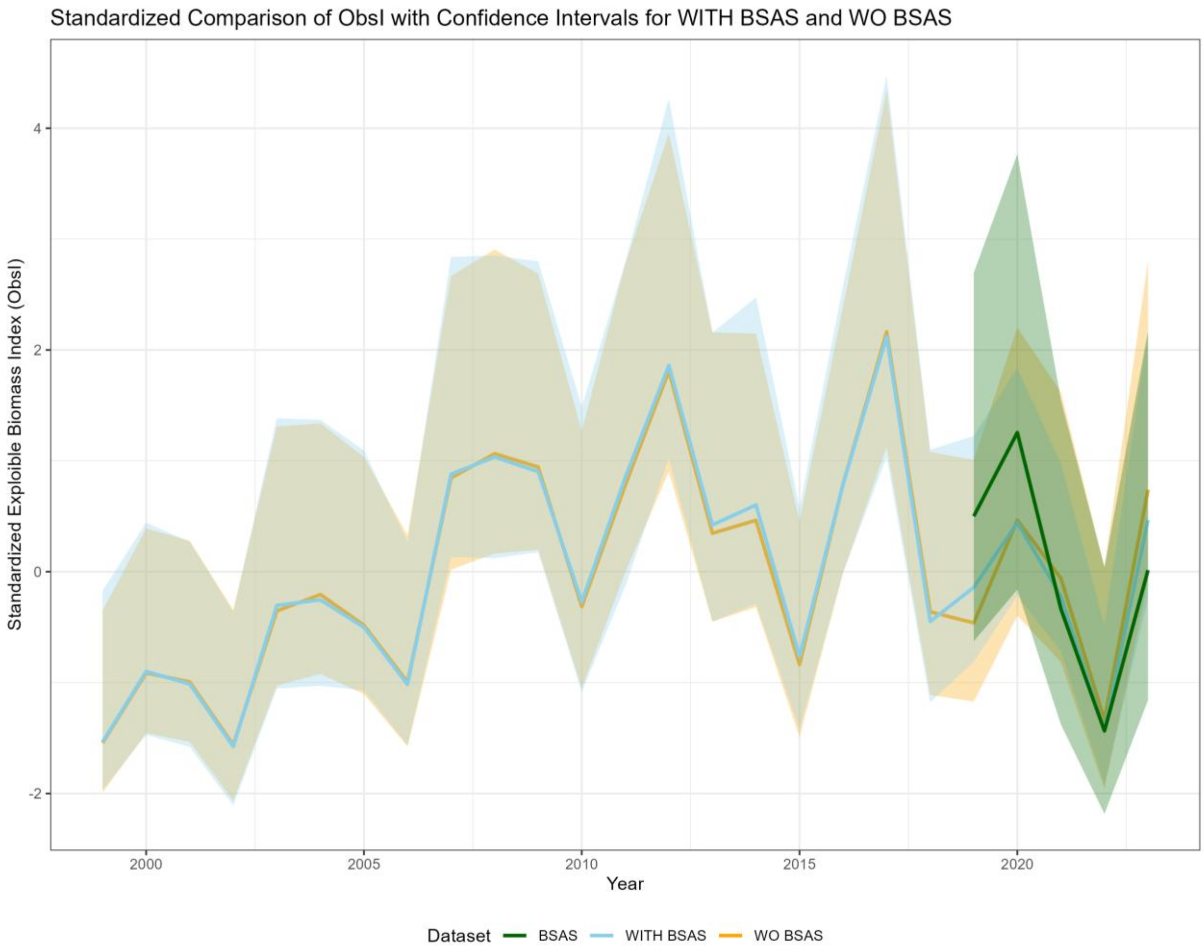


Figure 23: Comparison of the three standardized exploitable biomass indices (>30cm) for turbot in the North Sea.

3.5 Conclusions and decision

Conclusion	Outcome
Including the NL-BSAS into the combined model does no increase uncertainty, different trends in exploitable biomass or changes in the spatial distribution of the stock.	Do not see a reason on why excluding the NL-BSAS from the approach.
Deviation from assumed assumption (Tweedie)	Other distributions should be explored
Deviation mostly occurs in the upper and lower limits.	Explore effect of outliers?

WD 3.1 Whiting in Division 7.a Catch Data

Working document to WKBNSCS 2024

Sara Jane Moore, Hans Gerritsen – Marine Institute – Ireland – November 2024

Summary

WKBNSCS re-aggregated the international data from 2003 based on updated data. Following the data call, new or updated catch data was submitted to Intercatch by the UK (England, Wales, Scotland and the Isle of Man), Belgium, France and the Netherlands. National data has been submitted to Intercatch since 2015 but to date Intercatch has not been use to compile the international data. Recreational data was made available for the first time for Whiting 27.7a following the data call and 4 plausible recreational catch scenarios were proposed for sensitivity testing.

Catch Numbers at age

Catch numbers (both landings and discards) at age data were revised from 2003 to 2023 using updated information received in the data call. New or updated catch information was submitted to Intercatch by the UK (England, Wales, Scotland and the Isle of Man), Belgium, France and the Netherlands. There were no updates to data from Ireland and Northern Ireland as the data submitted previously was considered to be the best estimates from both countries. A summary overview of the fishery dependent data available and used by WKBNSCS for whiting 27.7.a is provided in Table 1.

For 2003-2015, the catch numbers were aggregated using already combined Ireland and Northern Ireland raised to the new or revised international catch data. This was partly due to incomplete data for Ireland and Northern Ireland in Intercatch for those years. Since 2016 there has been more complete national data submitted to Intercatch however raising the international data was continued using spreadsheets.

Catch Weights at age

Catch weights were also using updated with the new information supplied following the data call.

Sampling Levels

Sampling levels were also explored during WKBNSCS. Sampling of landings in recent years is sparse as landings have been low. Furthermore, discard sampling levels in recent years has also disimproved with low numbers of trips sampled and patchy coverage. In 2020, 2022 and 2023 discards were derived for Ireland as actual sampling data was insufficient to provide reliable estimates. Discard sampling needs to improve for this stock since discards account for the vast majority of the catch in weight and number.

Recreational Data

Recreational data was made available for the first time for Whiting 27.7a following the data call. Both retained and released catch estimates were provided. For released catch it is suggested by the WGRFS experts that a 35.1% mortality rate should be applied to released catches based on the upper limit of the boat-based mortality for cod (Capizzano *et al*. 2016).

Recreational catch data from the UK (England, Wales, Scotland, Isle of Man) was available for 2016-2023. For the years that data was provided, recreational catches accounted for on average 11% of the total international trawl catch.

Historic sampling and estimation of recreational catch for Ireland was preliminary and only available for 2022. Recreational catches from Ireland are considered negligible for this stock (4t in 2022).

A number of plausible scenarios to reconstruct the recreational catches will be explored in the benchmark to integrate recreational catches in the assessment model (Figure 3).

- **S1** – Recreational removals are proportional to the SSB with no limits on catches.
- **S2** – Removals are proportional to the SSB until 1995, then become constant.
- **S3** – Catches are proportional to the SSB, but recreational anglers have an upper limit on whiting catches (based on the average diarist who caught whiting in 7.a).
- **S4** – Recreational removals have been consistent over time (based on the average removals from 2016-2023).

Results

There was marginal difference in the catch estimates with the addition of new information for the data call (Figure 1). Only minor difference in the discard estimates from 2003 onwards are observable in Figure 1.

There are some notable differences between estimates of numbers-at-age for landings and discards. New discard samples were available for some of the older ages between 2003 and 2012 (Figure 2). New landing samples were available for ages 5 and 6 between 2003 and 2012 (Figure 2).

References

Connor W. Capizzano, John W. Mandelman, William S. Hoffman, Micah J. Dean, Douglas R. Zemeckis, Hugues P. Benoît, Jeff Kneebone, Emily Jones, Marc J. Stettner, Nicholas J. Buchan, Joseph A. Langan, James A. Sulikowski, Estimating and mitigating the discard mortality of Atlantic cod (Gadus morhua) in the Gulf of Maine recreational rod-and-reel fishery, ICES Journal of Marine Science, Volume 73, Issue 9, September/October 2016, Pages 2342–2355,

https://doi.org/10.1093/icesjms/fsw058

Table 1. Time series of fishery dependent data types by country available and used to construct the whiting 27.7.a assessment inputs. New or updated data shown in red.

	Northern Ireland				Ireland				
Year	Landings (t)	Discards (t)	LNAA	DNAA	Landings (t)	Discards (t)	LNAA	DNAA	Recreational
1980	yes but no info		Market	SS	yes but no info				
1981	yes but no info		Market	SS	yes but no info				
1982	yes but no info		Market	SS	yes but no info				
1983	yes but no info		Market	SS	yes but no info				
1984	yes but no info		Market	SS	yes but no info				
1985	yes but no info		Market	SS	yes but no info				
1986	yes but no info		Market	SS	yes but no info				
1987	yes but no info		Market	SS	yes but no info				
1988	Yes	Yes	Market	SS					
1989	Yes	Yes	Market	SS	Yes				
1990	Yes	Yes	Market	SS	Yes				
1991	Yes	Yes	Market	SS	Yes				
1992	Yes	Yes	Market	SS	Yes		Market		
1993	Yes	Yes	Market	SS	Yes		Market		
1994	Yes	Yes	Market	SS	Yes		Market		
1995	Yes	Yes	Market	SS	Yes		Market		
1996	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1997	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1998	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
1999	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
2000	Yes	Yes	Market	SS	Yes	Yes	Market	Used	
2001	Yes	Yes	Market	SS	Yes	Yes	Market	Not used	
2002	Yes	Yes	Market	SS	Yes	Yes	Market	Not used	
2003	Yes	Yes	Insufficent data	Insufficent data	Yes	Yes	Market	Obs	
2004	Yes	Yes	Insufficent data	Insufficent data		Yes	Market	Obs	
2005	Yes	Yes	Insufficent data	Insufficent data	Yes	Yes	Market	Obs	
2006	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2007	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2008	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2009	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2010	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2011	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2012	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2013	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2014	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2015	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2016	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2017	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2018	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2019	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2020	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	
2021	Yes	Yes	Market	Obs	Yes	Yes	Market	Obs	
2022	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	Yes
2023	Yes	Yes	Market	Obs	Yes	Yes	Market	Derived	

Table 1 continued. Time series of fishery dependent data types by country available and used to construct the whiting 27.7.a assessment inputs. New or updated data shown in red.

Year	England, Wales, Scotland, Isle of Man					Belgium			
	Landings (t)	Discards (t)	LNAA	DNAA	Recreational	Landings (t)	Discards (t)	LNAA	DNAA
1980	yes but no info					yes but no info			
1981	yes but no info					yes but no info			
1982	yes but no info					yes but no info			
1983	yes but no info					yes but no info			
1984	yes but no info					yes but no info			
1985	yes but no info					yes but no info			
1986	yes but no info					yes but no info			
1987	yes but no info					yes but no info			
1988	Yes					Yes			
1989	Yes					Yes			
1990	Yes					Yes			
1991	Yes					Yes			
1992	Yes					Yes			
1993	Yes					Yes			
1994	Yes					Yes			
1995	Yes					Yes			
1996	Yes		Provided but not used			Yes			
1997	Yes		Provided but not used			Yes			
1998	Yes		Used			Yes			
1999	Yes		Used			Yes			
2000	Yes		Used			Yes			
2001	Yes		Used	Provided but not used		Yes			
2002	Yes		Used	Provided but not used		Yes			
2003	Yes	Yes	Used	Used		Yes	Yes		
2004	Yes	Yes	Used	Used		Yes	Yes		Used
2005	Yes	Yes	Used	Used		Yes	Yes		Used
2006	Yes	Yes				Yes	Yes		Used
2007	Yes	Yes		Used		Yes	Yes		Used
2008	Yes	Yes		Used		Yes	Yes		Used
2009	Yes	Yes		Used		Yes			
2010	Yes	Yes		Used		Yes	Yes		
2011	Yes	Yes		Used		Yes	Yes		Used
2012	Yes	Yes				Yes	Yes		Used
2013	Yes	Yes				Yes	Yes		
2014	Yes	Yes		Used		Yes	Yes		
2015	Yes	Yes		Used		Yes	Yes		
2016	Yes	Yes		Used	Yes	Yes	Yes		
2017	Yes	Yes		Used	Yes	Yes	Yes		
2018	Yes	Yes		Used	Yes	Yes	Yes		
2019	Yes	Yes		Used	Yes	Yes	Yes		
2020	Yes	Yes		Used	Yes	Yes	Yes		
2021	Yes	Yes		Used	Yes	Yes	Yes		
2022	Yes	Yes	Used	Used	Yes	Yes	Yes		
2023	Yes	Yes		Used	Yes	Yes	Yes		

Table 1 continued. Time series of fishery dependent data types by country available and used to construct the whiting 27.7.a assessment inputs. New or updated data shown in red.

	France		Netherlands		WKIRISH2	WKBNSCS
Year	Landings (t)	Discards (t)	Landings (t)	Discards (t)	Data compilation	Data compilation
1980	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1981	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1982	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1983	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1984	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1985	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1986	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1987	yes but no info		yes but no info		Taken from WGNSDS 2003	Taken from WGCSE 2024
1988	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1989	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1990	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1991	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1992	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1993	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1994	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1995	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
1996	Yes		Yes		Taken from WGNSDS 2003	Taken from WGCSE 2024
1997	Yes		Yes		Taken from WGNSDS 2003	Taken from WGCSE 2024
1998	Yes		Yes		Taken from WGNSDS 2003	Taken from WGCSE 2024
1999	Yes		Yes		Taken from WGNSDS 2003	Taken from WGCSE 2024
2000	Yes		Yes		Taken from WGNSDS 2003	Taken from WGCSE 2024
2001	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
2002	Yes				Taken from WGNSDS 2003	Taken from WGCSE 2024
2003	Yes	Yes			Re-aggregrated	Re-aggregrated
2004	Yes	Yes			Re-aggregrated	Re-aggregrated
2005	Yes	Yes	Yes		Re-aggregrated	Re-aggregrated
2006	Yes	Yes			Re-aggregrated	Re-aggregrated
2007	Yes	Yes			Re-aggregrated	Re-aggregrated
2008	Yes	Yes	Yes	Yes	Re-aggregrated	Re-aggregrated
2009	Yes	Yes			Re-aggregrated	Re-aggregrated
2010	Yes	Yes			Re-aggregrated	Re-aggregrated
2011	Yes	Yes			Re-aggregrated	Re-aggregrated
2012	Yes	Yes			Re-aggregrated	Re-aggregrated
2013	Yes	Yes			Re-aggregrated	Re-aggregrated
2014	Yes	Yes			Re-aggregrated	Re-aggregrated
2015	Yes	Yes			Re-aggregrated	Re-aggregrated
2016	Yes	Yes	Yes	Yes		Re-aggregrated
2017	Yes	Yes				Re-aggregrated
2018	Yes	Yes				Re-aggregrated
2019	Yes					Re-aggregrated
2020	Yes	Yes				Re-aggregrated
2021	Yes					Re-aggregrated
2022	Yes	Yes				Re-aggregrated
2023	Yes	Yes				Re-aggregrated

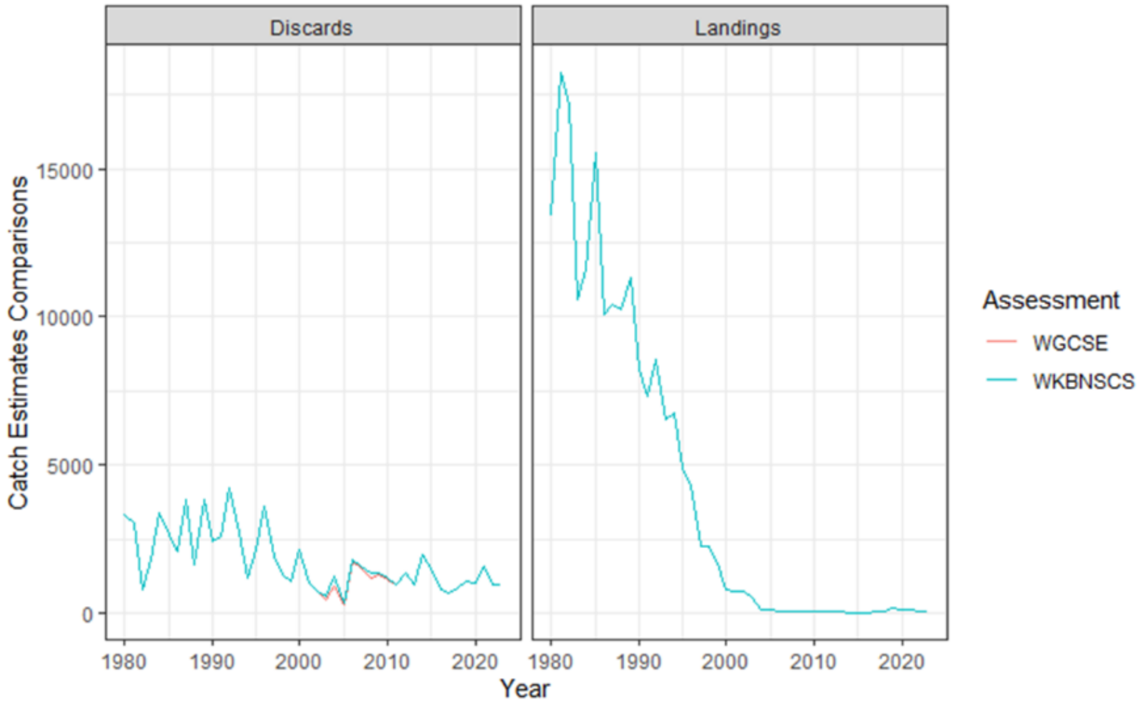


Figure 1. Comparison between discards and landings estimates for WGCSE and WKBNSCS.

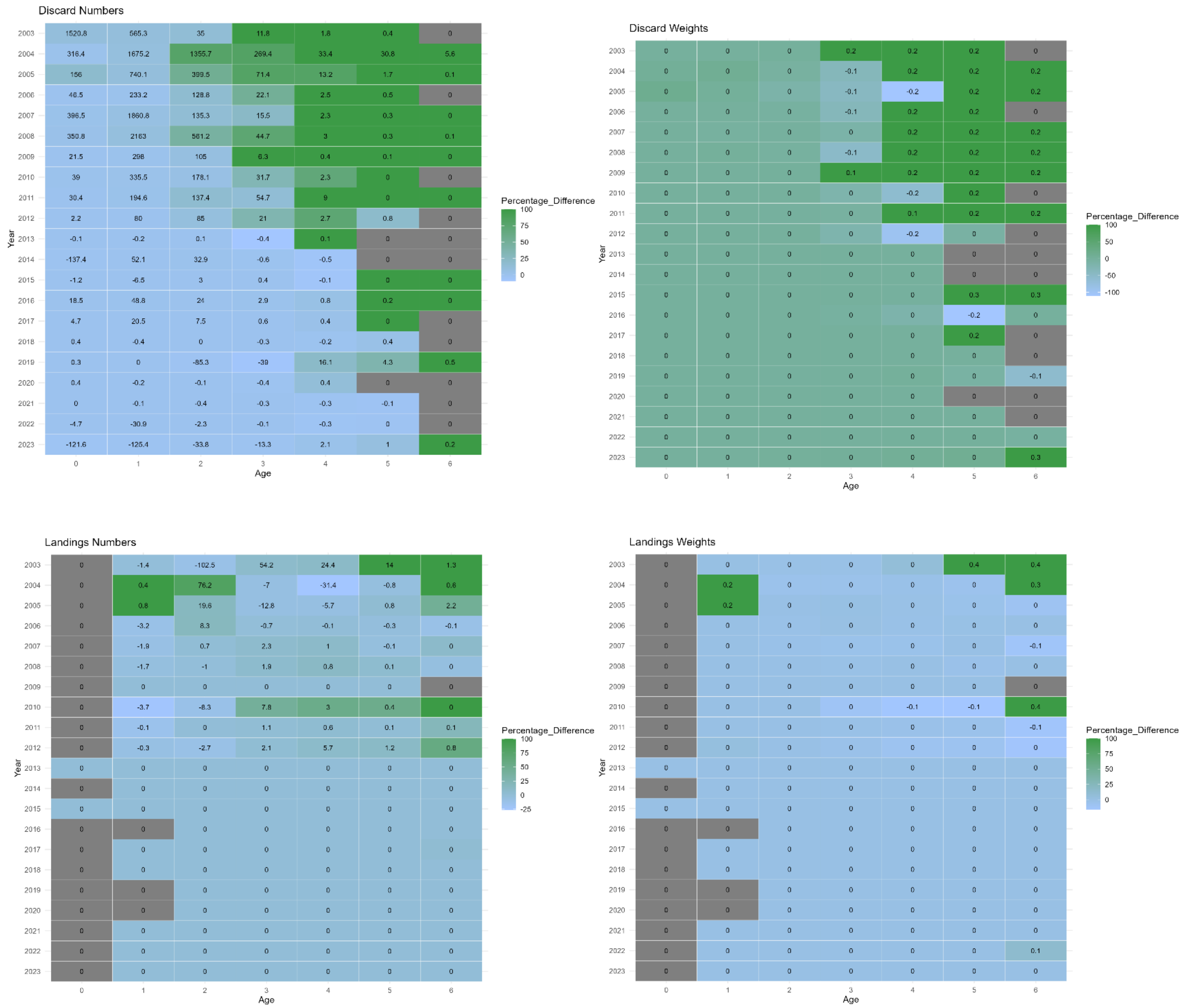


Figure 2. Percentage Difference between estimates of discard numbers (top left), discard weights (top right), landings numbers (bottom left) and landings weights (bottom right) as estimated in WGCSE and WKBNSCS

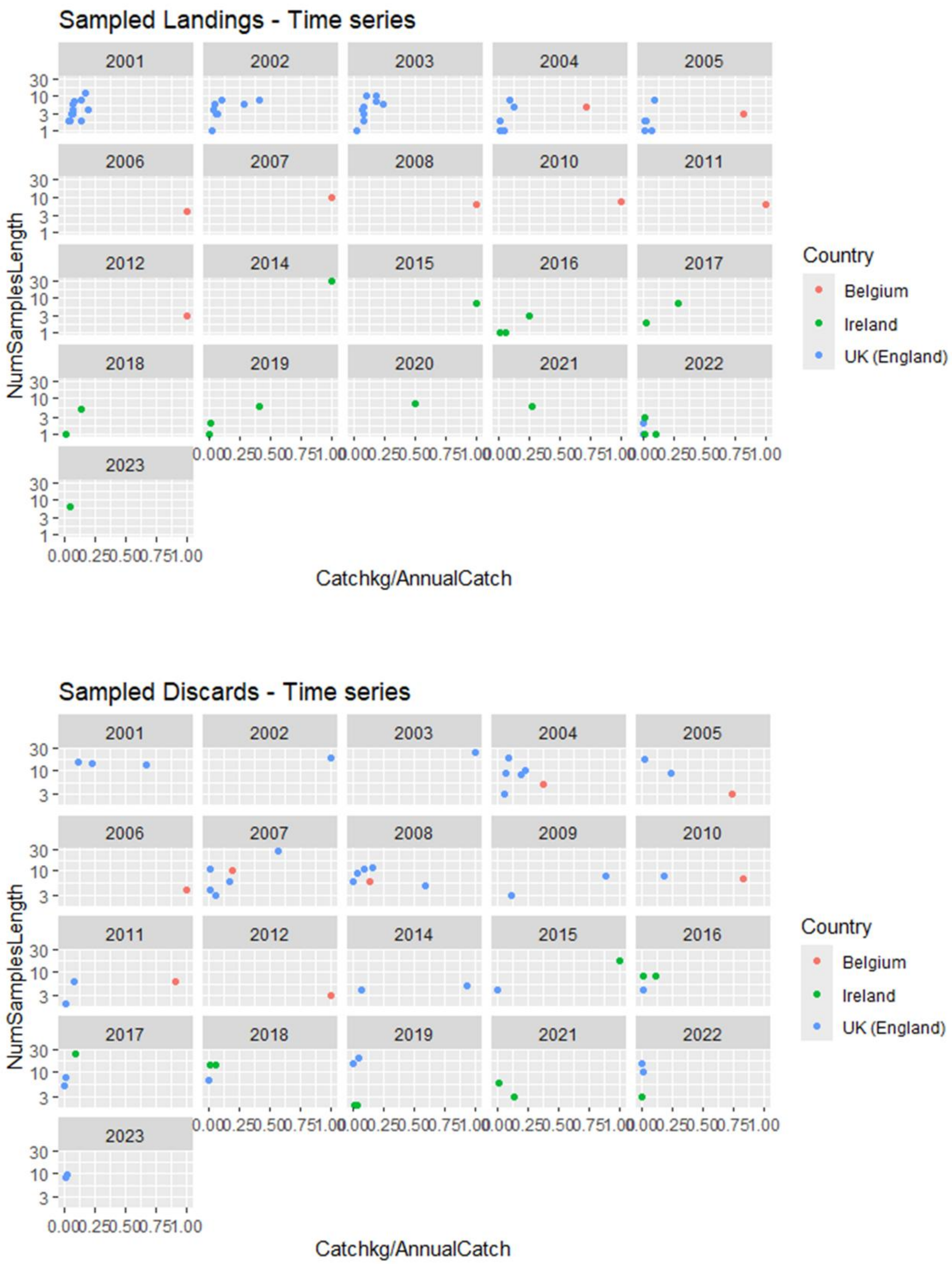


Figure 3. Sampling Levels as available to WKBNSCS for landings (top) and discards (bottom) from Intercatch.

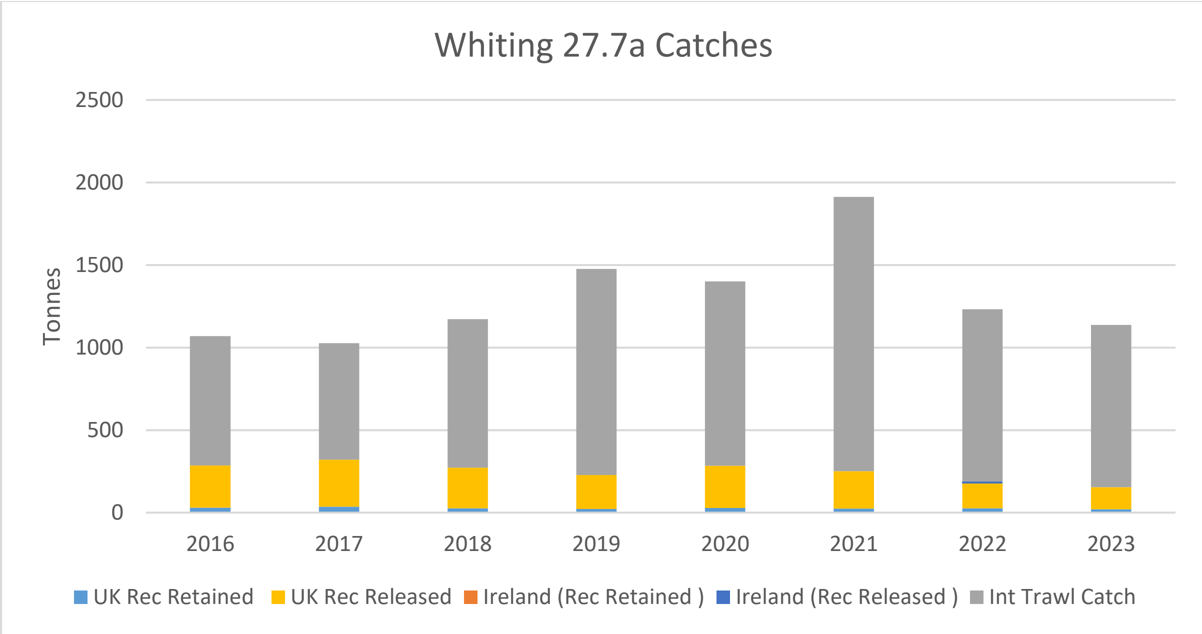


Figure 4. Recreational catches provided to WKBNSCS

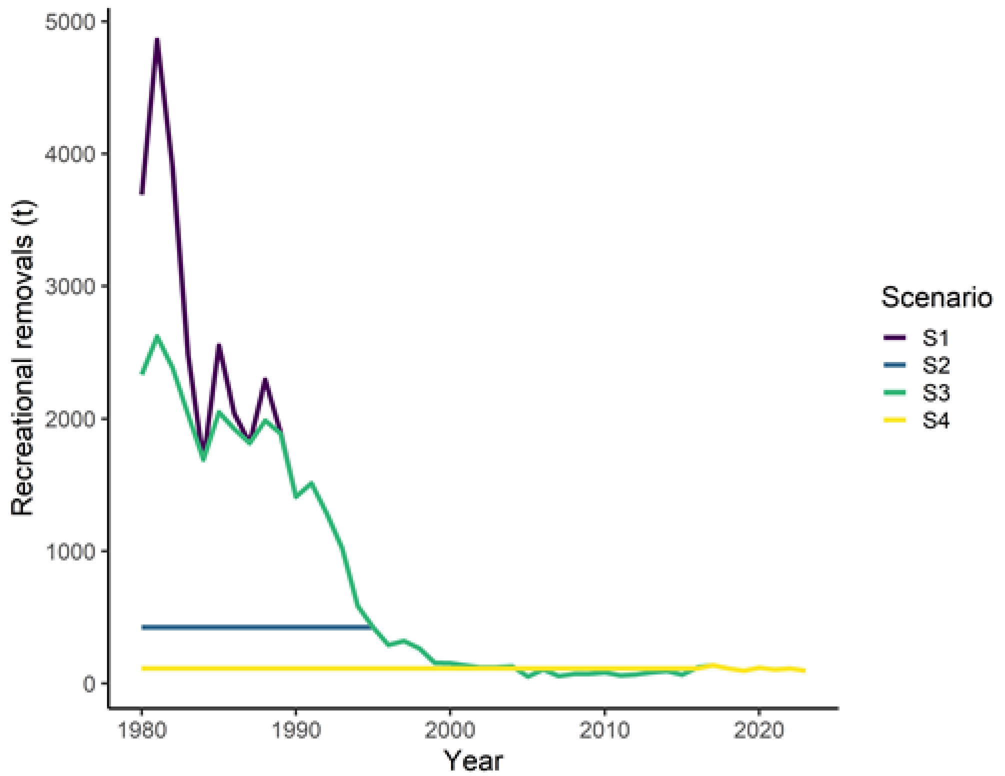


Figure 5. Recreational catch scenarios to be explored during to WKBNSCS

Irish Sea whiting – life history parameters

Working document to WKBNSCS 2024-25

Hans Gerritsen, Sara Jane Moore – Marine Institute – Ireland – November 2024

Summary of decisions

Stock weights: Weights-at-age from the Q1 NIBTS survey will be used for the period that they are available (1992 onwards). For earlier years the catch weights will be used, set back to 1 January. A running average smoother will be applied to reduce noise while still accounting for the trends over time that are observed.

Maturity: The Q1 NIBTS has good sampling for maturity, probably sufficient to support time-varying maturity for the period of the survey. Female maturity will be used. A running average smoother will be applied to reduce noise while still accounting for the trends over time that are observed. Estimates from the start of the survey time-series will be used to extrapolate to the start of the assessment time series (close to zero for age 1 and close to 1 for age 2 and 1 for age 3+).

Natural mortality: Various empirical methods were explored. Most of these resulted in estimates of at least 0.6 for mature fish and considerably higher for juveniles. It is likely that small individuals will be more susceptible to predation and various size-based methods resulted in similar estimates, therefore there is no reason to deviate from the current Lorenzen method. The method was updated with recent estimates of size-at-age from survey data resulting in higher estimates of M. Time-varying M (based on time-varying stock weights) will be explored as a sensitivity run but because this does not account for other changes in the ecosystem, this is not considered a realistic option.

Stock weights

The current stock weights are based on the catch weights, set back to the start of the year (by averaging the catch weight at age *a* in year *y* with the weight at age *a*-1 in year *y-1* under the assumption that the average catch takes place in the middle of the year). The weights are smoothed using a weighted running average with a 3-year window and giving a weight of ½ to the current year and ¼ to each of the years before and after.

WKBNSCS considered that the survey data are is more appropriate to estimate stock weights than the catch because the survey has good spatial coverage of the stock. However, the survey does not cover the full time-series, so catch weights will be used to estimate stock weights at the start of the time-series.

Figure 1 shows the stock weights estimated from the catch and estimated by the NI groundfish surveys in Q1 and Q4. There is reasonably good agreement between the catch and Q1 survey and the trends between the Q1 and Q4 surveys are in good agreement. WKBNSCS investigated making use of the Q4 survey data by offsetting it to the start of the year it was considered this this may lead to unnecessary bias as there were consistent differences between the Q1 and Q4 estimated survey weights-at-age when set back to the start of the year.

The existing 3-year running mean smoother will be applied to both the new stock weights for the period where the catch data are used and for the more recent period for ages 1, 2 and 3. For ages 5 and 6 a 5-year window will apply because data are sparser and therefore noisier. The weights will be 1/9, 2/9, 3/9, 2/9 and 1/9 respectively for years y-2 to y+2. For age 6+ a 7-year window will be applied with weights of 1/16, 2/16, 3/16, 4/16, 3/16, 2/16 and 1/16 respectively for years y-3 to y+3.

The proposed new stock weights are shown in Figure 2 and Table 1.

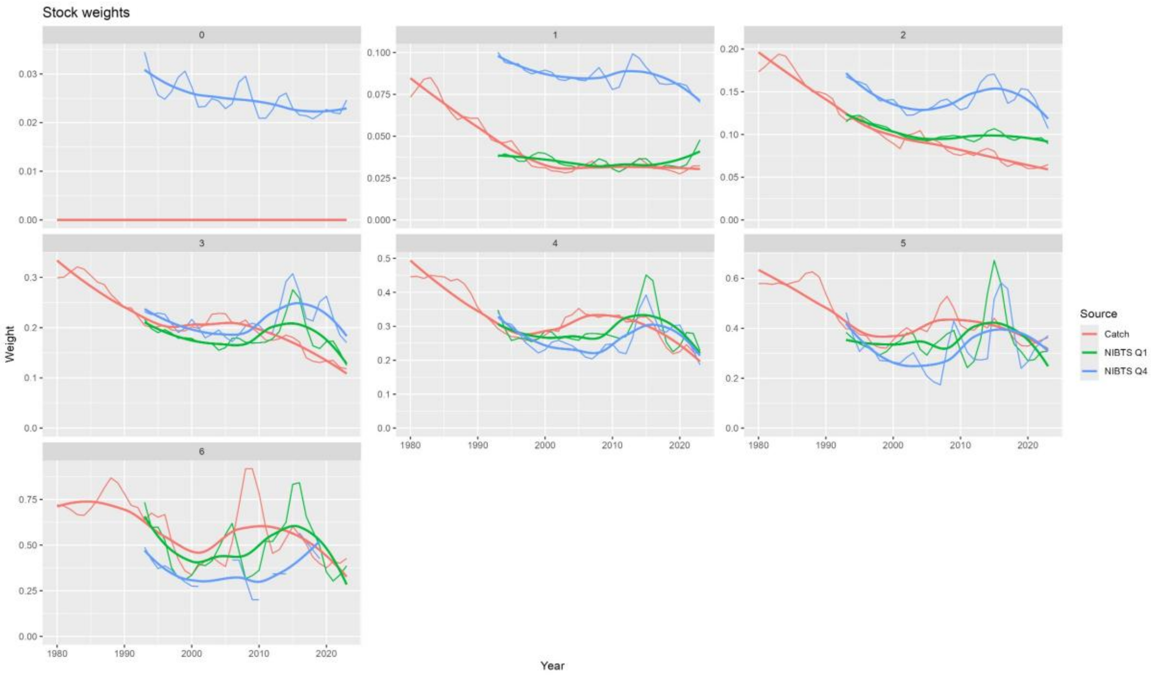


Figure 1. Stock weights estimated from the catch (corrected for the start of the year) and estimated by the NI groundfish surveys in Q1 and Q4.

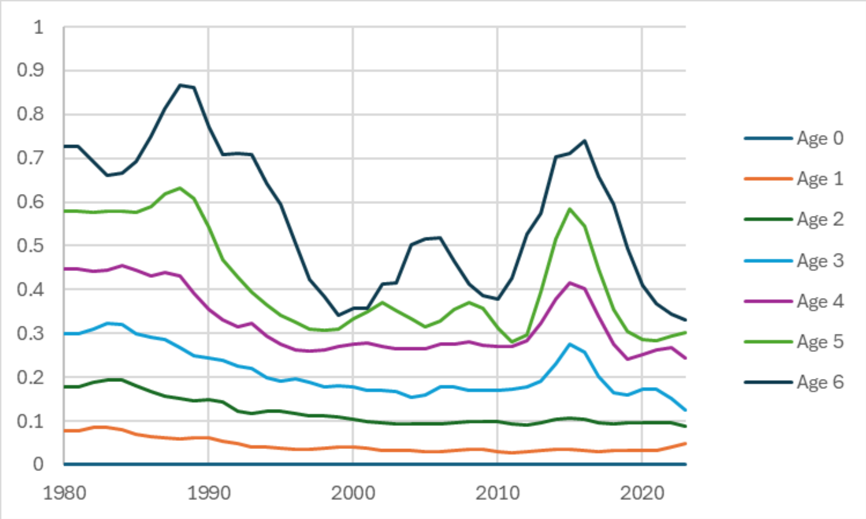


Figure 2. Proposed stock weights-at-age.

Table 1. Proposed stock weights-at-age. Note that the estimates for the first year (1980) are set to be the same values as 1981 because the stock weights are calculated as the average of the catch weight-at-age in the current year and the weight-at-age of the same cohort in the previous year, which for 1979 are not available.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1980	0	0.078	0.179	0.300	0.447	0.580	0.726
1981	0	0.078	0.179	0.300	0.447	0.580	0.726
1982	0	0.085	0.188	0.309	0.443	0.577	0.692
1983	0	0.086	0.194	0.324	0.445	0.578	0.661
1984	0	0.079	0.193	0.320	0.454	0.580	0.666
1985	0	0.070	0.182	0.300	0.444	0.577	0.693
1986	0	0.063	0.167	0.291	0.431	0.590	0.750
1987	0	0.061	0.158	0.287	0.439	0.619	0.815
1988	0	0.060	0.150	0.268	0.433	0.632	0.867
1989	0	0.062	0.147	0.249	0.393	0.608	0.861
1990	0	0.061	0.150	0.243	0.354	0.542	0.771
1991	0	0.055	0.142	0.238	0.332	0.469	0.710
1992	0	0.048	0.123	0.225	0.314	0.429	0.712
1993	0	0.040	0.117	0.221	0.322	0.394	0.707
1994	0	0.039	0.122	0.198	0.295	0.365	0.641
1995	0	0.038	0.122	0.190	0.275	0.342	0.594
1996	0	0.035	0.118	0.196	0.262	0.325	0.506
1997	0	0.035	0.113	0.189	0.261	0.310	0.422
1998	0	0.038	0.111	0.179	0.262	0.308	0.384
1999	0	0.040	0.109	0.180	0.269	0.310	0.340
2000	0	0.040	0.103	0.178	0.275	0.335	0.357
2001	0	0.038	0.100	0.171	0.278	0.350	0.357
2002	0	0.034	0.096	0.171	0.270	0.370	0.414
2003	0	0.033	0.094	0.168	0.265	0.352	0.416

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
2004	0	0.032	0.094	0.155	0.264	0.334	0.503
2005	0	0.031	0.093	0.160	0.265	0.314	0.515
2006	0	0.031	0.095	0.179	0.274	0.329	0.520
2007	0	0.034	0.097	0.179	0.275	0.354	0.466
2008	0	0.036	0.098	0.171	0.280	0.370	0.413
2009	0	0.035	0.099	0.169	0.273	0.357	0.388
2010	0	0.030	0.098	0.170	0.271	0.313	0.378
2011	0	0.029	0.094	0.171	0.270	0.279	0.426
2012	0	0.031	0.092	0.178	0.283	0.298	0.527
2013	0	0.034	0.095	0.192	0.324	0.394	0.572
2014	0	0.036	0.104	0.231	0.379	0.516	0.703
2015	0	0.037	0.107	0.275	0.416	0.584	0.712
2016	0	0.033	0.103	0.258	0.402	0.545	0.740
2017	0	0.031	0.096	0.201	0.339	0.446	0.658
2018	0	0.033	0.093	0.164	0.277	0.354	0.594
2019	0	0.032	0.096	0.158	0.242	0.305	0.495
2020	0	0.031	0.096	0.172	0.253	0.286	0.409
2021	0	0.033	0.095	0.173	0.261	0.284	0.369
2022	0	0.040	0.096	0.151	0.268	0.295	0.343
2023	0	0.048	0.089	0.125	0.244	0.302	0.331

Maturity

The Q1 NIBTS has good sampling for maturity. Assignment of maturity stages is based on macroscopic observations which is considered sufficiently accurate to distinguish fish that are likely to spawn in the current season from virgin fish that will not. The previous benchmark (WKIrish3, 2017) decided to use time-invariant maturity. However, in order to account for the trend over time, WKBNSCS decided to use time-varying maturity estimates.

As before, the female maturity ogive will be used as SSB is intended to approximate reproductive potential, which is more likely limited by female than male maturity. The proportion mature at ages 3+ will be set to 1, as any observations of immature fish are more likely to be errors than

A running average smoother will be applied to reduce noise while still accounting for the trends over time that are observed. Estimates from the start of the survey time-series (average from the first three years of survey data) will be used to extrapolate to the start of the assessment time series (close to zero for age 1 and close to 1 for age 2 and 1 for age 3+). The lower proportions mature at age 1 at the start of the time series are supported by historical literature (as cited in the discussion of Gerritsen et al 2003).

Figure 3 and Table 2 give the proposed maturity-at-age input.

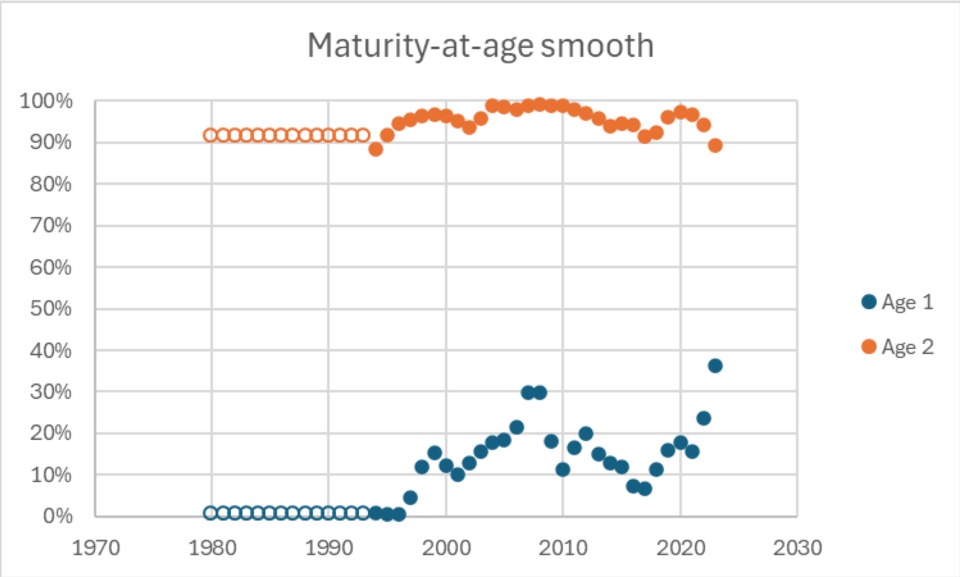


Figure 3. Proportion mature at ages 1 and 2 over time. Ago 0 are 100% immature and ages 3+ are considered 100% mature. Solid points are observed values; open circles are extrapolated from the three earliest observed values.

Table 2. Proportion mature-at-age over time.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1980	0	0.007	0.916	1	1	1	1
1981	0	0.007	0.916	1	1	1	1
1982	0	0.007	0.916	1	1	1	1
1983	0	0.007	0.916	1	1	1	1
1984	0	0.007	0.916	1	1	1	1
1985	0	0.007	0.916	1	1	1	1
1986	0	0.007	0.916	1	1	1	1
1987	0	0.007	0.916	1	1	1	1
1988	0	0.007	0.916	1	1	1	1
1989	0	0.007	0.916	1	1	1	1
1990	0	0.007	0.916	1	1	1	1
1991	0	0.007	0.916	1	1	1	1
1992	0	0.007	0.916	1	1	1	1
1993	0	0.007	0.916	1	1	1	1
1994	0	0.010	0.884	1	1	1	1
1995	0	0.006	0.917	1	1	1	1
1996	0	0.004	0.946	1	1	1	1
1997	0	0.044	0.954	1	1	1	1
1998	0	0.121	0.964	1	1	1	1
1999	0	0.153	0.967	1	1	1	1
2000	0	0.122	0.962	1	1	1	1
2001	0	0.102	0.953	1	1	1	1

2002	0	0.128	0.936	1	1	1	1
2003	0	0.156	0.958	1	1	1	1
2004	0	0.177	0.988	1	1	1	1
2005	0	0.184	0.984	1	1	1	1
2006	0	0.216	0.980	1	1	1	1
2007	0	0.298	0.987	1	1	1	1
2008	0	0.299	0.992	1	1	1	1
2009	0	0.182	0.989	1	1	1	1
2010	0	0.113	0.989	1	1	1	1
2011	0	0.166	0.980	1	1	1	1
2012	0	0.199	0.970	1	1	1	1
2013	0	0.151	0.956	1	1	1	1
2014	0	0.128	0.938	1	1	1	1
2015	0	0.121	0.944	1	1	1	1
2016	0	0.075	0.942	1	1	1	1
2017	0	0.068	0.916	1	1	1	1
2018	0	0.113	0.925	1	1	1	1
2019	0	0.160	0.960	1	1	1	1
2020	0	0.177	0.972	1	1	1	1
2021	0	0.158	0.968	1	1	1	1
2022	0	0.238	0.942	1	1	1	1
2023	0	0.364	0.894	1	1	1	1

Natural mortality

Various empirical methods were explored. Many of these methods are based on growth parameters or population size-at-age. Therefore, the first step was to get an accurate estimate of Von Bertananffy (VB) growth parameters from the survey data. In order to obtain size-at-age data, an ALK was constructed for each survey (i.e for each year and quarter) and applied to the aggregated catch length frequency distribution for each survey. Gaps in the ALK were initially filled in using ALKs for all years combined, but separate for the two quarters and the few remaining gaps after that were filled in using a multinomial model fitted.

Figure 4 shows the fit of the VB curve to the catch numbers at length and age. Fish aged zero in Q4 and age 1 in Q1 appear to fit well on the curve, which suggest that there is no strong bias in the length distribution of the smallest fish due to size selectivity of the survey gear. Therefore, all ages classes were included in the fit. The figure also shows the growth of whiting in the Irish sea is a bit slower and has a lower L infinity than growth curves for other stocks obtained from fishbase.

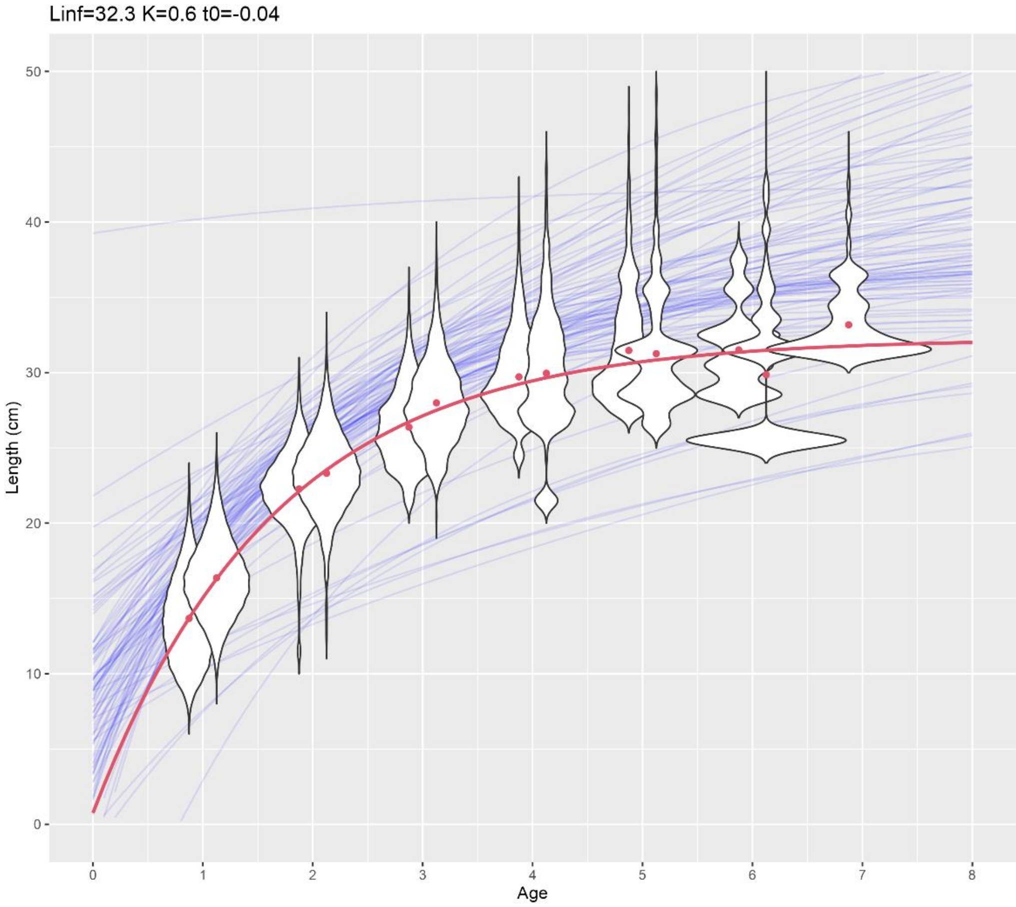


Figure 4. Growth curve for whiting in the Irish Sea based on catch numbers at age and

The growth parameters estimated from the survey data are given in Table 3. The same dataset was used to estimate length-weight parameters; the oldest observed age; and the age at 50% maturity (Table 3). A value for GSI was obtained from Yildiz et al (2022) and a value for the mean temperature from Young and Holt (2007). These life-history parameters were used to explore a range of empirical methods of estimating natural mortality (most of them based on the fishmethods R package):

Based on growth parameters

- Jensen (1996,1997) – requires Kl
- Pauly (1980) length equation - requires Linf, Kl, and TC;
- Then et al. (2015) growth - requires Kl and Linf.

Taxonomy and LH parameters

- Thorsen (2017,2023) – based on taxonomic hierarchy and correlations between parameters (FishLife package)

Based on oldest observed age

- Alverson and Carney (1975) - requires Kl and tmax;
- Hoenig (1983) joint equation - requires tmax;
- Then et al. (2015) tmax - requires tmax;

Based on reproductive parameters

- Gunderson and Dygert (1988) - requires GSI;
- Rikhhter (1976) – requires tm
- Roff (1984) - requires Kl and tm;

Based on size at age

- Charnov et al (2013) - requires Linf, Kl, and L.
- Chen(1989) – requires Kl
- Gislason et al. (2010) - requires Linf, K and Bl;
- Lorenzen (1996) - requires Wwet;

Table 3. Life-history parameters used as inputs for various methods of estimating M.

	Parameter	**Value**
a	Coefficient of the length-weight relationship	0.0041
b	Exponent of the length-weight relationship	3.2
Linf	Length-infinity value from a von B growth curve (length)	32.3
Winf	Weight-infinity value from a von B growth curve (wet weight)	a * Linf^b
Kl	Growth coefficient from a von B growth curve for length.	0.6
TC	Mean water temperature (Celsius) experienced by the stock.	9
tmax	Oldest age observed for the species.	8
tm	Age at maturity.	1.5
GSI	Gonadosomatic index	0.05
L	Length at age	Linf * (1 - exp(-Kl * (t - t0)))
Wwet	Wet weight at age	a*L^b

The resulting estimates of M are shown in Figure 5. Most of the estimates are at least 0.6 for mature fish and considerably higher for juveniles. It is likely that small individuals will be more susceptible to predation, therefore a size-based method seems sensible. Because the various size-based methods resulted in similar estimates, there is no reason to deviate from the current Lorenzen method. The method was updated with recent estimates of size-at-age from survey data resulting in higher estimates of M (Table 4). Time-varying M (based on time-varying stock weights) will be explored as a sensitivity run but because this does not account for other changes in the ecosystem, this is not considered a realistic option for a production model.

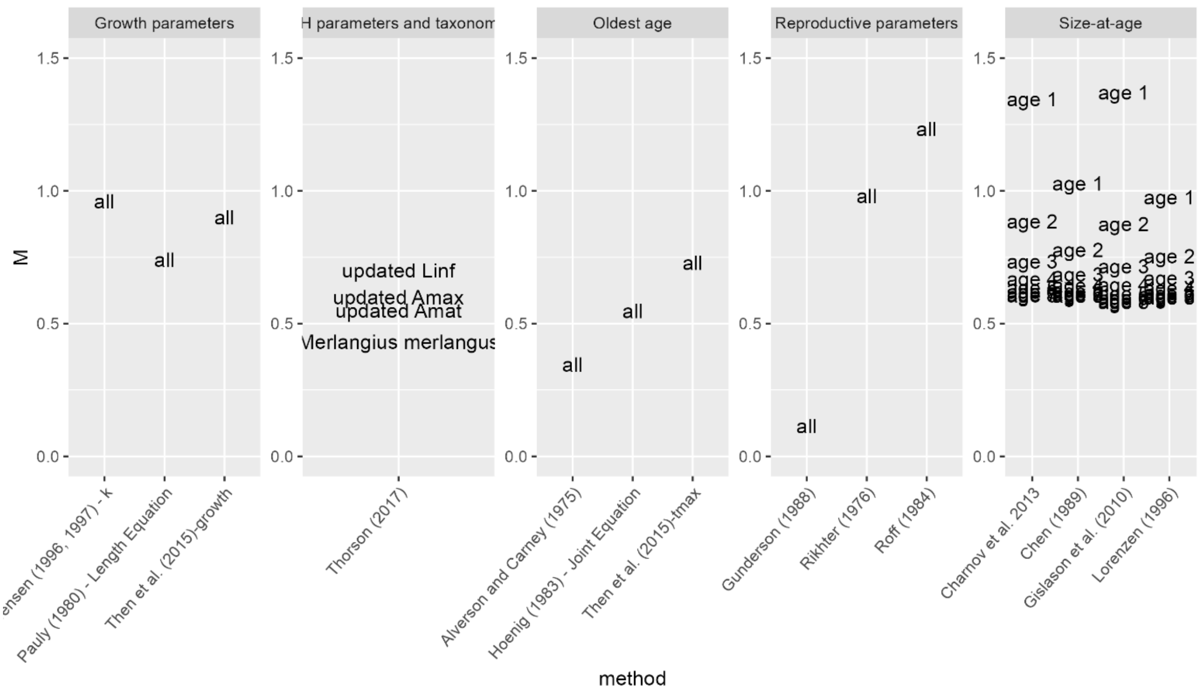


Figure 5. Estimates of natural mortality using a range of methods. 'All' means the estimate applies to all age classes, otherwise the age class is given in the label. For Thorson the estimate is based on the taxonomy and correlations between life history parameters. The Gunderson method is based only on GSI and is by far the lowest.

Table 4a. Updated M estimates using the Lorenzen method on growth parameters from the NI IGFS survey.

Age	***0***	***1***	***2***	***3***	***4***	***5***	***6***
Current	*1.08*	*0.80*	*0.72*	*0.61*	*0.55*	*0.52*	*0.52*
Updated	*2.20*	*0.98*	*0.75*	*0.67*	*0.63*	*0.62*	*0.61*

Table 4b. Time-varying M based on the Lorenzen method applied to the stock weights. To be used for sensitivity analysis only.

Year	**Age 0**	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 6**
1980	2.2	0.870906	0.679747	0.580824	0.517741	0.480133	0.45098
1981	2.2	0.853884	0.672684	0.58021	0.517474	0.480133	0.452068
1982	2.2	0.837392	0.664707	0.574389	0.519493	0.480972	0.455686
1983	2.2	0.834543	0.658013	0.569178	0.516412	0.479705	0.461116
1984	2.2	0.852324	0.660178	0.571601	0.517307	0.481381	0.461916
1985	2.2	0.88363	0.67161	0.578277	0.517909	0.47942	0.454746
1986	2.2	0.904392	0.685268	0.585665	0.521893	0.47782	0.44602
1987	2.2	0.923488	0.699106	0.588598	0.520208	0.470992	0.435635
1988	2.2	0.915207	0.70861	0.600705	0.524983	0.469535	0.427365
1989	2.2	0.919524	0.709018	0.609361	0.535661	0.474058	0.431271
1990	2.2	0.919088	0.712326	0.6189	0.552911	0.490651	0.44048
1991	2.2	0.948504	0.720322	0.619421	0.563779	0.507757	0.451396
1992	2.2	0.983838	0.749763	0.633118	0.572384	0.52385	0.453685

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1993	2.2	0.994109	0.761174	0.648099	0.584509	0.534924	0.467482
1994	2.2	0.994728	0.75931	0.652078	0.592146	0.535778	0.459398
1995	2.2	0.98801	0.754199	0.650399	0.598577	0.544169	0.464045
1996	2.2	1.022411	0.766502	0.647644	0.599863	0.546233	0.460917
1997	2.2	1.062912	0.784625	0.656845	0.606143	0.562465	0.495076
1998	2.2	1.10372	0.794103	0.658013	0.60493	0.568312	0.525876
1999	2.2	1.112768	0.809463	0.658306	0.602669	0.569076	0.551218
2000	2.2	1.113794	0.822235	0.650864	0.595604	0.553721	0.561404
2001	2.2	1.134131	0.838833	0.653492	0.586772	0.541688	0.540264
2002	2.2	1.137498	0.798226	0.64728	0.589193	0.533425	0.529923
2003	2.2	1.147873	0.794783	0.629146	0.5666	0.540264	0.521237
2004	2.2	1.139767	0.78635	0.627952	0.562804	0.534847	0.531868
2005	2.2	1.102734	0.816249	0.628349	0.554038	0.539659	0.541076
2006	2.2	1.094992	0.810949	0.643429	0.561981	0.523358	0.496869
2007	2.2	1.075764	0.820655	0.644761	0.563388	0.502108	0.45225
2008	2.2	1.114824	0.84471	0.63865	0.5666	0.493096	0.420515
2009	2.2	1.094992	0.858642	0.653303	0.563437	0.50678	0.420542
2010	2.2	1.099802	0.863191	0.663689	0.564122	0.529442	0.440107
2011	2.2	1.112768	0.855457	0.677839	0.563388	0.535895	0.47689
2012	2.2	1.105702	0.86418	0.678062	0.573488	0.537189	0.514771
2013	2.2	1.09215	0.846812	0.674856	0.573119	0.528156	0.508556
2014	2.2	1.06125	0.838544	0.666973	0.5663	0.533884	0.490808
2015	2.2	1.087486	0.847719	0.671717	0.565503	0.519663	0.474872
2016	2.2	1.11794	0.889936	0.682023	0.574709	0.533616	0.486144
2017	2.2	1.12004	0.911817	0.722682	0.597494	0.536325	0.499544
2018	2.2	1.125367	0.898405	0.733588	0.620769	0.552866	0.521963
2019	2.2	1.137498	0.905203	0.737282	0.635689	0.564318	0.534538
2020	2.2	1.15503	0.922601	0.732479	0.63043	0.565454	0.543918
2021	2.2	1.130809	0.921276	0.731065	0.61437	0.559025	0.530481
2022	2.2	1.102734	0.91478	0.75366	0.630834	0.553857	0.533846
2023	2.2	1.102734	0.902376	0.759125	0.636529	0.549592	0.524451

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WD 3.3 Whiting in Division 7.a VAST index for NIGFS

Working document to WKBSNCS 2024-25

Hans Gerritsen – Marine Institute – Ireland – Version 2 – 9 Jan 2025

Summary

The Vector Autoregressive Spatio-Temporal package was used to model the Northern Irish Groundfish Survey index for Irish Sea whiting.

The annual age data collected on the surveys appeared to be insufficient to construct a reliable age-length-key (ALK) for each year and quarter; therefore all age data for each survey period was combined to create time-invariant ALKs.

The final modelled index performed better in terms of internal consistency for most age classes than the current design-based index and the consistency between the two survey periods (Q1 and Q4) was considerably better. This likely explains why the stock assessment model fits more closely to the VAST index than the current index. However, the improved fit was detrimental to the fit to the catch numbers which needs to be investigated further.

The estimated distribution of whiting in the Irish sea indicates that older fish have limited overlap with the main fishery, at the same the apparent mortality signal in the catch and survey numbers-at-age is very high. This indicates that there may be other sources of removals (very high M; migration out of 7a; and/or significant recreational catches)

Survey design

The Northern Irish Groundfish Survey (NIGFS) survey is a fixed station bottom trawl survey, which takes place annually towards the end of Q1 and the start of Q4 in the Irish Sea. Figure 1 shows the coverage of the survey in time and space.

Data preparation

Length frequency distributions of the catch are available for each haul. The distance towed and mean door width for each haul were used to calculate the swept area, which was used as an offset in the model.

Age data was relatively sparse, generally between 50 and 130 fish were aged on a survey although no age data was available for some surveys and 3 surveys had more than 700 aged fish. Two approaches were tested to convert the length data into age distributions:

1. A hierarchical process where an age-length key (ALK) was constructed for each year and quarter. Gaps (lengths without age data) were first filled using an ALK for all years combined (but separate for Q1 and Q4) and any further gaps were filled using modelled ALKs (Gerritsen et al. 2006) (also for all years combined).
2. Alternatively, only the modelled ALKs were applied (i.e. a time-invariant ALKs).

The second approach does not account for changes over time in the proportions at each age class in a given length in size-at-age. However, Figure 2 shows that there is no clear trend in the mean size at age during the period of the survey. The ALK for all years combined also would not account for changes in proportions at age given length due to changes in cohort strength but the current model indicates that recruitment during the survey period has not been very variable so it is unlikely that this will create a significant bias.

The hierarchical (annual) ALK resulted in raw mean catch numbers at age that had considerably poorer internal consistency compared to the modelled (all years combined) ALK for most age classes (Figure 3). Therefore, the modelled ALK was used as the basis for most model runs.

Model runs

The Vector Autoregressive Spatio-Temporal package (VAST; Thorson, 2019) was used to model the survey index. Age classes were fitted as categories and swept area was included as an offset. Haul depth was available as a covariate. Separate models were fitted for the Q1 and Q4 surveys. No temporal correlation was specified; each year was treated as a fixed effect. The observation model was lognormal for positive observations with a Poisson link and a delta model for the binomial component (the lognormal error model was more robust than the default gamma model).

Run 1: field 3033

The base run had the following spatial configuration:

```
FieldConfig <- c(Omega1 = 3,        # overall spatial distribution for presence/absence (encounter probability)
           Epsilon1 = 0,        # spatio-temporal variation (how individual years deviate) for presence absence
           Omega2 = 3,        # overall spatial distribution for non-zero observations
           Epsilon2 = 3)        # spato-temporal variation for non-zero observations
## 0 is off, "AR1" is an AR1 process, and >0 is the number of elements in a factor-analysis covariance
```

In all runs, spatio-temporal variation in the presence/absence (Epsilon 1) was switched off to simplify the model. The model is expected to be able to absorb any spatio-temporal variation in the presence/absence by the spatio-temporal variation in the non-zero observations (Thorsen, 2019), particularly because for the younger ages, hauls with zero catches are rare. In the base run, each of the other processes were given 3 elements in the factor analysis, allowing flexibility in the distribution of the various age classes but with the expectation that older age classes will share attributes in their spatial distributions and the spatio-temporal variation in those distributions; it is expected that the young age classes may have a different distribution (and variation in that distribution) than the older age classes but it is unlikely that the distribution of, say, 5-year-old fish will be very different from 6-year-old fish.

A number of runs were preformed to investigate the impact of changes to the number of elements in each of the processes (Table 1).

Run 2: field 1033

Reducing Omega1 from 3 to 1 resulted in a slightly improved AIC for Q1 but a deterioration for Q4 compared to the base run. It did not improve the run time. Note that setting Omega1 to 1 means that a single spatial distribution for presence/absence is fitted (same for all age classes but with a year effect). Because most of the spatial structure appears to be in the non-zero observations this seems a reasonable approach.

Run 3: field 1031

Also reducing Epsipon2 from 3 to 1 resulted in a slight deterioration for both Q1 and Q4 compared to the base run – this indicates that there are some differences in the spatio-temporal variation between age classes. However: the increase in AIC is quite moderate; the estimated indices are very similar (Figure 5). Because the runtime was much improved over the base run, further models were explored using this spatial configuration. (Long run times often led to models failing to converge.)

Run 3.1 more knots – Final model

Increasing the number of knots from 100 in run 3 to 250 in run 3.1 improved the AIC considerably (Table 1). Increasing the knots to 500 resulted in a failure to converge. Run 3.1 was chosen as the final model; it had the following spatial configuration:

```
FieldConfig <- c(Omega1 = 1,        # overall spatial distribution for presence/absence (encounter probability)
         Epsilon1 = 0,      # spatio-temporal variation (how individual years deviate) for presence absence
         Omega2 = 3,        # overall spatial distribution for non-zero observations
         Epsilon2 = 1)      # spato-temporal variation for non-zero observations
## 0 is off, "AR1" is an AR1 process, and >0 is the number of elements in a factor-analysis covariance
```

It did not include a depth covariate and had 250 knots.

The indices estimated by final model had considerably better internal consistency for most age classes than the current design-based indices (Figure 6). The indices are provided in Appendix 1.

Dead-end runs

A number of runs resulted in a deterioration or lack of improvement in the model:

- Increasing the number of knots in the base run from 100 to 250 resulted in an improvement in the AIC for Q4 but the model did not converge for Q1. It also increased the runtime considerably. For this reason, a simpler spatial configuration was investigated.

- Using the annual (hierarchical) ALK instead to the modelled ALK (all years combined) resulted in a poorer fit as well as a strong reduction in internal consistency (Figure 6). The use of the annual ALK was not further investigated.
- Including a depth covariate. This was done for a number of runs and in all cases resulted in no perceptible improvement in AIC. While depth clearly plays a role in the distribution of whiting, it appears that the spatial configuration is sufficient to account for the depth effect.
- Increasing Omega2 (the spatial distribution) beyond 3 did not improve the AIC and increasing it above 4 resulted in failure to converge. It appears that 3 elements in the factor analysis is sufficient to account for the differences in distribution between the age classes.
- Setting Epsilon2 to zero – this switches off all spatio-temporal variation; i.e. the spatial distribution of each age class is simply scaled up and down for each year but the distribution itself does not change between years. This setting resulted in a significant deterioration in AIC as well as the internal consistency.

Table 1 and Figure 4 give an overview of the model settings and AIC. Figure 5 shows the indices and Figure 6 shows the internal consistency of the various runs. The modelled runs generally had a better internal consistency than the current, design-based indices (with the exception of the run with the annual ALK). The 'external' consistency (how well the Q1 and Q4 surveys correlate is considerably better for the modelled indices.

Table 1. Overview of the settings and AIC of the test runs. FieldConfig specifies the spatial configuration (see main text); ALK is either combined for all years but separate for the quarters (combined) or annual and by quarter (annual). A depth covariate was fitted for some of the runs and the number of knots was initially set at 100 to ensure relatively fast convergence and set at 250 for the final run (highlighted in yellow). NA values indicate that the model did not converge.

Run	FieldConfig	ALK	Covariate	Knots	AIC Q1	AIC Q4
1 field 3033	c(3,0,3,3)	combined	none	100	67042.87	71031.16
1.1 more knots	c(3,0,3,3)	combined	none	250	NA	66180.82
1.2 depth	c(3,0,3,3)	combined	depth	100	66310.99	70823.95
1.2.1 more knots	c(3,0,3,3)	combined	depth	250	NA	66138.76
1.3 annual alk	c(3,0,3,3)	annual	none	100	71062.5	74335.66
2 field 1033	c(1,0,3,3)	combined	none	100	67032.59	71679.72
3 field 1031	c(1,0,3,1)	combined	none	100	67381.63	72499.04
3.1 more knots	c(1,0,3,1)	combined	none	250	63637.89	68652.88
3.2 depth	c(1,0,3,1)	combined	depth	100	66689.82	72337.44
3.2.1 more knots	c(1,0,3,1)	combined	depth	250	63342.95	68639.59
4 field 1041	c(1,0,2,1)	combined	none	100	67369.61	72497.72
5 field 1030	c(1,0,3,0)	combined	none	100	72371.54	79964.69

Performance in the stock assessment model

The current (ASAP) model and the SAM model that is in development for this benchmark both have some conflict between the catch numbers-at-age and the survey numbers-at-age. The SAM model that uses the traditional, design-based indices fits closely to the catch numbers and relatively poorly to the surveys (Figure 7). This probably reflects the poor internal consistency of the survey as well as poor correlation between the Q1 and Q4 indices (Figure 6). Using the VAST surveys as indices in the model results in a fit that is much closer to the index values but poorer to the catch numbers-at-age. The model settings will need to be adjusted to attempt to address this conflict but the indication is that the assessment model gets a more consistent signal from the modelled indices than from the current design-based indices.

Distribution of the whiting stock

Figure 8 shows the estimated distribution of whiting at each age class in Q1 and Q4. In Q1 the young fish (mainly age 1) are concentrated in the western Irish sea and in shallow water (<50m) over sandy ground. Older fish are found in higher concentrations in the eastern Irish Sea and to the south-west of the Isle of Man. While spawning takes place in Q1, It is unclear whether these concentrations of mature fish in Q1 represent the spawning grounds of whiting in the Irish Sea.

In Q4 (which may be more representative of the distribution outside of the spawning season), highest concentration of the youngest fish (age 0) is also along the shallow grounds in the western Irish Sea (similar to the age 1 fish in Q1). Older fish are widely distributed but seem to avoid most of the muddy *Nephrops* grounds as well as the course sediment in parts of the central and southern Irish Sea.

The differences in distribution between age classes have implications for the availability of the various age classes to the fishery. Table 2 shows the overlap of the estimated whiting distribution with the main *Nephrops* fishing grounds (this fishery accounts for the vast majority of whiting catches). Immature fish have a lot of spatial overlap with the fishery and are therefore more available to the fishery. Older fish have a lower amount of overlap (and therefore availability). Selectivity of the fleet is a combination of availability and size selection; age zero fish are rarely caught in the commercial fishery, despite the large amount of overlap – presumably they escape through the meshes. The (commercial) catch curves (not shown here) indicate that selection of age 1 fish is incomplete, but age 2 fish appear fully selected. The continual decline of overlap from 34% for age 2 fish to 21% for age 7 fish in Q4, indicates that the selectivity might be dome shaped.

The relatively low overlap between mature whiting and the fishery implies that there is some level of protection against overfishing. However, the Z signal in both the survey and the commercial catch curves is very high (in the order of 1.5 to 2 in recent years). With an M of 0.6 for older fish, this implies an F of 0.9 to 1.4, corresponding to removals are 60%-75% of the stock each year though fishing. It is difficult to understand how the fishery could be so efficient at catching the stock when the spatial overlap with the mature fish is in the order of 30%. This implies that natural mortality could be significantly higher than estimated; whiting migrate out of the Irish Sea; and/or recreational catches are significant.

Table 2. Overlap of the estimated spatial distribution of whiting with the Nephrops fishing grounds.

	Overlap with nep fishery	
Age	Q1	Q4
0		58%
1	45%	41%
2	34%	34%
3	31%	30%
4	31%	28%
5	32%	29%
6	34%	27%
7	32%	21%

Figures

Quarter 1 Quarter 4

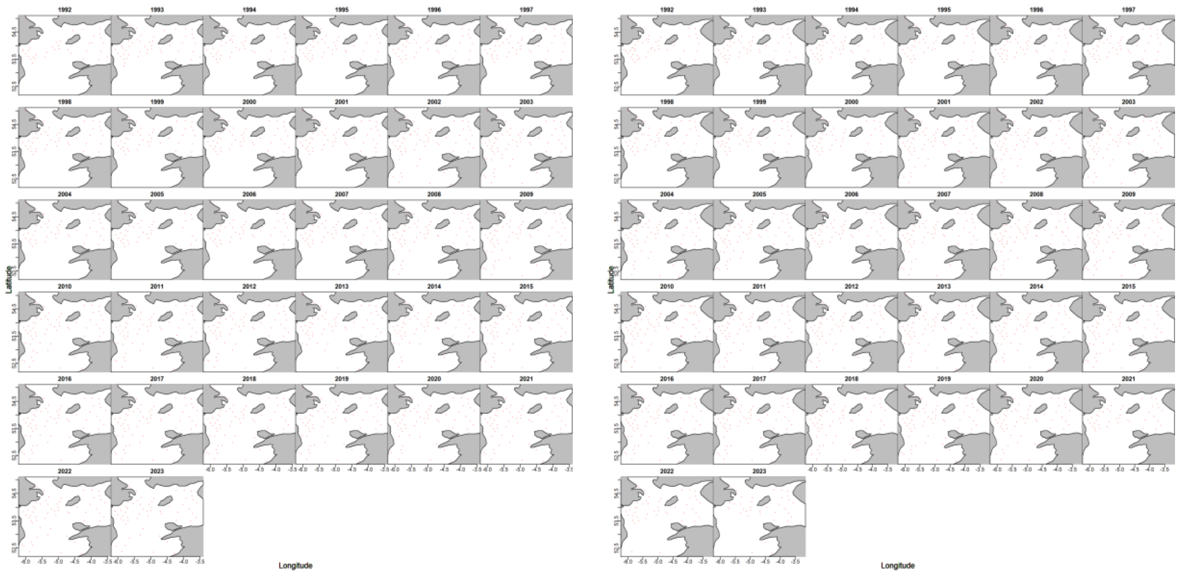

Figure 1. NIGFS station positions (in the Irish Sea) by year in the Q1 (left) and Q4 (right) survey. Until 2000 the survey took place in the northern part of the Irish Sea only, since then the southern part has also been sampled although not every year and quarter.

Figure 2. Mean length-at-age estimated from the survey data using the hierarchical ALK.

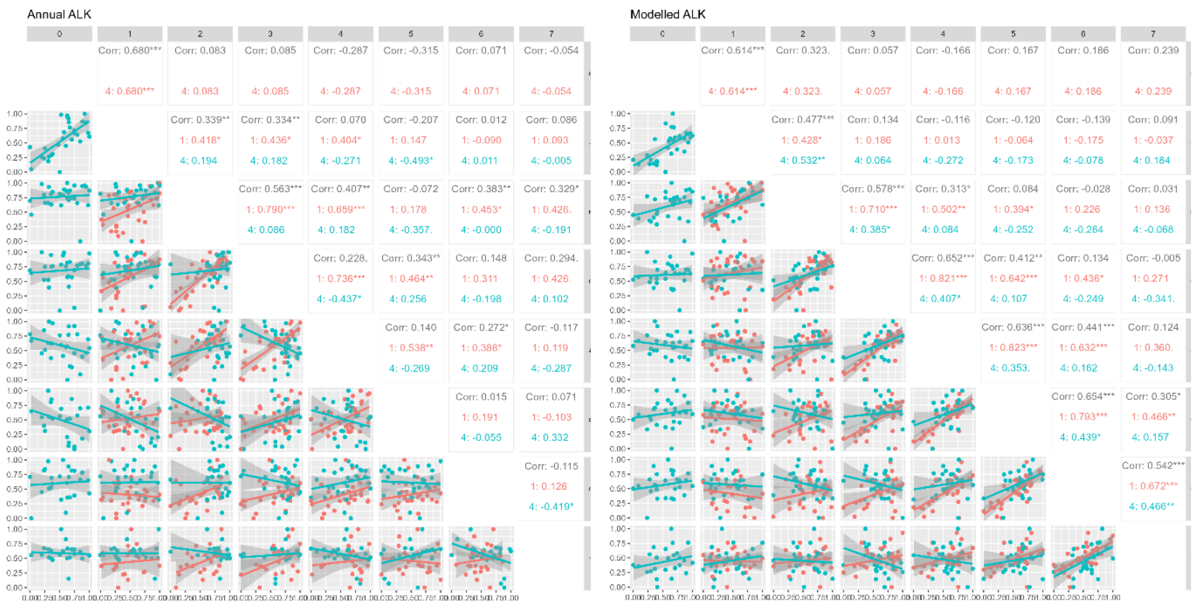

Figure 3. Internal consistency of the raw survey data mean catch numbers per swept area (without accounting for the survey design). The modelled ALK (all years combined) performed better for older fish (5+) in Q1 and considerably better for all ages except zero in Q4.

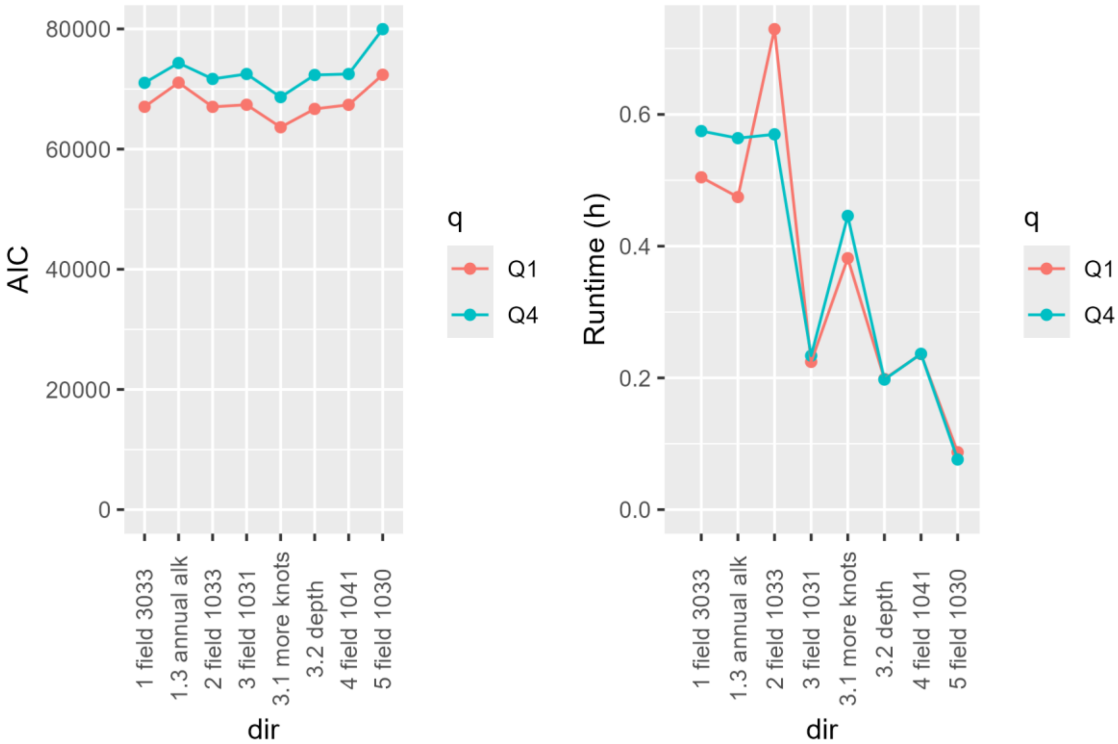

Figure 4. AIC of a selection of test runs (left) and run time (right)

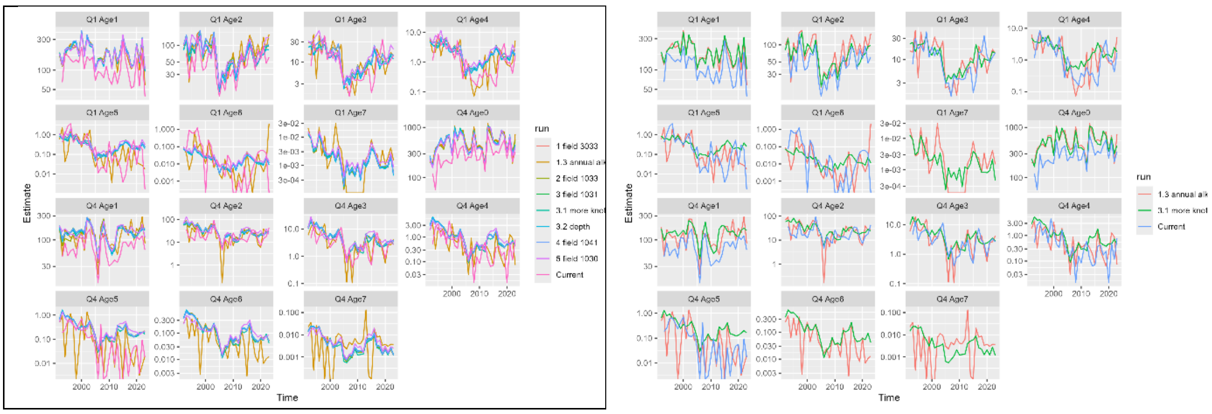

Figure 5. Index estimates of all runs (left) and the base run, final run and current (design-based) index (right).

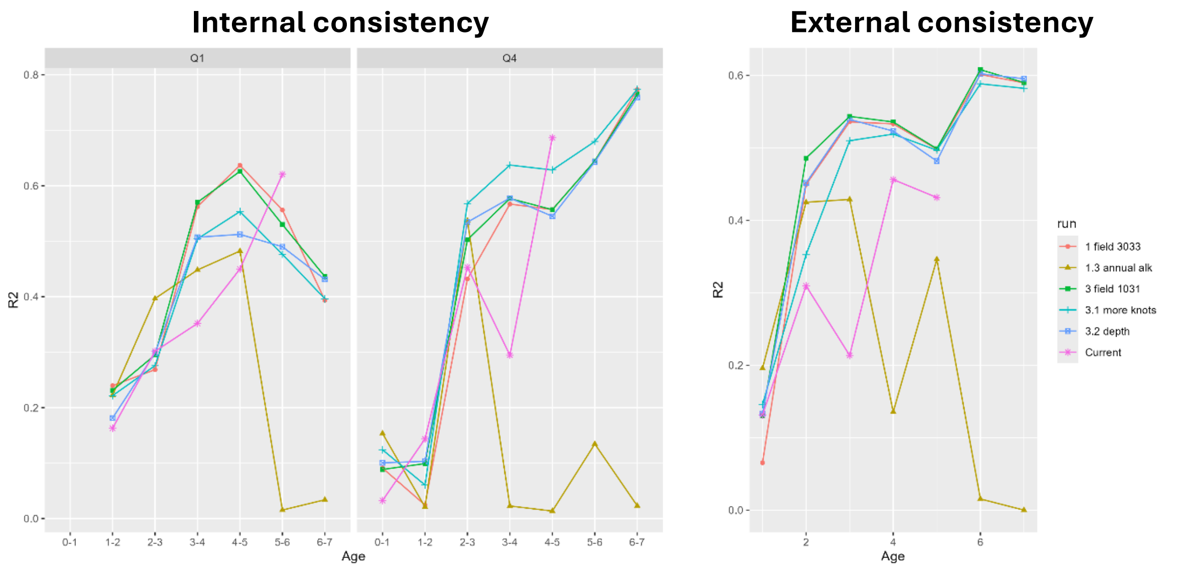

Figure 6. Internal consistency of the indices (correlation between log numbers of age a *in year* y *with age* a+1 *in year* y+1*) of a selection of runs and 'external' consistency (correlation between the log numbers of the same age of the Q1 and Q4 indices).*

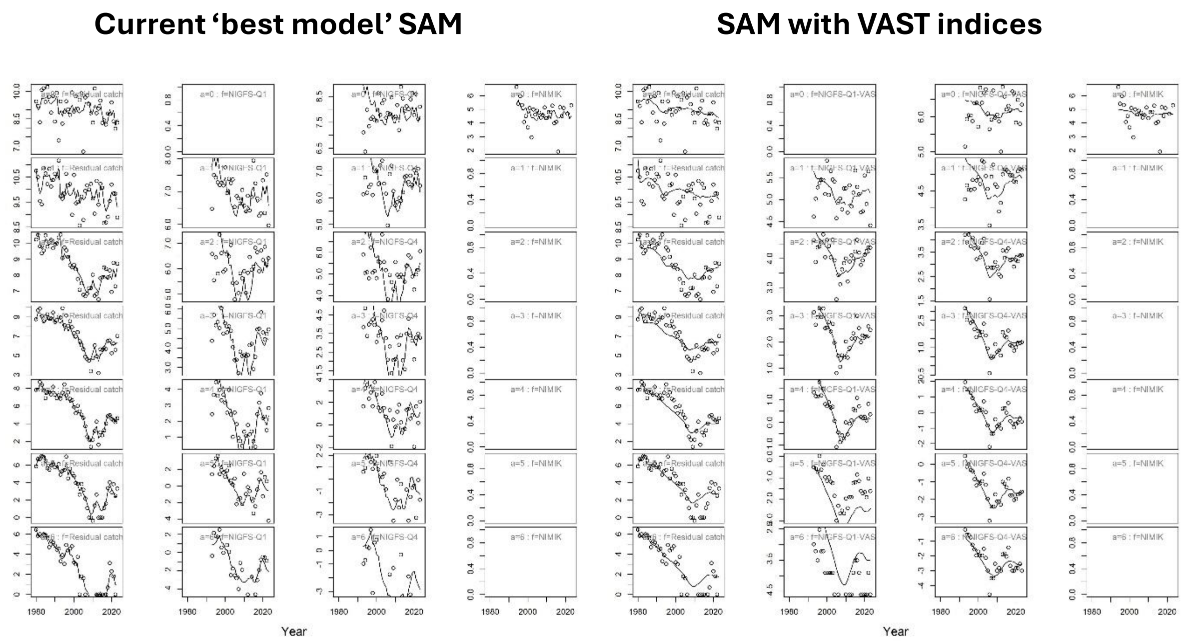

Figure 7. SAM model fit; the current best model (left) which uses the design-based survey indices and the same model with the VAST survey indices (right).

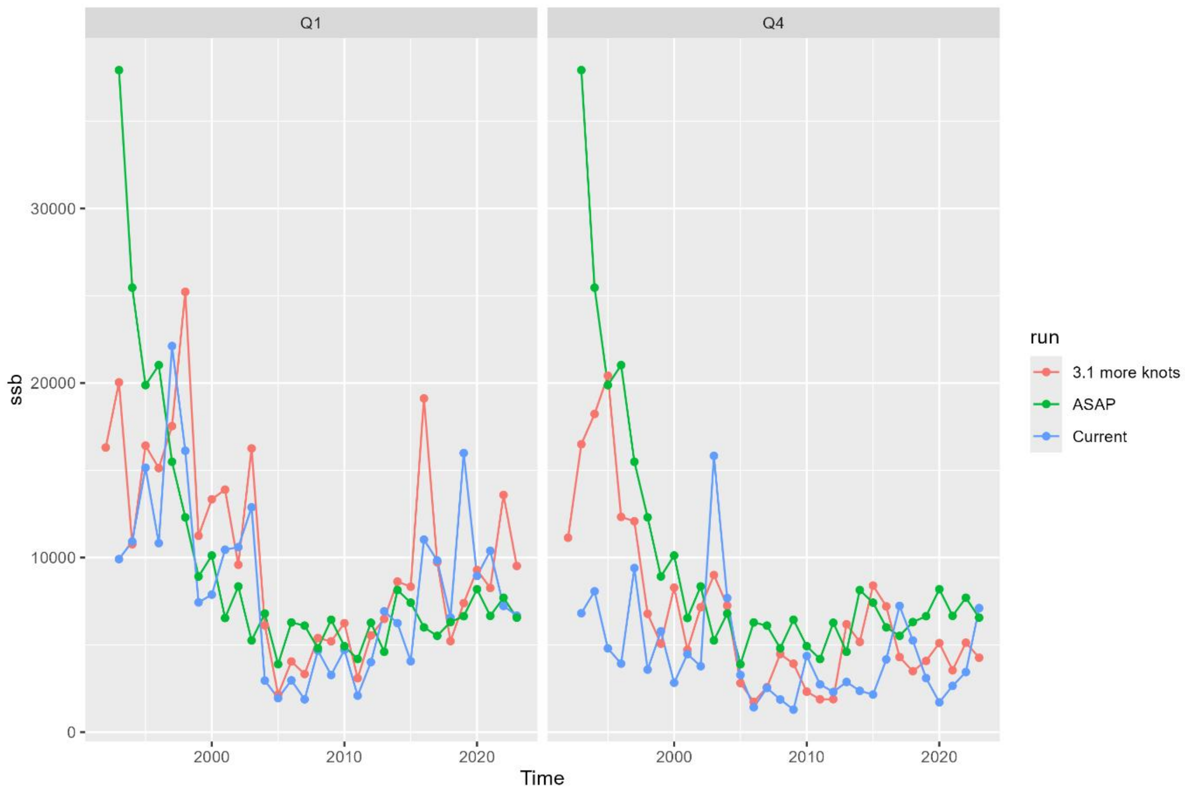

Figure 7b. SSB estimates from the preferred VAST index (calculated from the index numbers at age) compared to the current (design-based estimate of the index) as well as the scaled SSB from the current ASAP assessment. The VAST Q4 index shows somewhat better agreement with the ASAP SSB (apart from the first 2 years) than the design-based index. For Q1 there is no major difference.

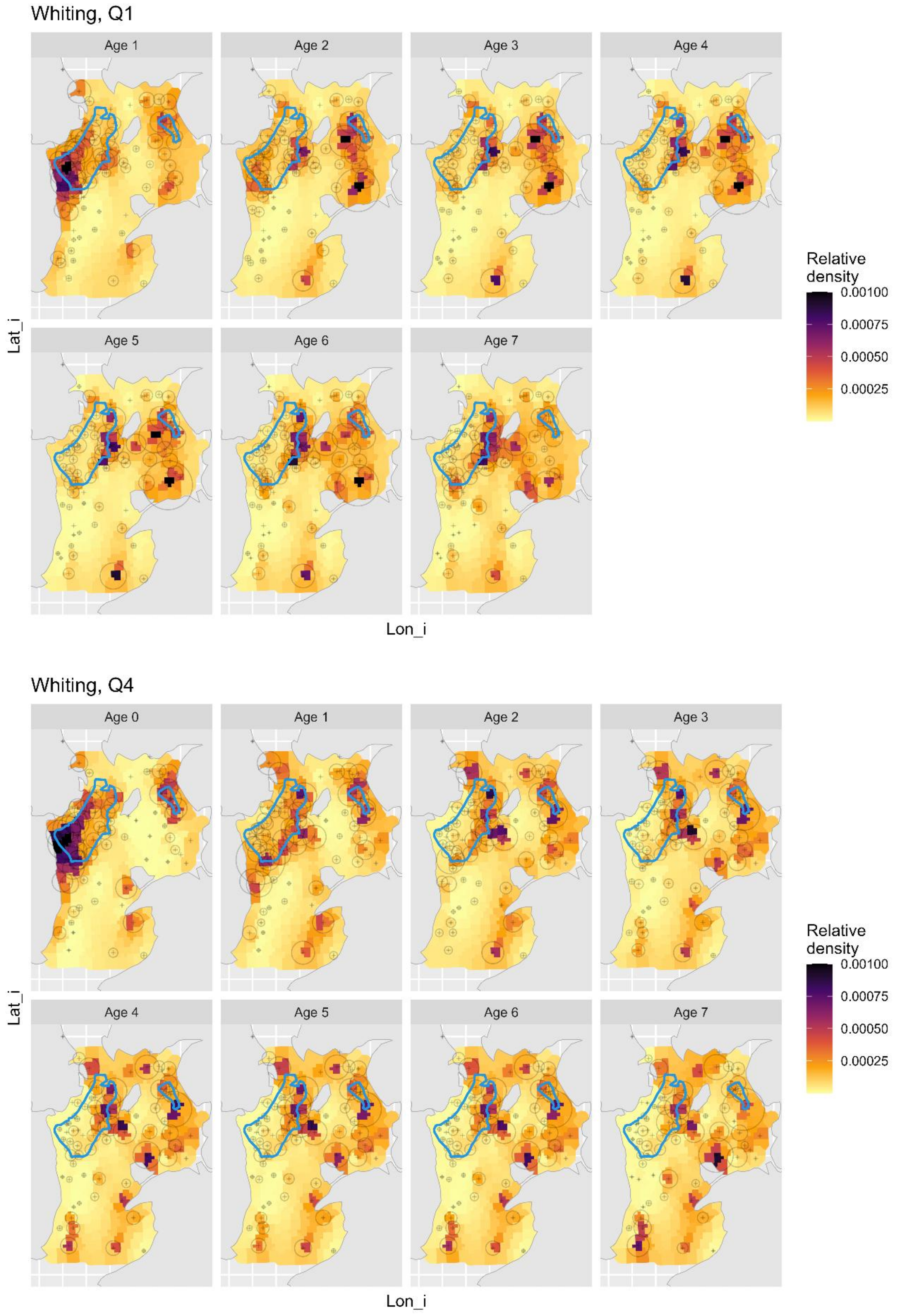

*Figure 8. Spatial distribution of whiting in Q1 (top) and Q4 (bottom) estimated by the final model. The crosses indicate the sampling locations, the circles indicate the average catch numbers per swept area; the areas outlined in blue are the main fishing grounds (*Nephrops).

References

Gerritsen, Hans D., David McGrath, and Colm Lordan. "A simple method for comparing age–length keys reveals significant regional differences within a single stock of haddock (Melanogrammus aeglefinus)." *ICES Journal of Marine Science* 63, no. 6 (2006): 1096-1100.

Thorson, James T. "Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments." *Fisheries Research* 210 (2019): 143-161.

Appendix 1

Quarter 1 index (run 3.1)

	Estimate								Standard error on log scale						
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7		Age1	Age2	Age3	Age4	Age5	Age6	Age7
1992	189.296	81.231	22.475	4.930	0.880	0.073	0.013		0.158	0.189	0.206	0.214	0.221	0.235	0.231
1993	126.006	128.181	24.323	3.709	0.589	0.053	0.009		0.141	0.177	0.212	0.223	0.228	0.223	0.231
1994	190.088	52.018	15.288	3.637	0.643	0.044	0.003		0.151	0.191	0.223	0.231	0.234	0.231	0.309
1995	219.571	90.178	21.378	3.442	0.519	0.033	0.004		0.146	0.181	0.215	0.232	0.242	0.254	0.328
1996	212.733	72.249	22.101	5.228	0.949	0.087	0.012		0.152	0.185	0.215	0.226	0.231	0.232	0.233
1997	263.558	107.551	22.691	3.848	0.613	0.047	0.006		0.143	0.174	0.196	0.205	0.212	0.224	0.236
1998	273.048	166.324	34.074	5.721	0.908	0.048	0.003		0.146	0.196	0.239	0.258	0.264	0.262	0.408
1999	166.890	63.899	15.315	2.943	0.498	0.031	0.002		0.146	0.193	0.233	0.243	0.244	0.237	0.304
2000	378.891	104.646	12.548	2.073	0.329	0.021	0.002		0.141	0.175	0.203	0.218	0.225	0.240	0.293
2001	169.174	89.233	18.880	3.081	0.479	0.027	0.003		0.143	0.185	0.222	0.236	0.241	0.244	0.282
2002	344.858	70.393	12.791	2.209	0.353	0.019	0.001		0.130	0.153	0.164	0.168	0.173	0.207	0.320
2003	253.867	122.657	18.567	2.609	0.377	0.025	0.003		0.125	0.155	0.180	0.185	0.187	0.192	0.302
2004	252.377	53.089	7.182	1.104	0.167	0.009	0.001		0.145	0.198	0.251	0.270	0.273	0.266	0.396
2005	103.992	18.037	3.015	0.437	0.064	0.003	0.000		0.154	0.217	0.278	0.300	0.305	0.371	0.639
2006	142.668	30.999	4.460	0.682	0.110	0.008	0.001		0.143	0.189	0.239	0.259	0.263	0.277	0.373
2007	152.728	24.670	3.702	0.593	0.095	0.007	0.001		0.141	0.185	0.232	0.245	0.248	0.249	0.384
2008	123.887	37.602	4.836	0.648	0.095	0.005	0.001		0.132	0.163	0.203	0.216	0.223	0.253	0.395
2009	211.956	46.770	3.941	0.504	0.075	0.004	0.000		0.126	0.153	0.181	0.193	0.202	0.237	0.469
2010	187.783	46.701	6.343	0.923	0.136	0.011	0.001		0.128	0.156	0.180	0.188	0.193	0.202	0.298
2011	109.996	24.239	3.982	0.614	0.093	0.005	0.000		0.127	0.155	0.173	0.176	0.179	0.209	0.428
2012	213.797	46.146	5.640	0.920	0.149	0.011	0.001		0.127	0.162	0.191	0.200	0.203	0.213	0.304
2013	128.141	52.290	7.310	1.035	0.151	0.009	0.001		0.132	0.157	0.182	0.192	0.194	0.211	0.305

2014	190.432	51.186	9.087	1.657	0.271	0.018	0.002		0.132	0.152	0.169	0.173	0.177	0.188	0.287
2015	337.034	73.748	8.552	1.783	0.322	0.033	0.004		0.126	0.148	0.162	0.162	0.164	0.168	0.208
2016	225.366	106.614	21.987	3.478	0.522	0.033	0.003		0.125	0.147	0.176	0.192	0.194	0.193	0.228
2017	180.222	73.351	13.533	2.198	0.353	0.021	0.002		0.125	0.151	0.170	0.174	0.178	0.185	0.287
2018	109.436	40.147	6.792	1.184	0.195	0.012	0.001		0.125	0.145	0.159	0.166	0.171	0.185	0.338
2019	126.863	47.513	10.535	1.477	0.208	0.012	0.001		0.127	0.152	0.174	0.180	0.186	0.224	0.364
2020	240.764	63.409	9.873	1.468	0.223	0.011	0.001		0.128	0.158	0.188	0.192	0.191	0.205	0.364
2021	130.860	69.848	9.574	1.165	0.160	0.008	0.001		0.126	0.152	0.170	0.169	0.170	0.194	0.385
2022	316.036	94.436	15.104	2.466	0.385	0.024	0.002		0.128	0.151	0.176	0.188	0.190	0.191	0.259
2023	102.702	97.376	14.010	1.777	0.245	0.011	0.000		0.130	0.157	0.182	0.191	0.193	0.202	0.465

Quarter 4 index (run 3.1)

	Estimate									**Standard error on log scale**							
Year	**Age 0**	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 6**	**Age 7**		**Age0**	**Age1**	**Age2**	**Age3**	**Age4**	**Age5**	**Age6**	**Age7**
1992	239.186	166.862	57.023	9.908	2.851	0.639	0.355	0.015		0.196	0.210	0.287	0.346	0.405	0.352	0.382	0.324
1993	166.524	97.678	66.850	18.442	5.453	1.313	0.665	0.023		0.206	0.209	0.281	0.340	0.402	0.346	0.375	0.295
1994	344.214	133.716	54.853	11.097	4.025	0.786	0.527	0.024		0.204	0.219	0.295	0.346	0.395	0.350	0.373	0.307
1995	420.721	142.338	81.937	15.936	4.176	0.937	0.531	0.019		0.217	0.238	0.320	0.382	0.442	0.385	0.415	0.344
1996	597.895	141.736	51.844	9.884	3.020	0.640	0.415	0.023		0.202	0.207	0.256	0.298	0.345	0.303	0.330	0.286
1997	422.946	153.564	59.768	10.782	2.591	0.650	0.303	0.009		0.201	0.216	0.271	0.308	0.344	0.308	0.329	0.317
1998	639.541	118.155	37.551	6.294	1.506	0.400	0.184	0.006		0.197	0.214	0.254	0.280	0.305	0.282	0.302	0.395
1999	621.397	134.599	22.550	3.990	0.846	0.245	0.098	0.003		0.205	0.216	0.240	0.244	0.259	0.244	0.264	0.332
2000	278.935	154.091	41.718	6.464	1.433	0.363	0.196	0.007		0.203	0.226	0.284	0.323	0.358	0.324	0.347	0.359
2001	1017.868	128.214	24.996	4.488	1.040	0.297	0.119	0.003		0.186	0.184	0.201	0.218	0.243	0.223	0.247	0.359
2002	556.219	240.332	49.036	5.630	1.054	0.338	0.122	0.003		0.183	0.186	0.226	0.256	0.293	0.264	0.297	0.357
2003	970.971	219.313	46.052	7.534	1.658	0.474	0.192	0.003		0.181	0.167	0.174	0.185	0.208	0.188	0.207	0.321
2004	732.505	169.693	30.961	4.336	0.852	0.249	0.096	0.004		0.178	0.181	0.201	0.215	0.246	0.223	0.258	0.312

2005	398.200	100.559	15.144	1.972	0.321	0.107	0.037	0.001		0.182	0.192	0.221	0.235	0.254	0.239	0.255	0.519
2006	281.986	41.779	5.985	0.665	0.091	0.029	0.011	0.001		0.218	0.223	0.241	0.254	0.283	0.259	0.285	0.544
2007	338.025	127.151	15.628	1.340	0.189	0.067	0.021	0.001		0.187	0.167	0.173	0.179	0.202	0.191	0.223	0.399
2008	868.134	225.468	21.712	1.815	0.248	0.087	0.028	0.001		0.176	0.163	0.177	0.190	0.214	0.199	0.236	0.423
2009	395.881	104.372	21.388	2.807	0.509	0.147	0.063	0.002		0.177	0.172	0.188	0.204	0.224	0.207	0.226	0.335
2010	399.685	69.742	11.806	1.444	0.292	0.089	0.035	0.001		0.167	0.162	0.181	0.198	0.221	0.201	0.217	0.306
2011	348.993	54.138	10.119	1.421	0.313	0.084	0.039	0.001		0.191	0.172	0.168	0.163	0.179	0.164	0.193	0.351
2012	151.401	61.516	10.932	1.290	0.255	0.077	0.033	0.001		0.191	0.178	0.195	0.214	0.238	0.217	0.238	0.397
2013	1062.318	162.274	30.960	4.860	0.957	0.287	0.116	0.004		0.192	0.184	0.204	0.220	0.244	0.222	0.238	0.275
2014	995.702	193.029	22.351	3.223	0.816	0.212	0.102	0.005		0.186	0.179	0.201	0.220	0.244	0.222	0.238	0.273
2015	561.899	186.402	32.726	4.235	0.930	0.250	0.122	0.006		0.178	0.166	0.179	0.195	0.217	0.198	0.215	0.239
2016	468.437	148.703	33.427	6.052	1.832	0.416	0.230	0.009		0.176	0.164	0.191	0.229	0.277	0.231	0.250	0.220
2017	449.033	142.406	22.456	2.725	0.516	0.151	0.064	0.003		0.182	0.173	0.182	0.195	0.211	0.195	0.216	0.295
2018	846.424	150.815	19.447	2.299	0.437	0.139	0.045	0.002		0.180	0.168	0.181	0.229	0.280	0.235	0.266	0.326
2019	682.972	124.451	17.962	2.233	0.381	0.124	0.047	0.001		0.177	0.170	0.178	0.190	0.209	0.195	0.211	0.334
2020	334.447	113.878	20.751	2.382	0.479	0.130	0.059	0.002		0.182	0.172	0.188	0.204	0.224	0.205	0.223	0.340
2021	639.244	154.660	20.505	2.783	0.466	0.159	0.053	0.001		0.197	0.207	0.239	0.274	0.311	0.278	0.310	0.457
2022	301.750	172.246	28.109	3.480	0.727	0.201	0.091	0.003		0.194	0.199	0.234	0.268	0.306	0.271	0.288	0.382
2023	438.263	153.222	24.180	2.787	0.445	0.163	0.042	0.001		0.218	0.229	0.233	0.242	0.262	0.244	0.303	0.492

WD 3.4 Whiting in Division 7.a Environmental and ecosystem considerations

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3.4.1 Executive Summary

The Irish Sea ecosystem has undergone major changes in recent decades, with evidence of large changes in the abundance and composition of species communities, including phytoplankton, zooplankton and fish species. The majority of these changes began in the early 1990's onwards and are co-incident with rising sea temperatures. This is referred to by some authors as a 'regime shift' in the Irish Sea ecosystem (e.g. ICES 2016, Bentley et al. 2020, Mitchell, 2021, Tironen, 2023). In this document we review the key changes in the ecosystem, and how they correlate with changes in Irish Sea whiting biology.

These changes were presented during the WKNSCS data benchmark, and it was agreed by the experts present that there was sufficiently evidence of a 'regime shift' to consider the use of a shortened time-series for reference point setting (ICES, 2021; see WD 3.7 Whiting in Division 7a Reference Points for further details).

Finally, we review recent genetic data which shows that the stock retains a high level of genetic diversity, despite these large changes in fishery, ecosystem and stock biology.

3.4.2 Broadscale changes in the Irish Sea ecosystem

An overview of temporal changes in the Irish Sea is represented by a traffic light plot using Integrated Ecosystem Analysis. This technique brings together a range of variables representing key components of the ecosystem, including climate, phytoplankton, zooplankton and fish species. Variables are analysed and scaled using PCA, and then sorted according to their principal components PC1 loadings for visualisation purposes. This generates a pattern with variables that demonstrated an increasing trend with time (red to green), to variables demonstrating a decreasing trend (green to red). Parameters with more variable trends are located in the centre of the plot (Fig. 1).

The traffic light plot highlights a switch in ecosystem conditions beginning in the early 1990's. Over the time-series (1970-present) increases in Sea Surface Temperature (SST) are observed, and a positive phase of the Atlantic Multidecadal Oscillation (AMO) in present in the more recent time-period. Concurrently, there was a strong decline in cold water affinity zooplankton species such as *Calanus finmarchicus* and *Para-Pseudocalanus* spp., both favoured by whiting larval and juveniles (Rowlands, Dickey-Collas et al. 2008). These changes in zooplankton community structure are likely to have general implications for energy transfer efficiency to higher trophic levels, and for the sustainability of fisheries resources (Pitois and Fox 2006; Heath and Lough 2007). Over the same time period declines in demersal fish species including sole and whiting have been observed in the Irish Sea.

The PCI (the Phytoplankton Colour Index) has increased over the time-series, reflecting increases in the biomass of diatoms and dinoflagellates (Richardson, Walne et al. 2006). These increases in phytoplankton have been linked to possible reductions in grazing pressure from zooplankton in the ecosystem (Lynam, Lilley et al. 2011).

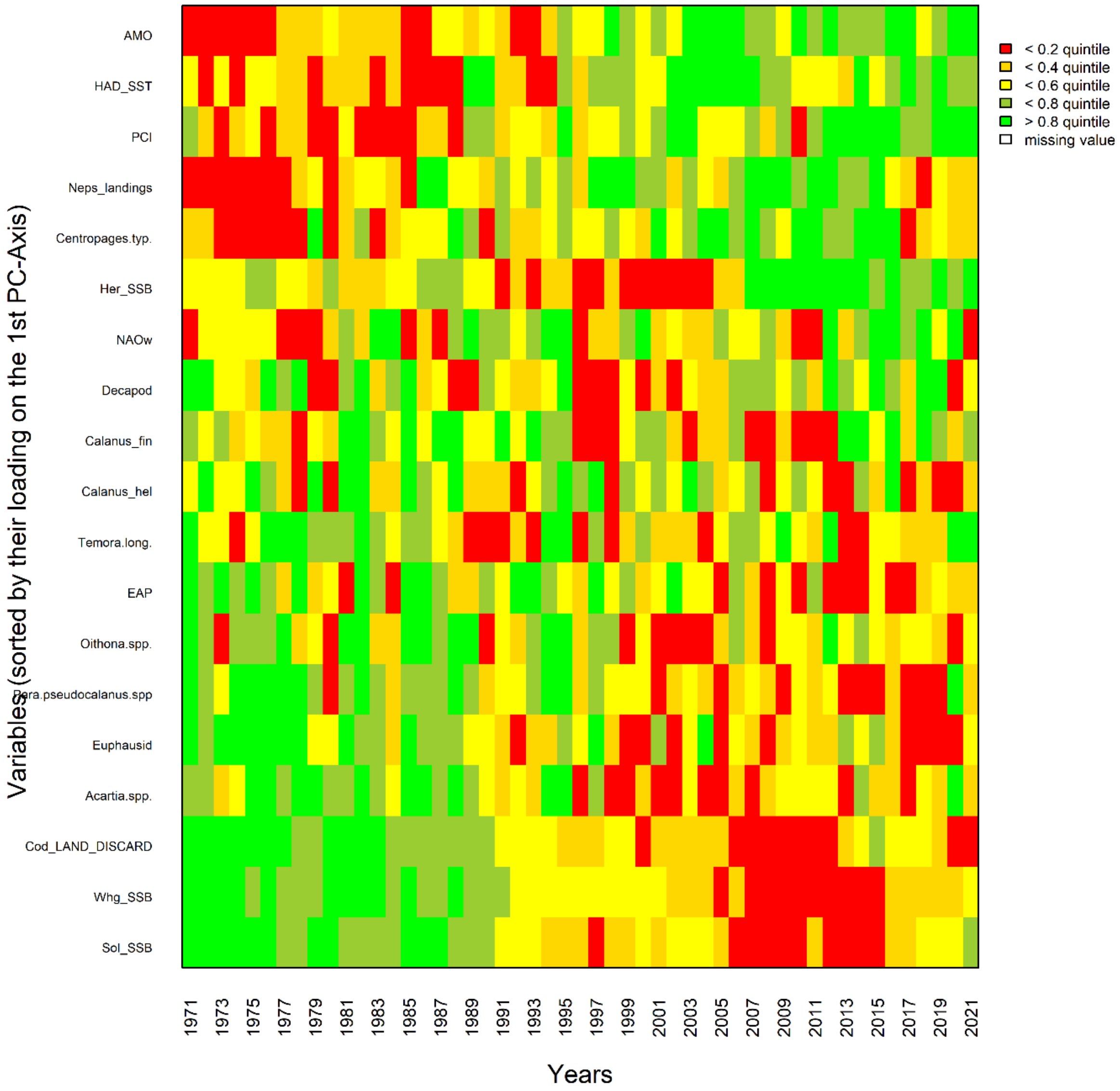

Fig. 1. Integrated ecosystem analysis traffic-light plot of temporal changes in the Irish Sea ecosystem (1971- 2021).

3.4.3 Environmental correlates of biological parameters

Comparisons in the section below examine relationships between whiting biological parameters and sea surface temperature. However, it is likely they that underlying mechanisms for the observed biological changes in whiting are more complex, and also relate to other elements of the ecosystem which changed concurrently with temperature such as food availability, predation pressure, and fishing pressure. maturity and

Mean weights at age

The mean weights at age of Irish Sea whiting in the commercial fishery declined sharply during from the 1980's to the 2000's, before becoming more stable since then at a lower level (Figure 2). Subsequently the mean weights at ages 3 and 4 have been estimated to be around 60% of the values recorded in the early 1980s.

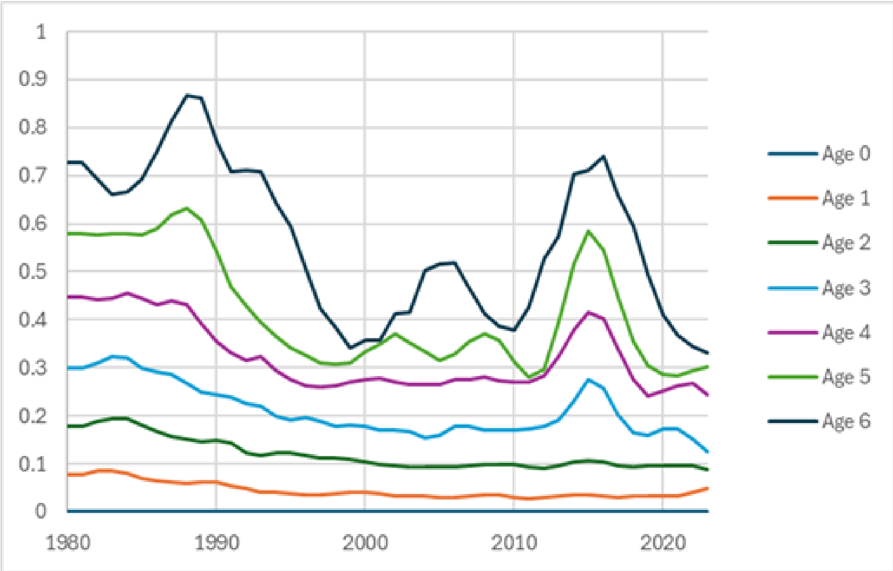

Fig. 2 Stock-weights at age for Whiting 27.7a.

Comparisons between the decline in weights at ages 1 and mean Sea Surface Temperatures (SST; 5-year running average) demonstrate a significant negative correlation (Fig. 3), whereby the decline in weights at age 1 has occurred against a backdrop of increasing SST. Data on weights at age for this analysis are from the WGCSE working group report (ICES, 2024).

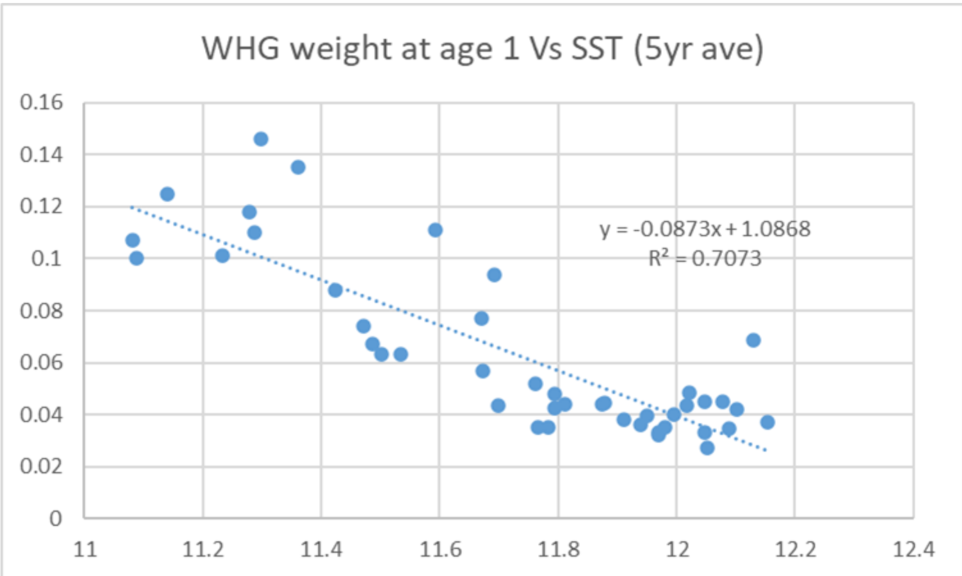

Fig. 3. Correlation between mean weights at age 1 and mean SST (5yr running average) 1980 – 2022.

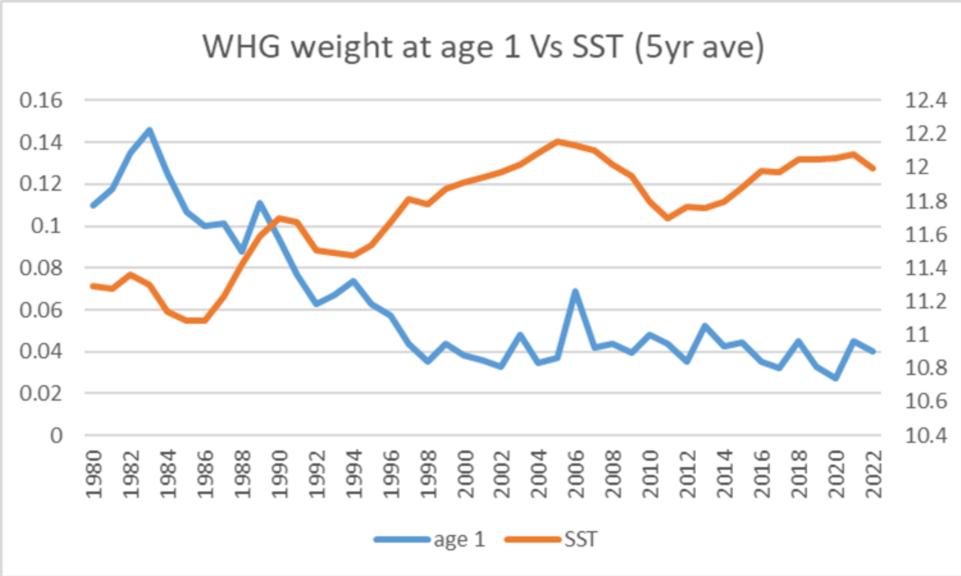

Fig. 4. Mean weights at age 1 and mean Sea Surface Temperature (5yr running average) 1980 – 2022.

Mortality

Mortality was estimated from catch curves (ages 1-5) calculated using stock numbers for whiting (ICES, 2024). Mortality rates have increased since 1980, with some evidence of a decline in the most recent years (Fig. 5). These mortality rates were found to be negatively correlated with weights at age 1 data and positively with the SST data (Fig. 6).

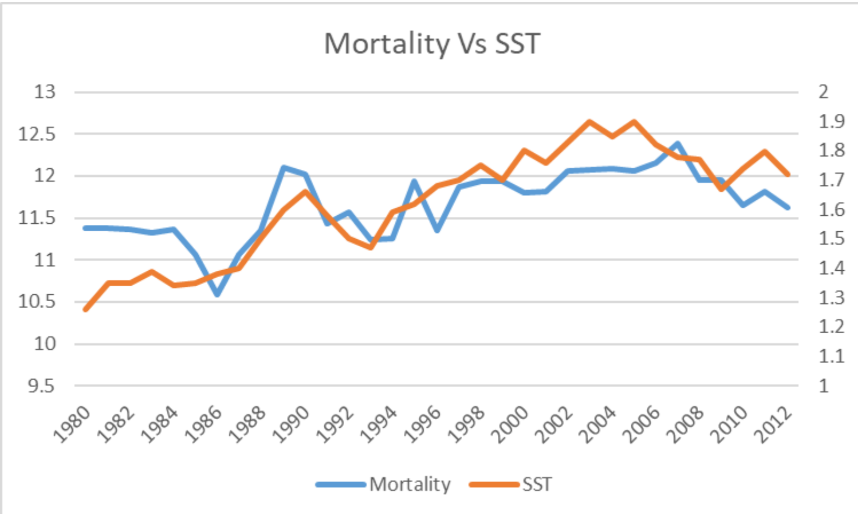

Fig. 5. Mortality rates calculated from catch curves of stock number at age (1-5) and Sea Surface Temperature.

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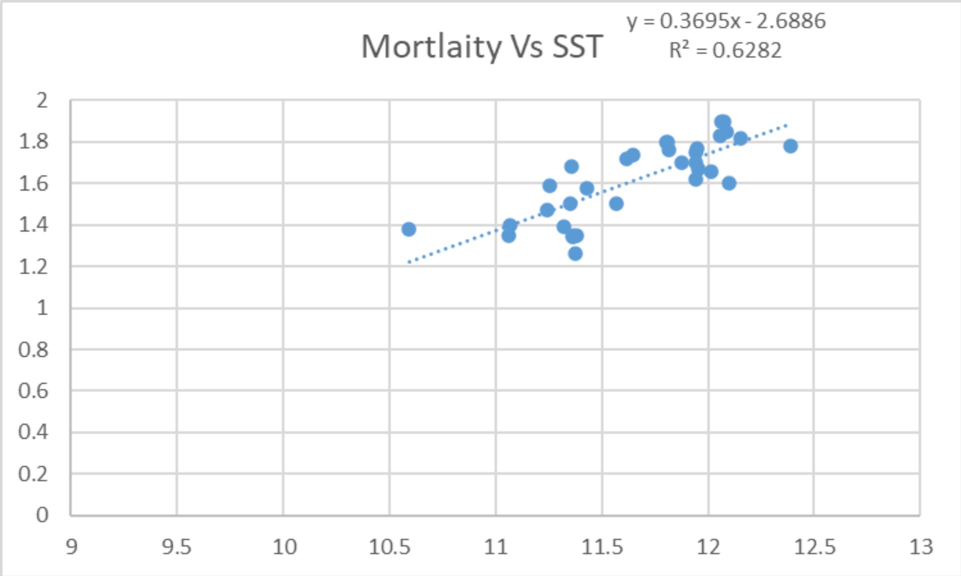

Fig. 6. Correlation between mortality rates catch curves of stock number at age (1-5) and Sea Surface Temperature.

Recruitment

Whiting recruitment declined over time in the Irish Sea shows significant negative correlations with SST, the AMO, and PCI (Fig. 7, Bentley et al., 2020).

	SST (annual)	SST (Jan-Jul)	NAOw	NAOw 10yr	AMO	AMO 10yr	PCI	Large Zoop.	Small Zoop.	Cod	Haddock	Herring	Plaice
SST (Jan-Jul)	*** 0.91												
NAOw	0.18	0.21											
NAOw 10yr	0.23	0.11	* 0.33										
AMO	*** 0.60	** 0.43	-0.23	0.23									
AMO 10yr	*** 0.61	** 0.44	0.01	* 0.32	*** 0.83								
PCI	*** 0.63	** 0.48	0.23	* 0.33	*** 0.59	*** 0.79							
Large Zoop.	-0.13	-0.07	-0.17	*** -0.56	-0.20	* -0.35	-0.24						
Small Zoop.	-0.24	-0.33	-0.17	-0.15	-0.13	-0.31	-0.29	*** 0.54					
Cod	*** -0.77	*** -0.70	-0.03	-0.11	*** -0.76	*** -0.84	*** -0.70	0.14	0.29				
Haddock	-0.13	-0.30	0.05	-0.25	0.10	0.10	0.17	-0.02	-0.21	0.07			
Herring	-0.07	0.04	-0.10	*** -0.80	-0.24	-0.27	-0.28	*** 0.67	0.08	-0.04	0.08		
Plaice	0.10	0.05	-0.16	-0.30	0.28	** 0.45	0.29	0.12	-0.18	* -0.39	0.02	0.27	
Whiting	** -0.60	** -0.51	0.07	-0.07	*** -0.65	*** -0.88	*** -0.73	0.11	0.26	*** 0.85	0.01	-0.08	-0.28

Figure 7. Reproduced from Bentley et al. 2020. Correlation matrix for environmental variables, plankton trends, and fish recruitment in the Irish Sea using Pearson's cross product-moment correlation. Variables include sea surface temperature (SST; °C), phytoplankton colour index (PCI), North Atlantic Oscillation winter index with a 10-year low-pass filter (NAO), Atlantic Multidecadal Oscillation with a 10-year low-pass filter (AMO), large zooplankton abundance (L.zoop.), and small zooplankton abundance (S.zoop.). Fish

recruitment time series (log_{10} tranformed for normality) were taken from ICES stock assessments for cod, haddock, herring, plaice, and whiting. The correlation matrix is shaded to signify the strength of positive (blue) and negative (red) correlations in relation to their r values. Statistically significant correlations are denoted: *p<0.05; **p<0.01; ***p<0.001.

Furthermore Bentley et al. 2020, demonstrate how the inclusion of the AMO as a temperature driver of cod and whiting recruitment, improved the ability of ecosystem models of the Irish Sea to predict whiting catches and spawning stock biomass (SSB), and resulted in a better overall fit of the ecosystem model (Fig. 8, Bentley et al. 2020).

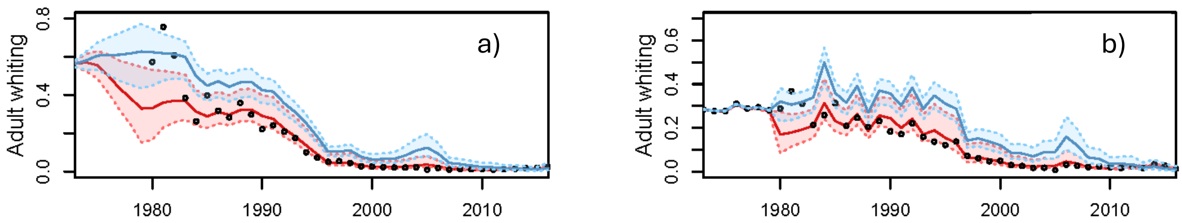

Fig. 7. Adapted from Bentley et al. 2020. a) Biomass and b) catch (t.km-2) simulations for commercial stocks in the Irish Sea from 1973 to 2016. Simulations were generated by a fitted model with environmental drivers (red) and a fitted model without environmental drivers (blue). Solid lines indicate baseline model simulations, shaded areas indicate 95% confidence intervals based on input uncertainty, and points indicate observed data trends.

Stock-recruitment

Analysis of potential change-points in whiting stock-recruitment relationships in relation in changes in Irish Sea temperatures and food availability (zooplankton abundance) are described in Tirronen et al. 2023. Using Bayesian Online Change-Point Detection (BOCPD) they identify 1992 as a change-point in the stock-recruitment relationship of whiting. This change relates primarily to the maximum number of recruits, with years from 1992 onwards showing lower levels of recruitment. The best evidence for environmental factors explaining recruitment was found for sea bottom temperatures at a depth of 47m, which was at its lowest temperature in 1993. The addition of sea bottom temperatures at a depth of 47m removed change-point at 1992 from the fitted model, suggesting a link between sea temperature and the shift in recruitment in that year (Fig. 8). Despite this the overall support for inclusion of sea bottom temperatures in the model was not strong when models were ranked by overall model likelihood criterion, and the authors suggest that additional factors such as changes in forage fish abundance and predation mortality and benthic prey availability may be needed to fully explain the change in the recruitment dynamics of whiting observed in the early 1990’s (eg Lauerburg et al., 2018; Henderson, 2019). The analysis conducted by Tirronen et al. is based on the recruitment estimates of the previous assessment model for Irish Sea whiting. Therefore, an independent decision was made by the benchmark working group as to the most appropriate change-point in the stock-recruitment relationship for reference point setting. However, this resulted in the selection of the same year (see WD 3.7 Whiting in Division 7a Reference Points).

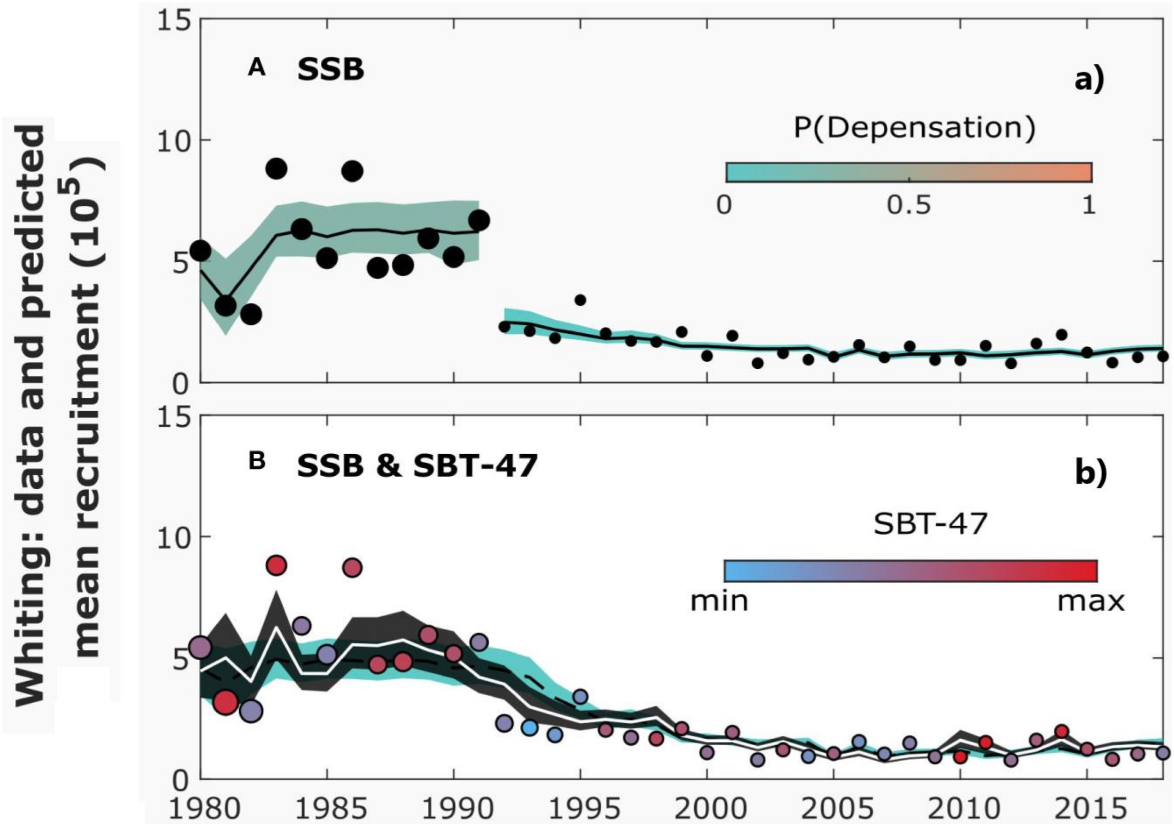

Fig. 8. Adapted from Tirronen et al. 2023. Data and predicted mean recruitment by different models for whiting. The plain Saila-Lorda (SL; equation 4; A) model includes only spawning stock biomass (SSB) as an explanatory variable, illustrating change-point at 1992 when environmental variables are unaccounted for. B) The extended SL model including also the sea-bottom temperature at the depth of 47 meters (SBT-47).

3.4.4 Irish Sea Whiting diet Analysis

Diet of juvenile (< 23cm) and adult Irish sea whiting were analysed to determine whether there had been changes in feeding and food web dynamics, using stomach content data from 1962 to 2023 (Fig. 9 & 10). Juvenile whiting (< 23cm) diet contained a high proportion of prawns and shrimps, small pelagic fish (e.g. European sprat) and epifauna. There was evidence of an increase in the incidence of cannibalism amongst this size class of whiting in the most recent period (2017-2023). Adult whiting (>23cm) have a diet consisting of higher proportions of fish. In adult whiting, a higher prevalence of cannibalism was detected from the early 1990's onwards. Diet data is patchy, and in some years sample numbers are low, but the overall picture is one of increased cannibalism during the period of decline in stock-size. This increased cannibalism may be evidence of a decline in alternative prey, or an increase in spatial overlap between adult and juvenile whiting.

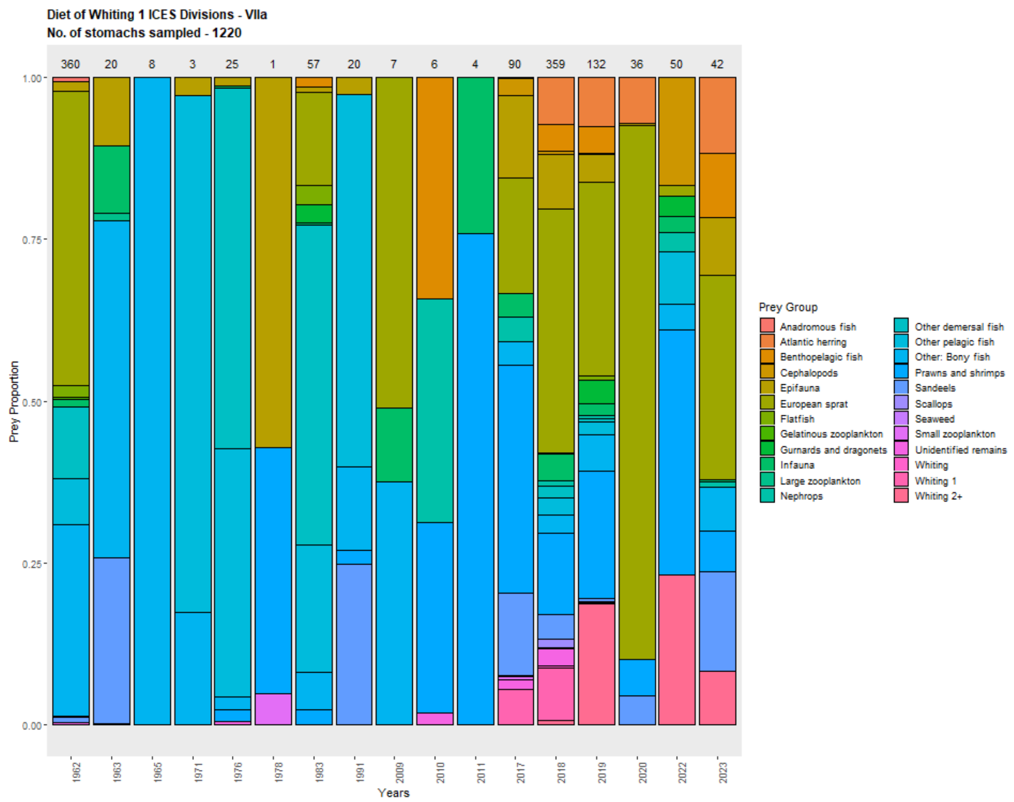

Fig. 9. Diet summary of juvenile whiting (<23cm). The total biomass weighted proportion of prey species, allocated to functional groups, found in predator stomachs during each survey year. Numbers above each bar denote the number of individual stomachs sampled.

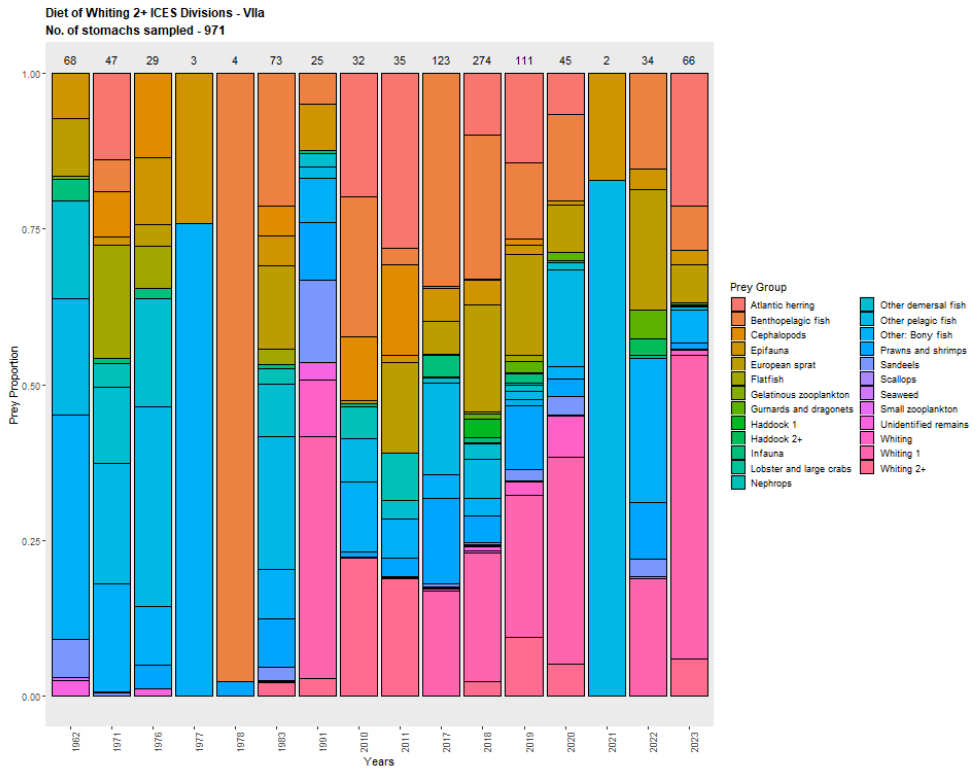

Fig. 10 Diet summary of adult whiting (>23cm). The total biomass weighted proportion of prey species, allocated to functional groups, found in predator stomachs during each survey year. Numbers above each bar denote the number of individual stomachs sampled.

3.4.5 Modelling whiting Irish sea Ecopath with Ecosim (EwE)

In 2015, stakeholders, scientists and policy makers commenced a process of carrying out the first International Council for the Exploration of the Sea (ICES) Integrated Benchmark Assessment, through a series of workshops known as WKIrish 1-6. This process culminated in the development of an Ecopath model (1973- 2016) for use in the ecosystem-based fisheries management of the Irish Sea (ICES. 2020, Bentley et al., 2020). The key-run of this model was presented at the ICES Working Group on Multispecies Assessment Models (WGSAM), and was accepted as an ICES key-run for informing ecosystem-based understanding of commercial fisheries in the Irish Sea (Bentley et al., 2019). Further model development in terms of further refinement of the diet matrices, and updating to more recent years is currently underway, with an updated model expected in 2025. The 2019 key-run is considered useful in the current benchmark considerations as it provides insights into the Irish Sea ecosystem and food-web interactions of whiting, for the majority of the stock assessment time-series.

Ecopath methods overview

In this section we describe the core components of the 2019 Irish Sea Ecopath key-run, which are of relevance to our current understanding of Irish Sea whiting in the context of the WKBNSCS benchmark (for full details see: Bentley et al. 2018, Bentley et al., 2019).

<u>Ecopath model groups</u>

Fish were represented in the model at a greater resolution compared to other organisms and comprise 22 out of the total 41 functional groups. Whiting (*Merlangius merlangus*) were split into 2 functional groups in the model: mature (age 2+) and immature (age 0-1). The spawning stock biomass of whiting in 1980 was estimated at 32,480 t based on the ICES stock assessment for 2017. Landings for mature whiting in 1973 were calculated using catch numbers and weight data (ICES 2016, Bentley et al. 2018).

Biomass for immature whiting was calculated as the total stock biomass minus the spawning stock biomass from 1980 (ICES, 2016). Landings of immature whiting were calculated by multiplying the number caught by their weight (ICES, 2016). An estimate for M was taken from the WKIrish model input (ICES 2016, Bentley, Serpetti et al. 2018).

Whiting 2+ and Whiting 1 were linked via a multi-stanza connection using a $Wmat$ estimate of 0.128 kg based on an $Lmat$ of 25.1 cm. $Wmat/W\infty$ was therefore calculated to be 0.221 (Bentley et al., 2018).

<u>Fishing mortality</u>

In equilibrium situations, fishing mortality (F) can be estimated as catch ($t.km^{-2}.year^{-1}$) over biomass ($t.km^{-2}$). Biomass lacks a time dimension and thus the fishing mortality is an instantaneous rate (per year):

$Fishing\ mortality\ (F) = catch/biomass$ (10)

<u>Natural mortality</u>

Natural annual mortality (M) for fish was estimated using (Pauly 1980) empirical model:

$log10M = -0.2107 - 0.0824 log10W\infty + 0.675 log10k + 0.4687 log10T$

where $W\infty$ is the species asymptotic weight, k is the curvature parameter of the von Bertalanffy growth function and T is the mean annual temperature (°C).

Ecopath (EwE) outputs

In this section, we describe the core results of the Ecopath key-run as they relate to Irish Sea whiting. When considering these results, it is first important to the note that during the construction the Irish Sea EwE model it was not possible to reproduce catch and landings of whiting based the standard effort time-series approach used in the EwE model. This may have been, in part, as a consequence of the lack of information on historical discard patterns and the changes in effort patterns between historical and more recent fisheries operating on whiting. Therefore, whiting landings in the model were also driven by an estimated fishing mortality parameter (*F* = *catch/biomass*). As both the catch and biomass are taken from the 2017 ICES assessment model, the EwE model in its current structure mirrors the perception of F mortality and to some extent natural mortality in the single-stock assessment.

Predation mortality

Despite this, the EwE model can give insights into changes in predation mortality (M2), due to the additional information on food-webs interactions and predator biomasses contained in it. Predation mortality is calculated as the sum of total consumption of prey over all predator groups. Predation mortality for both whiting stanzas have declined over the time-series, as the consumption rates of whiting predators have declined. This is driven largely by declines in biomass of Atlantic cod and whiting 2+ (Fig. 11, 12).

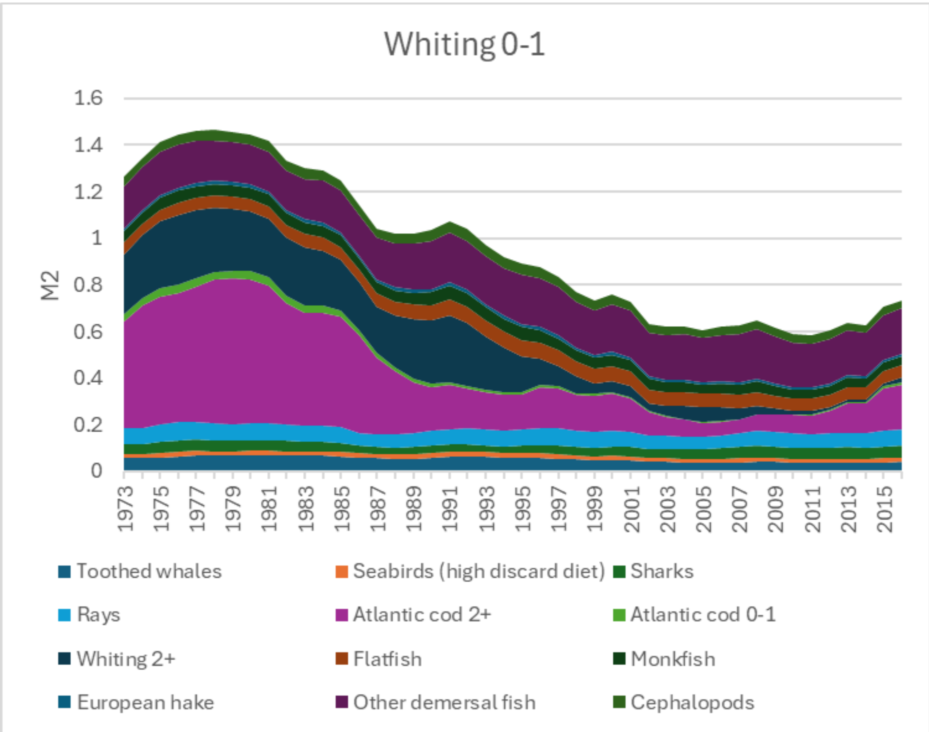

Fig. 11. Estimates of whiting 0-1 M2 (predation mortality) from Irish Sea EwE model.

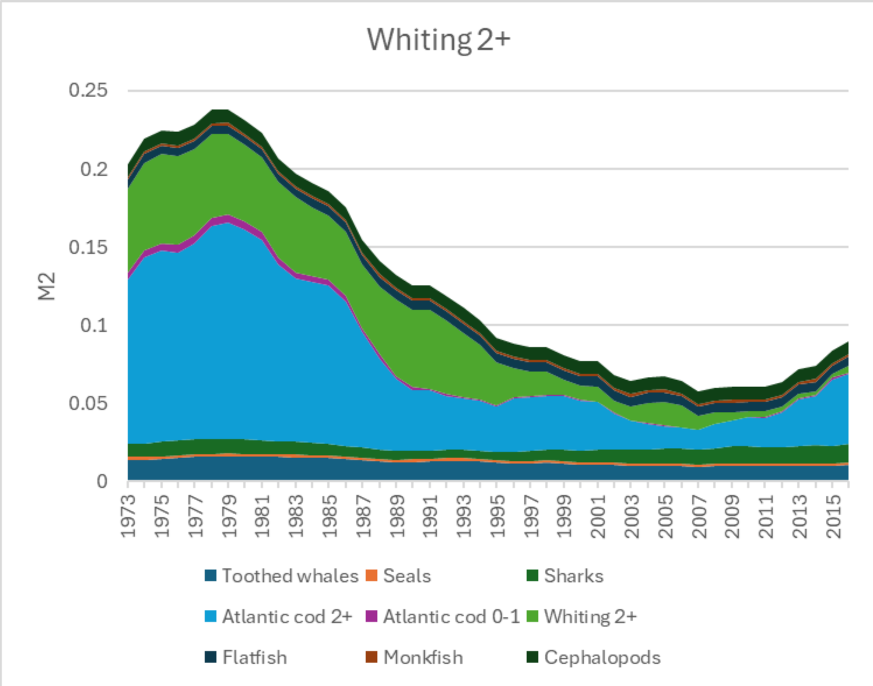

Fig. 12 Estimates of whiting 2+ M2 (predation mortality) from Irish Sea EwE model (Bentley, Serpetti et al. 2018).

<u>Ecopath model summary plots</u>

Summary plots from the Irish sea Ecopath model are provided (Fig. 13, 14). A separate output is provided for immature (0-1) and mature (2+) whiting groups in the model. These provide insights into the model parameters and ability of the model to match input time-series from assessment and catch data.

Both summary plots demonstrate the inability if the model to mirror the high biomass estimates of the stock assessment from the beginning of the time-series. The plots of predator mortality demonstrate the decline in predation mortality from the whiting and Atlantic cod as illustrated in the M2 plots above. These declines mirror the decline in biomass of these groups in the model. Mortality trends estimated from the assessment are used to drive catch in the model as effort time-series was unable to replicate catch sufficiently well.

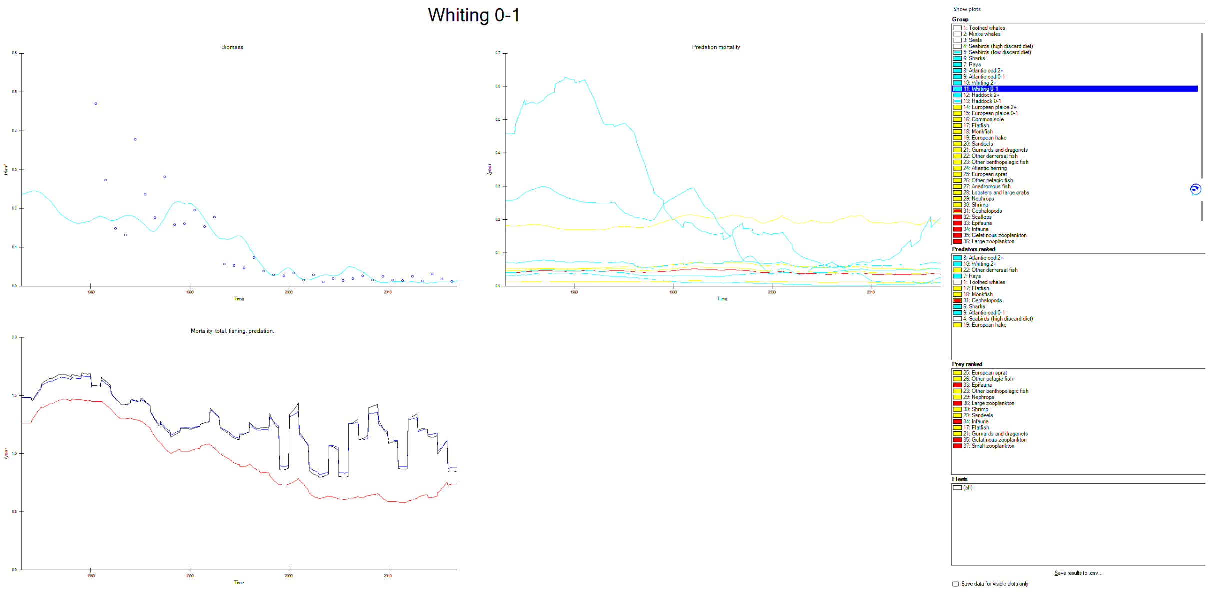

Fig. 13 Ecopath whiting 0-1 summary plots. From top left. Modelled biomass (cyan line) and time series (blue points) biomass from ICES single stock assessment (ICES, 2017). Predation mortality by group over time. Mortality estimates, Predation mortality (red line), Fishing mortality + Predation morality (Blue line) and total mortality (black line).

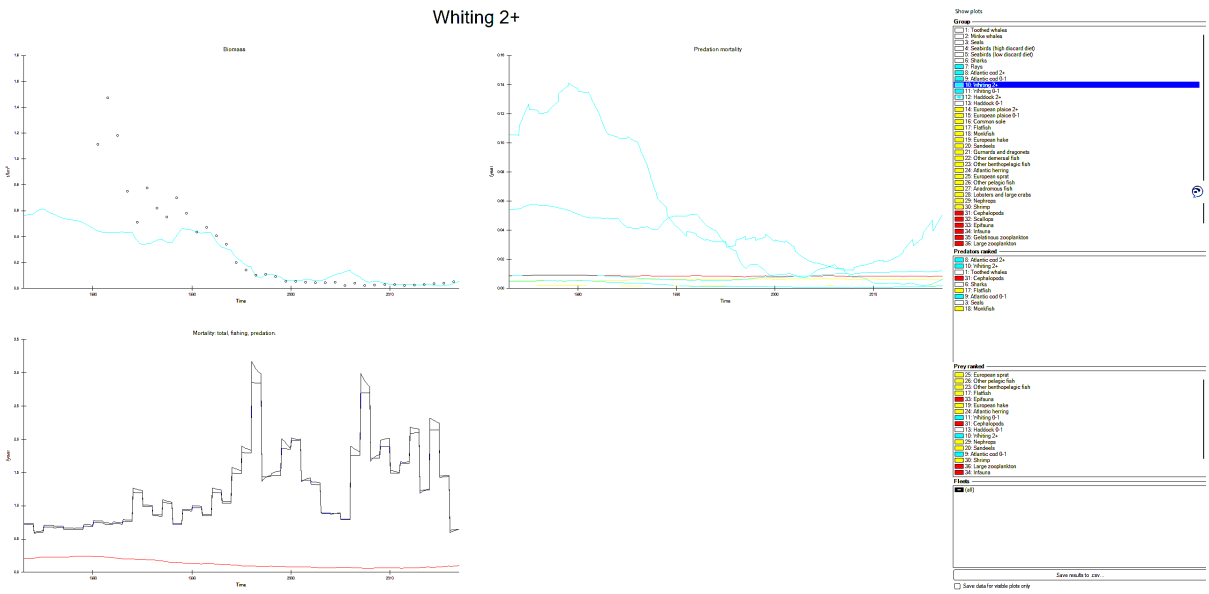

Fig. 14 Ecopath whiting 2+ summary plots. From top left. Modelled biomass (cyan line) and time series (blue points) biomass from ICES single stock assessment (ICES, 2017). Predation mortality by group over time. Mortality estimates, Predation mortality (red line), Fishing mortality + Predation morality (Blue line) and total mortality (black line).

Food availability index

An index of the food available to whiting based on prey preferences and prey biomass was calculated (food availability index). The Index was calculated by applying the equations described in Cafferty 2024, to the outputs of the Irish Sea Ecopath key-run.

The food availability index suggested an increase in the availability of prey over time for both mature and immature whiting (Fig. 15). Looking at more depth into the make-up of each index (Figs. 16, 17) it was clear that sprat was a major component of the index for both stanzas. While sprat is included as an important prey in the whiting 0-1 stanza (ind. <25.1cm) a closer look at whiting diet by size classes suggests that sprat is mainly an important prey item for whiting of sizes >15cm. Below this size range whiting feed predominantly on prawn and shrimps (e.g. *Crangon*, *Euphausiids*) (Armstrong 1979). Both this analysis and the ITA suggest that these prey have become less available since the early 1990’s. Removing sprat from the food availability index to reflect food available to juvenile whiting (<15cm), shows a strong decline in the food availability for this size class (Fig. 18). This perception of a decline in the prey field for small whiting mirrors that from the Integrated Ecosystem Analysis shown in figure 1 above.

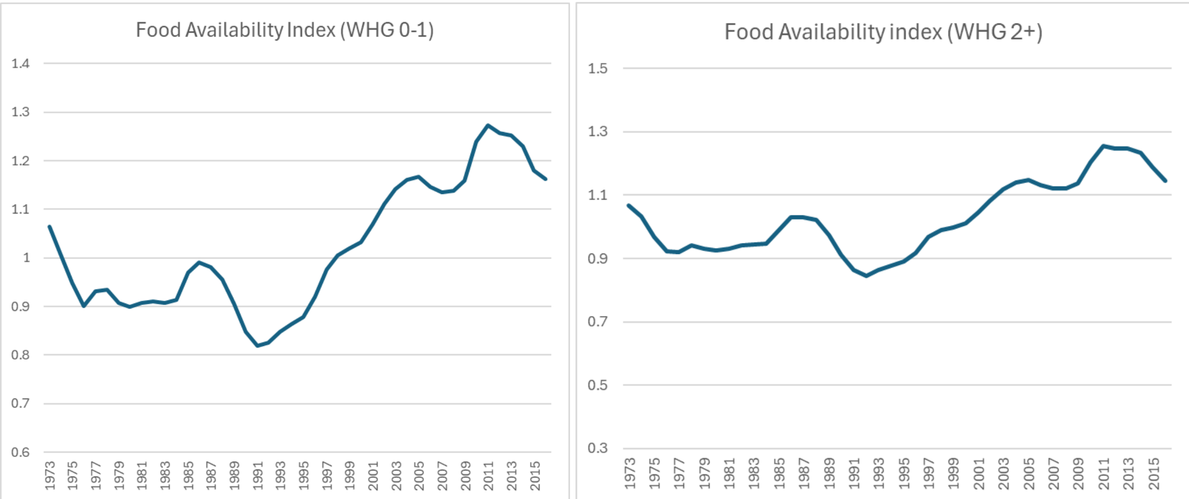

Fig. 15 Food availability index for whiting 0-1and whiting 2+ in the Ecopath Irish sea model 1973-2016.

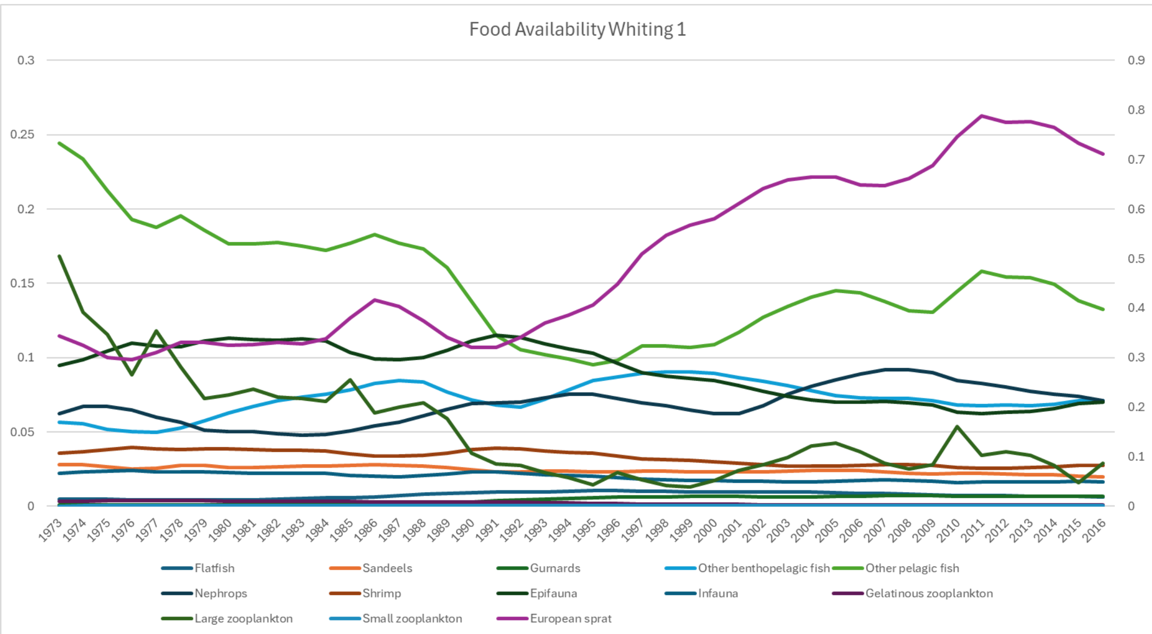

Fig.16 Trend in food availability by prey group for whiting 0-1, 1973-2016.

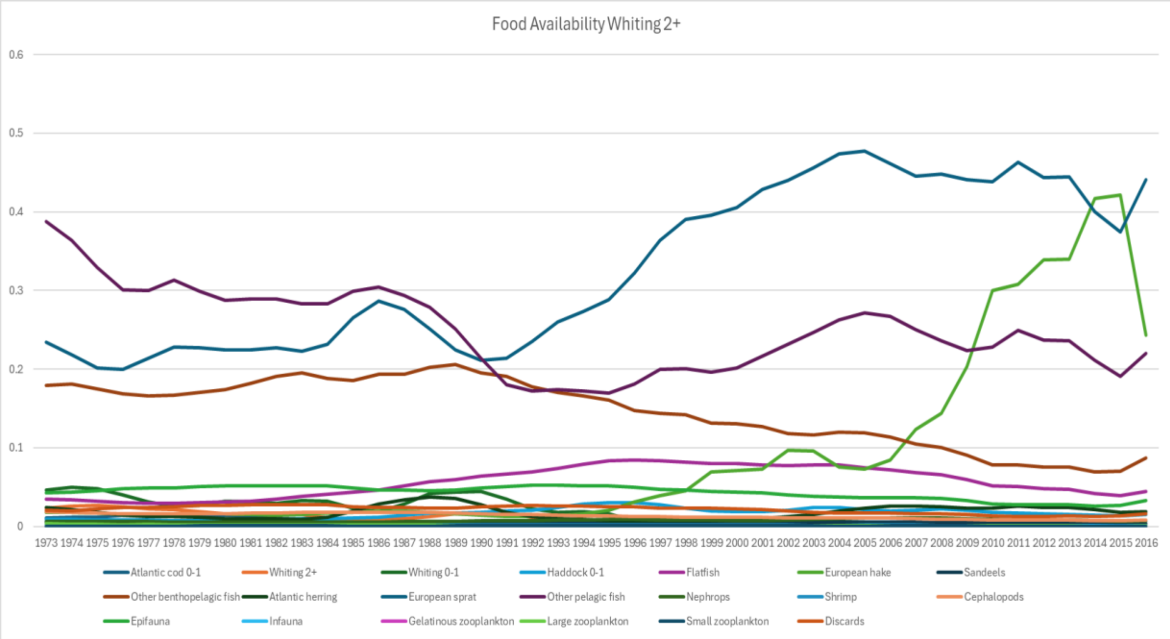

Fig. 17 Trend in food availability by prey group for whiting 2+, 1973-2016.

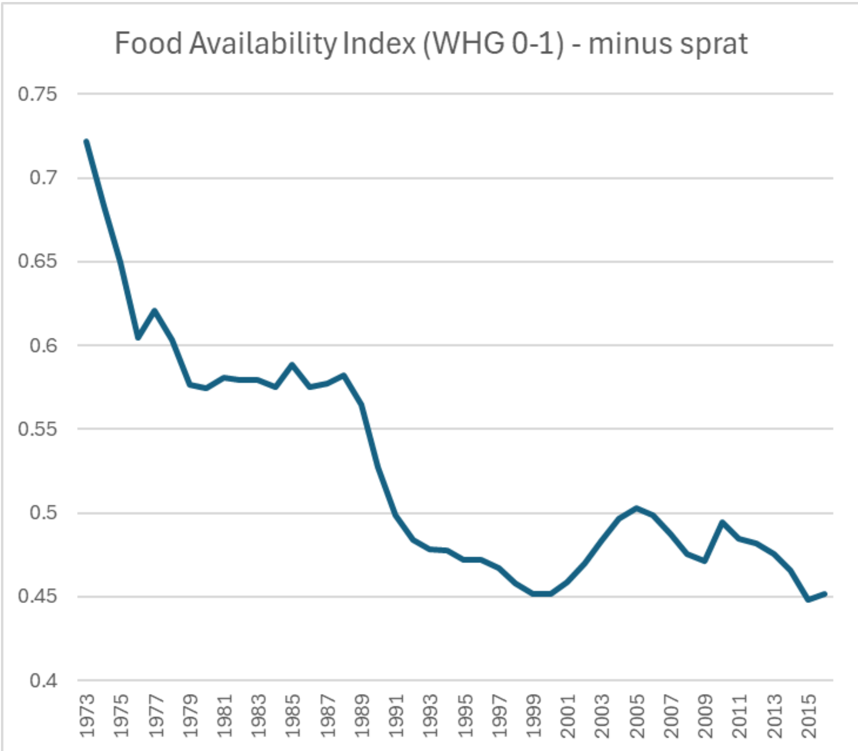

Fig. 18 Food availability index for whiting 0-1 in the EwE Irish sea model – minus sprat 1973-2016.

3.4.6 Genetic analyses of Irish Sea whiting

Recent genetic analysis conducted in partnership between AFBI and Queen's University Belfast suggest Irish Sea whiting retains a high level of genetic diversity, the despite the observed recent declines in stock biomass and reduction in weights-at-age. Specifically, this study found that there was no evidence for a genetic bottleneck in Irish Sea whiting when comparing contemporary (2004-2022) and historical (1957-1962) samples taken in the Irish Sea. DNA of adequate quality for genetic analysis was successfully extracted from 400 samples. All samples (contemporary and historical) were analysed using a panel of 14 highly polymorphic microsatellite markers, which were specifically developed and optimised for this project by 'mining' the withing genome available on the GenBank online genomic database. On average, the contemporary samples demonstrated an allelic richness of 60.1 alleles per locus, in contrast to 54.4 in the historical samples. There was also no evidence of population genetic substructuring observed in either the contemporary or historical samples, suggesting mixing between whiting in the western Irish Sea where the core fishery takes place and those sampled elsewhere in the Irish Sea. This suggests that the Irish Sea Whiting stock retains genetic reproductive potential despite recent declines in stock biomass.

3.4.7. Discussion

Declines in whiting spawning stock size (SSB), recruitment and weights at age have all occurred against a backdrop of ecosystem wide changes and the fisheries operating in it from the early 1990's onwards. Evidence for unfavourable conditions for growth may be apparent in the observed changes in whiting diet and ecosystem state. Increasing sea temperatures and decreases in the planktonic prey field in the Irish Sea may have led to unfavourable feeding conditions through changes in growth, phenology, spatial overlap and foodweb processes. Increases in cannibalism may be evidence of these unfavourable feeding conditions acting on whiting and the food-web as a whole.

Armstrong et al., 2004 suggested that the apparent paradox of a reduction in both the biomass and individual growth of whiting might be explained by the dynamics of cannibalism (e.g. lack of density dependent growth), if over-fishing of adult whiting had resulted in an increase in density of juvenile whiting in coastal waters. Despite the low abundance of adult whiting over large areas of the Irish Sea, juvenile whiting remain one of the most abundant components in research trawl hauls (e.g. the Northern Irish Groundfish Surveys (NIGFS)). Diet studies in the Irish sea have demonstrated however that cannibalism is now more prevalent in the Irish sea whiting stock with an apparent increase in the proportions of whiting identified in diet of individuals >25cm since the 1990's. Current estimates suggest whiting cannibalism could account for >20% whiting diet requirements. This suggests that a reduction of cannibalism may not be the main cause of the reduction in growth rates, in the period since the1990's.

More recent research continues to support the hypothesis that temperature changes are affecting fish growth and age at maturation in UK waters (Fox, Marshall et al. 2023). Ectotherms (cold-blooded animals) generally develop faster and mature at smaller body sizes at higher temperatures, leading to smaller maximum body sizes overall (Wright, Pinnegar et al. 2020). Increasing sea temperatures are therefore predicted to decrease body size of marine ectotherms based on the temperature size rule (TSR; Atkinson, 1994).

Evidence is accumulating that many marine ectotherms are undergoing rapid changes in their life-history characteristics. These changes have been variously attributed to fisheries-induced evolution, inhibited adult growth rate due to oxygen limitation at higher temperatures, and plastic responses to density dependence or changes in ocean productivity (Audzijonyte et al., 2016). While no one type of response appears to explain the observed declining trends in body size, and earlier maturation of Irish Sea whiting, earlier energy allocation into reproduction due to a combination of direct temperature effects, and evolutionary responses to elevated adult mortality from temperatures or fishing, together with the susceptibility of large fish to decreased oxygen supply in warming waters can all be expected to be involved (Audzijonyte et al., 2016).

The long-term trend in the reduction of Irish sea whiting growth rates and population may therefore be a combination of the sustained high rates of fishing mortality, especially on the juvenile fish, increased temperatures and reductions in overall productivity of the Irish Sea Ecosystem.

The trends in biology of the whiting stock identified herein are reliant on both commercial and research survey data of the Irish Sea whiting stock. Hence, a caveat should be applied that the underpinning data should be viewed in light of the historical changes Irish Sea fisheries. With the decline in the demersal whitefish otter trawl fleet and recent dominance of the Nephrops trawl fisheries, the interaction between the whiting population and the fishery has undoubtedly changed in terms of spatial and temporal coverage and selectivity. For further discussion, on the fishery and spatial overlap between the fishery and the Irish Sea whiting stock, see WD 3.5 Whiting in Division 7.a History of fishery and spatial considerations.

Taking a holistic approach an Ecopath with Ecosim (EwE) model for the Irish Sea revealed the indirect impacts of environmental change on fish biomass and catch through trophic interactions (Bentley et al., 2020). The ecosystem model suggested that historical environmental change supressed the overall production of commercial finfish, whilst also dampening the rate of stock recovery despite marked reductions in fishing effort. The better fitting models included environmental drivers (such as primary productivity anomaly, the Atlantic Multidecadal Oscillation (AMO), sea temperature, zooplankton abundances) suggesting that it may be important to include environmental drivers when formulating stock management and rebuilding strategies. Although climate projections were not undertaken, the best fitting model included negative relationships between the AMO and cod and whiting recruitment success. Thus, both these species in the Irish Sea may be expected to struggle to produce larger than average year-classes in a warming climate, a conclusion in line with other studies cited in (Wright et al., 2020) and (Fox et al., 2023).

Taken together the findings presented here, alongside those of the WKIrish process (ICES, 2016, ICES, 2017b, ICES, 2015, ICES, 2018a, ICES, 2018b, ICES, 2020), provide strong evidence of a 'regime shift' in the Irish Sea, which is likely to have impact on the population dynamics and biology of the Irish Sea whiting stock.

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WD 3.5 Whiting in Division 7.a_History of fishery and spatial considerations

Working document to WKBNSCS 2024-25

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3.5.1 Historical context of the Irish Sea whiting fishery

The whiting fishery in the Irish Sea expanded rapidly during the early 1940's, with effort off the County Down coast during the war years increasing after an influx of vessels from the east side of Scotland. It was thought this increase in effort was driven by the presence of some very strong whiting year-classes (Hillis 1968). The species was the most important by weight of all demersal commercial species landed in the Irish sea. The fishery traditionally operated during autumn and winter months (August – March) on areas of highest population density off County Dublin in the Lambay Island-Rockabill area and off County Down in the outer part of Dundrum Bay (Hillis 1968). Age 1 fish dominated the autumn fishery with older fish caught in deeper and more northern areas as the season progressed.

This fishery was mainly an unselective trawl fishery with mesh sizes of 50 or 60 mm most common. There was also some seine netting. Initially the fishery was mainly targeting whiting but by the late 1960s cod was becoming more important. Landings of whiting and cod were mainly >10 000 t/year throughout the 1970s and late 1980s (ICES 2017).

The decline in the catch rate and economic importance of whiting was accompanied by a switch from seining to trawling and from whitefish trawling to prawn trawling with small mesh net (Brander 1977). With the increase in proportion of small mesh fisheries high rates of rejection or discarding were recorded with estimates of undersized fish rejection 60% in 1973 (Brander 1977). Discarding of pre-recruit whiting has therefore been a major issue in this fishery for some at least fifty years with mortality rates between 2.0-2.5 estimated in the 1970's.

Effort of otter trawlers utilizing a larger mesh range, traditionally targeting whitefish (cod, haddock, whiting), has seen a steady decline since the 1970's, partially as a result of effort management restrictions. The effort of the *Nephrops* fleets show increases in the 1970's and early 1980's, and remain main demersal fishery in the Irish Sea despite declines in fishing effort since the early 1990's.

The majority of whiting caught since around the early 2000's are discarded in the *Nephrops* fishery. During 2021–2023, the mean catch of whiting was 1 229 tonnes with landings contributing to 5% of the catch. In 2023, 81% of the discards and 79% of the catch of whiting in Division 7.a originated from the *Nephrops* bottom-trawl fisheries. The majority of these are below the minimum conservation reference size (MCRS). Whiting is also caught as bycatch in lesser quantities by other demersal and pelagic fleets in the region.

3.5.2 Spatial distribution of the fishery and stock

Change in Irish Sea fisheries described above, from primarily whitefish targeting fleets to a *Nephrops* focused industry, have been accompanied by a shift in the spatial distribution of fishing effort of the fleets.

Irish Sea whiting fisheries from the 1960's to the 1980's were caught across two large areas; the western Irish Sea from County Dublin to the County Down, and the Eastern Irish Sea, from North Wales from North Wales to Anglesey. Catches had differing size distributions across these areas, with fish in 1-2 year age classes dominating in the western Irish Sea catches, and 2-4 year olds in the Eastern Irish Sea area (Hillis, 1968) (Fig. 1). A further fishery is noted by Hillis in the Clyde area at that time, now considered part of ICES Division 6a.

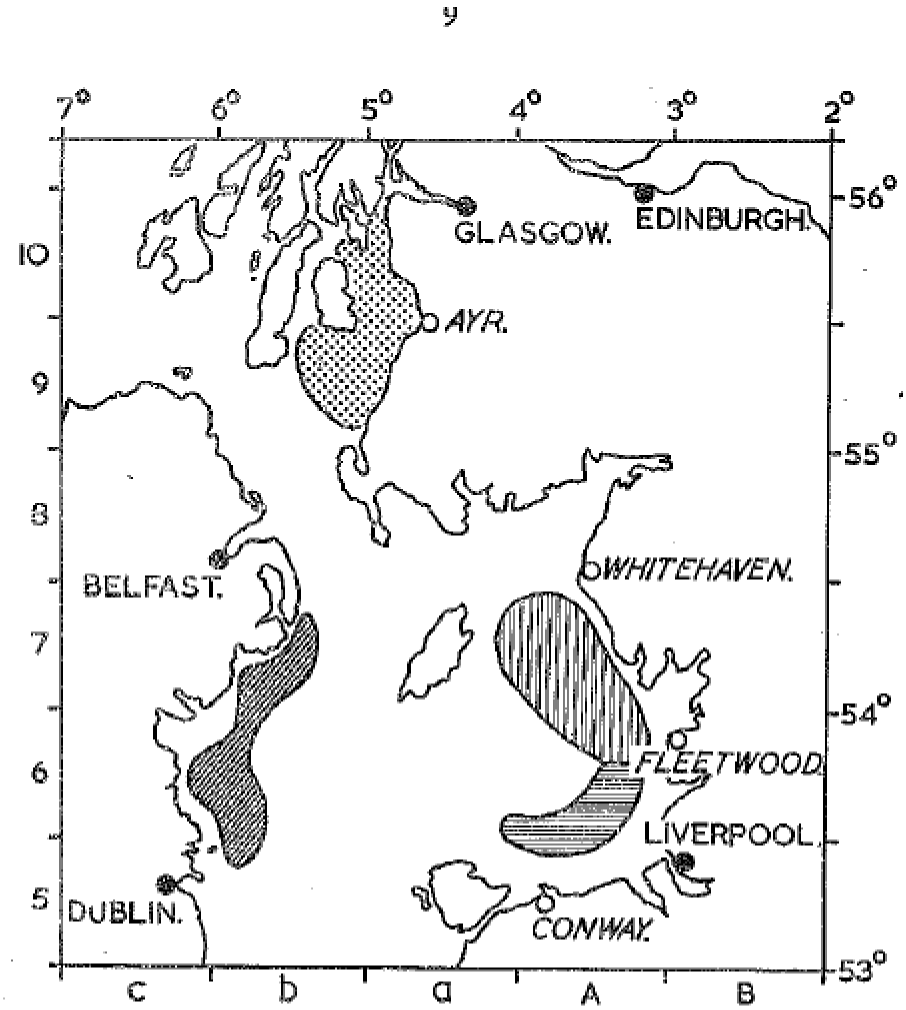

Fig 1. Distribution of Irish Sea whiting fisheries circa 1968, reproduced from Hillis, 1968.

Since the 2000's the distribution of whiting catches in the Irish Sea primarily reflects that of the *Nephrops* otter-trawl fishery, which is concentrated mainly in the Western Irish Sea off the county Down coast, on the FU15 *Nephrops* grounds. To a much lesser degree bycatch of whiting is observed in pelagic fisheries operating to the west of the Isle of Man (Fig. 2).

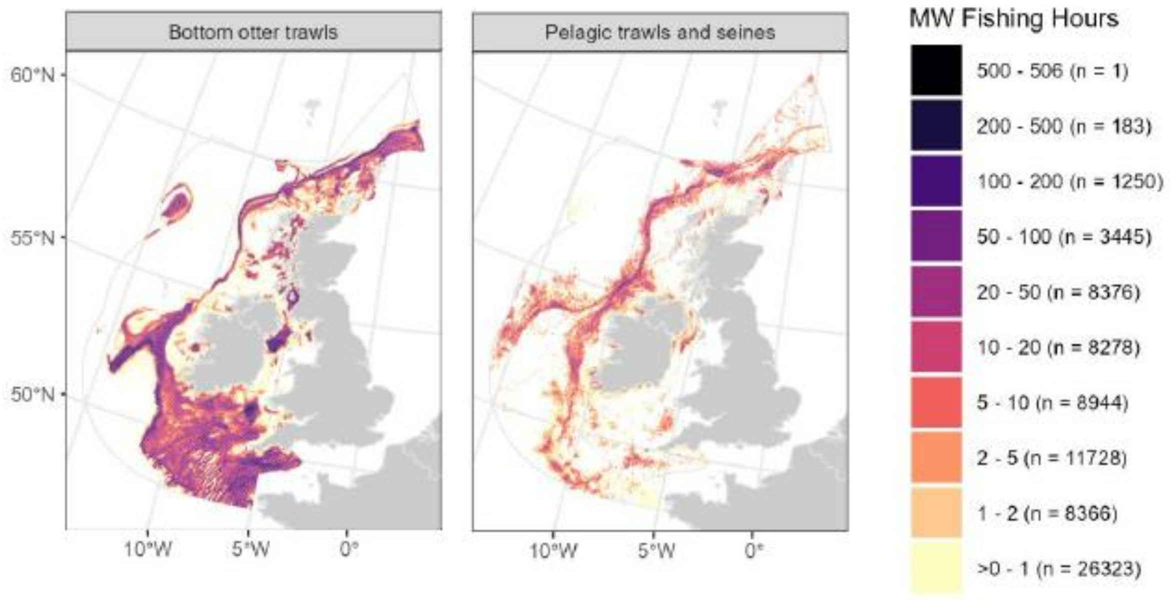

Fig. 2 Distribution of Irish Sea bottom trawl, pelagic and seine fisheries, 2019-2022, reproduced from ICES, 2024.

The current predominance of age 1-2 fish in the catch could be posited to reflect this change to the spatial distribution of the fishery, given that older fish in the earlier period were reported to have been primarily caught in the Eastern Irish Sea. This more easterly distribution of older fish is also reflected in the Northern Ireland ground fish survey of the region (Fig. 3), with adult whiting are generally found in the deeper offshore waters (>60m) of the central and southern regions (Burns, Bailey et al. 2019). Whilst, strong declines in numbers of fish are not corroborated by the Northern Irish Groundfish Survey, the weight-at-age of fish over time does decline over the period of the survey (1992-2023). Furthermore, the longer term decline in weight-at-age in Irish Sea whiting, observed during the 1980s in fishery catches, is confirmed however by the comparison between recent survey estimates of length at age with data collected from research hauls in the 1950s and 1960s (Gerritsen et al. 2003).

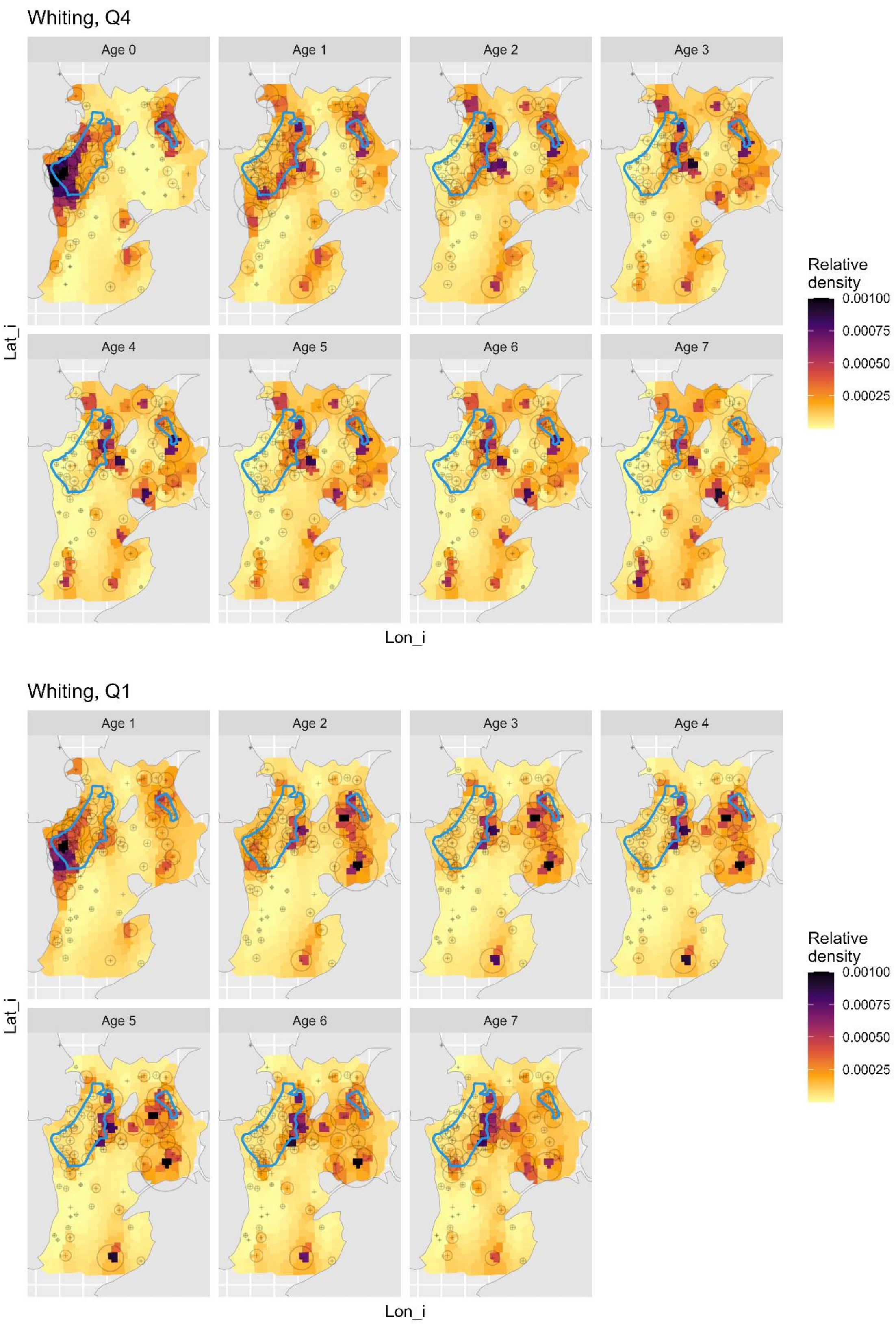

Fig. 3. Spatial distribution of whiting in Q1 (top) and Q4 (bottom) estimated by the 2025 whiting benchmark VAST model. The crosses indicate the sampling locations, the circles indicate the average catch numbers per swept area; the areas outlined in blue are the main fishing grounds for *Nephrops*. For more details see WD_3.3_Whiting in Division 7a VAST index for NIGFS.

Broader geographic distribution

Survey information for the various IBTS regional groundfish surveys were downloaded from DATRAS and mapped by year (Fig. 4, 5) as part of the WKIrish 3 workshop (ICES 2016). Figure 3 shows the annual (2003 – 2015) distribution of juveniles (ind. <20cm). This illustrates how the western Irish Sea (FU15 *Nephrops* ground) and to a lesser extent, the eastern Irish Sea account for the largest numbers juvenile whiting caught on all IBTS surveys in the region. By contrast, there were relatively few juveniles (ind. >20cm) caught in the Celtic Sea, west of Ireland and west of Scotland. The maps corroborate with historical reports that the east coast of Ireland is an important nursery area for juvenile whiting with high abundances observed. Whilst results of different IBTS surveys are not directly comparable, given differences in survey methodologies, fishing gears and survey timings, the map is considered to be indicative of the general pattern in juvenile distribution across the region.

Biomass maps for all size ranges of whiting (Fig. 5) demonstrate that high biomasses also occur in the Celtic Sea around the Smalls *Nephrops* ground and in the North Irish Sea in most years. These differences corroborate the spatial segregation between adult and juvenile whiting.

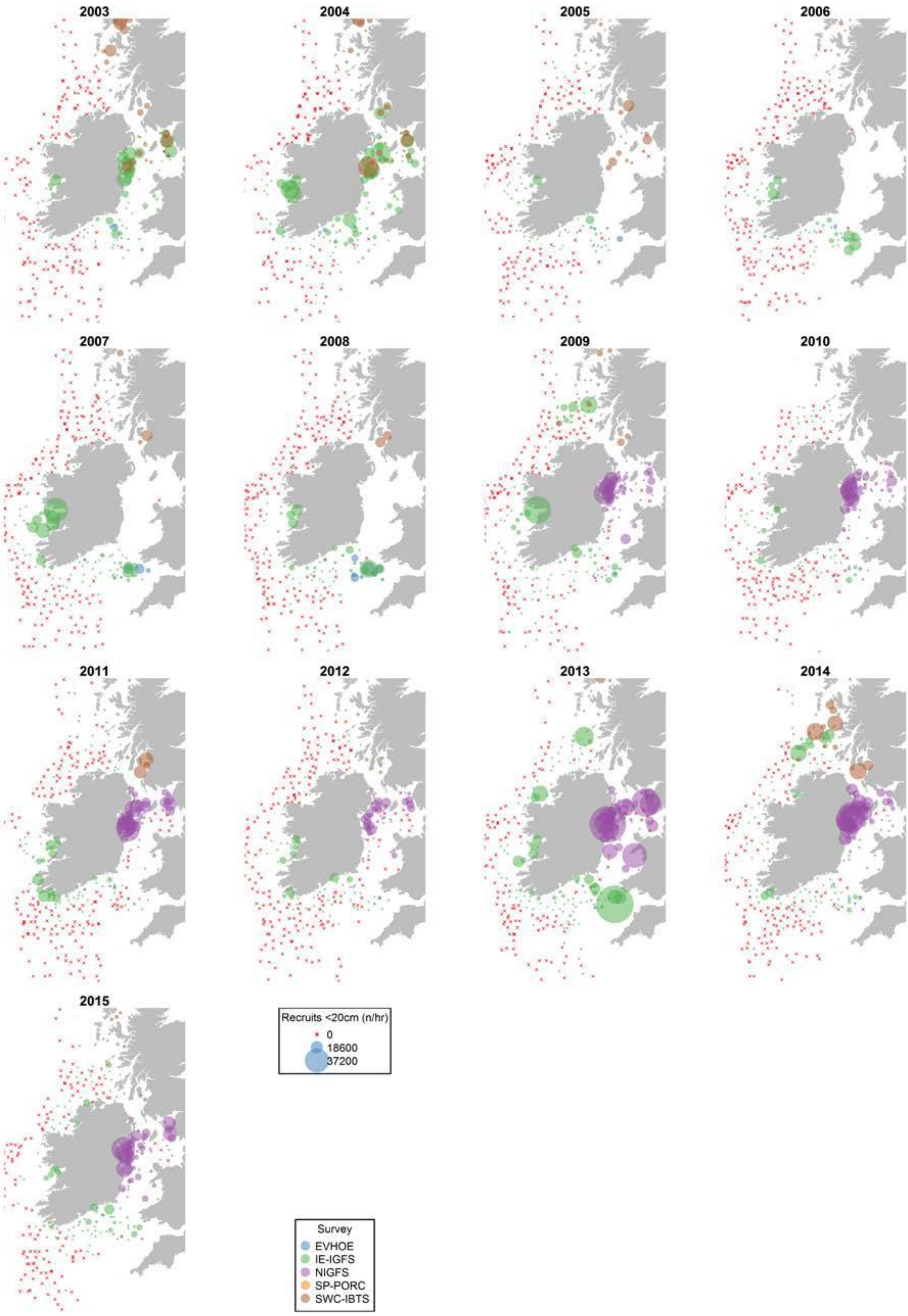

Fig. 4 Whiting numbers of recruits (<20 cm) by haul from IBTS survey in DATRAS around Ireland. NIGFS data available for 2009 – 2015 only

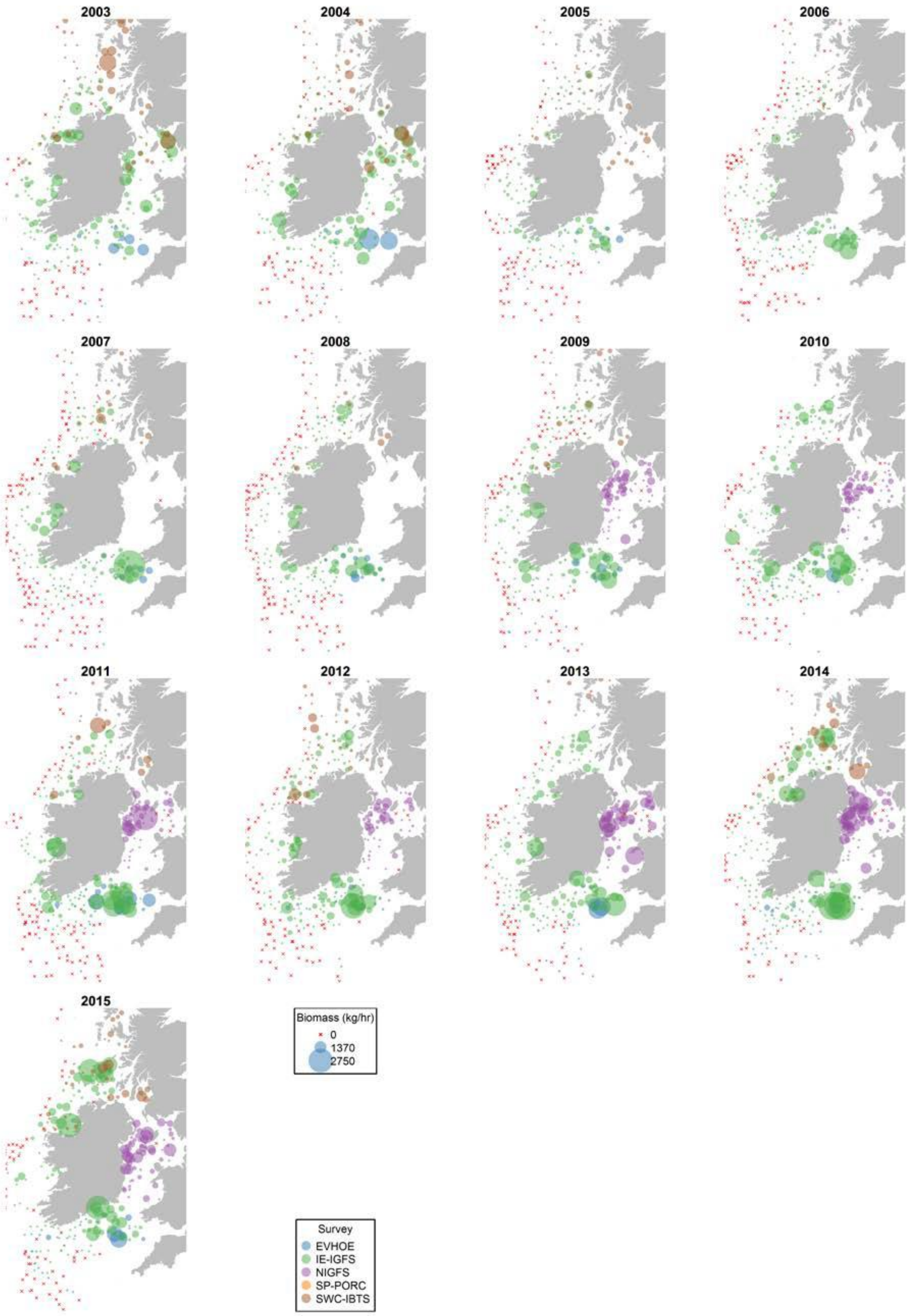

Fig. 5 Whiting biomass by haul from IBTS surveys in DATRAS around Ireland. NIGFS data available for 2009 – 2015 only

3.5.4 Movements and connectivity

Historical tagging experiments (1957/58) were conducted in the western Irish Sea area of the Downs whiting fishery, and demonstrated the connectivity between this nursery area and surrounding regions. The majority of recaptures were taken to the east of the Isle of Man but with further movements to the south-east of Ireland and Firth of Clyde, west coast of Scotland detected. The rate of emigration from these tagging studies was estimated at 40%, with no returns of these fish detected in subsequent seasons (Garrod, et al., 1963). Returns from tagging work in surrounding areas to the western Irish sea, particularly the Clyde and west IOM regions suggested extensive mobility and connectivity between areas.

More recent studies have examined connectivity between the Irish sea, west of Scotland whiting populations using otolith micro-chemistry. Clear connections and movement of juveniles between the areas was shown, supporting the previous tagging studies. The northerly movement of Irish Sea fish into the Firth of Clyde indicates a close link between these two areas (Burns, Hopkins et al. 2020). This study did not look at links with more southern populations in the Celtic Seas.

Further studies from the west coast of Scotland indicated that several identified whiting nursery areas contributed to identified spawning aggregations, while a lack of evidence for return migrations suggested an opportunistic and non-philopatric recruitment strategy within a single population unit. The study suggested the Scottish west coast could be viewed as a net source of recruits to the North Sea (Tobin, Wright et al. 2010).

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WD 3.6 Whiting in Division 7.a SAM assessment model

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1 Introduction

SAM is a state-based assessment model described in detail by (Nielsen and Berg, 2014 & 2016). It connects observed states (catches and survey indices) to unobserved states (stock size, and fishing mortality, *F*). The underlying process in the model is considered as the unobserved random variables. SAM allows for uncertainty in the observed states and produces estimates of the unobserved variables without the need to specify variances directly. Instead, the distribution of process error can be defined. Prediction noise is assumed to be Gaussian with mean zero, and three variance parameters (recruitment, other age groups, *F*). The component of prediction noise relating to stock size-at-age is assumed to be uncorrelated. A correlation structure for prediction noise in *F*-at-age can be specified. The model allows for time-varying selectivity which determines *F*-at-age.

The observation function consists of catch equations for both commercial catch, and survey fleets. Fleet catchabilities can be coupled across age groups. Measurement error is assumed to be Gaussian with mean zero. Each data source (i.e. catch and survey indices) an associated covariance matrix. Where autocorrelation is implemented in the covariance structure for a given fleet, parameters can be coupled across age groups. Model parameters are estimated from the observations, and the unobserved random variables can be predicted, conditioned on the observations. Laplace approximation is used to calculate the joint likelihood of observed and unobserved states. The software used to solve the high-dimensional non-linear models includes automatic differentiation and Laplace approximation.

2 Methods & Results

2.1 Base Model Configuration

All explorations of model sensitivity, and the relative improvement of the overall model fit (Section 2.2) were compared to the following configuration. All these settings were generated using the default configuration function ("defcon") in the "stockassessment" package (Nielsen and Berg, 2014 & 2016). The minimum age in the assessment was set to zero (i.e. modelled recruitment estimates at age zero). The maximum age was six, representing a plus group (henceforth, "six+"). The stock recruitment relationship was modelled as a plain random walk.

The SAM model was fitted to catch data (total commercial catch numbers-at-age only, i.e. no recreational catch), and three age-based survey indices (NIMIK MIK net larval recruit survey, and VAST modelled indices for the NIGFS Quarters 1 & 4 surveys weighted by coefficient of variance at age). Age-based biological parameters estimated for the stock were also input to each model configuration (i.e. natural mortality-at-age and maturity-at-age; (Gerritsen and Moore, 2024)). The time range of the assessment included catch data from 1980 onwards, and survey data from 1992 for NIGFS indices, and from 1994 for the MIK net recruitment index. Stock weights-at-age, and commercial catch weights-at-age, both of which were also reviewed as part of this benchmark process) from survey data, are included in the input data object for the calculation of SSB, landings and discards biomass.

Observed state process: Logarithms of total catches and survey indices were assumed to be independently distributed with error variance coupled for all ages in the commercial catch fleet. The survey catchabilities were uncoupled for the oldest age group in each NIGFS fleet (i.e. age six+).

Unobserved state process: Fishing mortality states of the two oldest age groups, age five and six+, were coupled. Process variance for fishing mortality was coupled across all age groups. The fishing mortality across ages was modelled with AR1 autocorrelation. Process variance of stock size was coupled for all ages except for age zero.

Table 1. SAM Base Model configuration settings. Where configuration settings are not specified, default configurations were used.

CONFIGURATION SETTING	DETAILS
Assessment age range	0-6+
Is maximum age considered a plus group	1 1 1 0
Coupling of the fishing mortality states	0 1 2 3 4 5 6 6
Correlation of fishing mortality across ages	AR1
Coupling of the survey catchability parameters	$\begin{pmatrix} - & - & - & - & - & - & - \\ - & 0 & 1 & 2 & 3 & 4 & 4 \\ 5 & 6 & 7 & 8 & 9 & 10 & 10 \\ 11 & - & - & - & - & - & - \end{pmatrix}$
Covariance structure for each fleet	Independent "ID" for all fleets
Stock recruitment code	Plain Random Walk
$\bar{F}$ range	1-3 (as per ASAP assessment; ICES, 2023)

The Base Model stock development is illustrated in Figure. Estimated catch, recruitment, and spawning stock biomass (SSB) initially follow steep declining trends until the early 1990s after which they all remain relatively stable at a low level. $\bar{F}_{1\text{-}3}$ increases steadily until 2006, after which it fluctuates around a value of 1. Overall, these trends in stock development were similar to the ASAP assessment model for the stock (ICES, 2023), but the recruitment estimates for the SAM model were scaled up due to the increased natural mortality. There were patterns in the Base Model one-observation-ahead fleet residuals which were indicative of a sub-optimal model fit (Fig. 2Figure). For the commercial fleet, the majority of residuals-at-age, mainly for fish between two and six+ years old, had positive values in the second quarter of the modelled period (~1990-2000), moving to majority negative values between ~2000-2015. The modelled NIGFS Q1 index had mostly positive residuals at age five, and negative residuals at age six+, whereas the opposite was apparent in the modelled NIGFS

Q4 index (i.e., negative residuals at age five, and positive residuals at age six+). There were no such obvious patterns in the MIK net recruit index, nor were there any obvious patterns in the process residuals (Fig. 3). The leave-one-out analysis failed to converge with successive removal of survey indices. The retrospective analysis (Fig. 4) suggested that the model was robust to removal of up to five years of data (*Rho*$_{rec}$ 0.03, *Rho*$_{SSB}$ -0.004, *Rho*$_{F}$ 0.07).

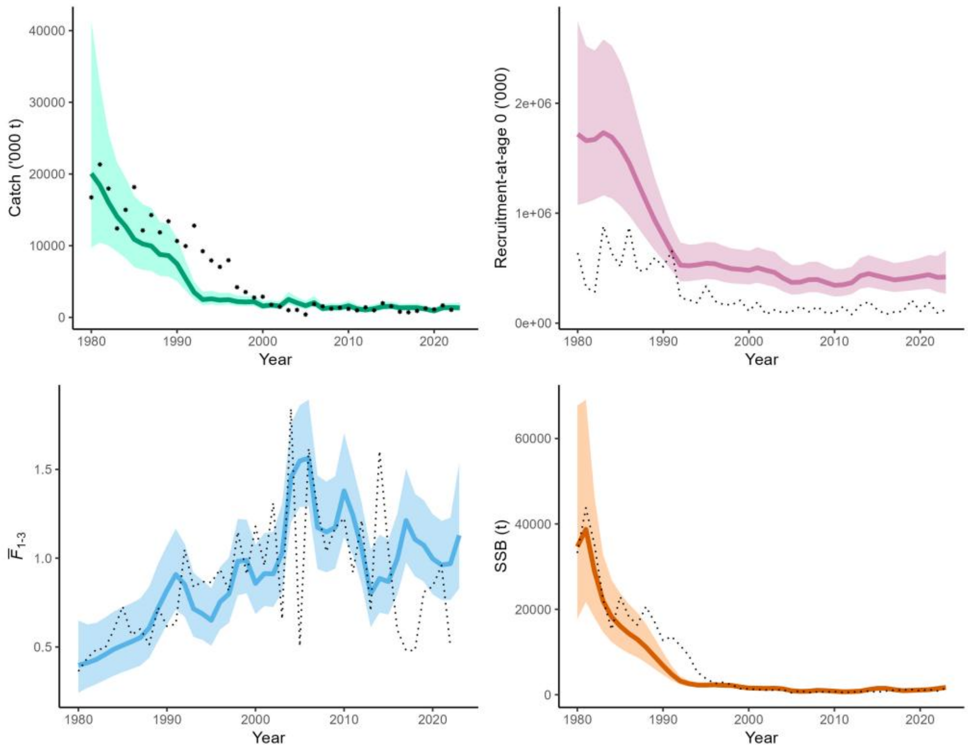

Figure 1. Summary of SAM stock development for the Base Model configuration. SAM estimates of catch (*green*), recruitment (*pink*), mean fishing mortality (*blue*), and spawning stock biomass (*orange*) with 95% confidence intervals (coloured bands) are presented. Equivalent estimates from the ASAP model are shown with dotted *black* lines.

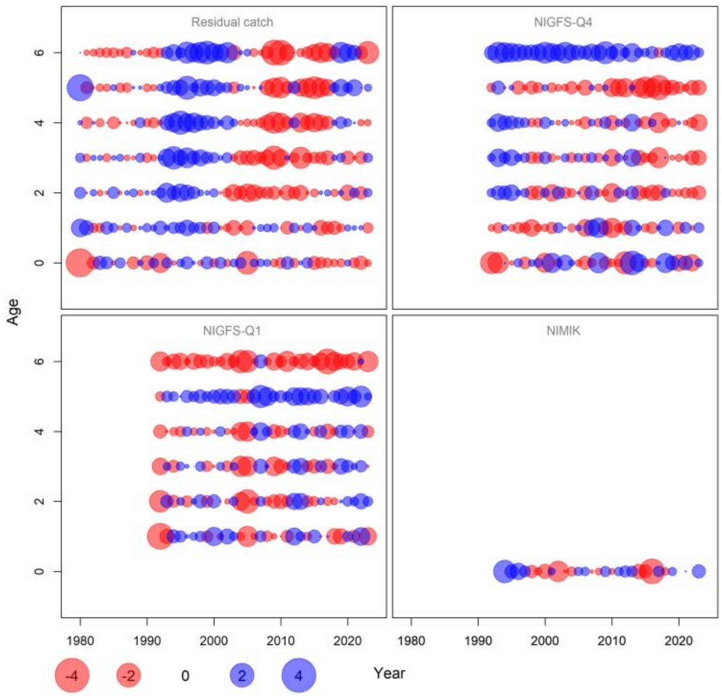

Figure 2. One-observation-ahead fleet residuals for SAM Base Model

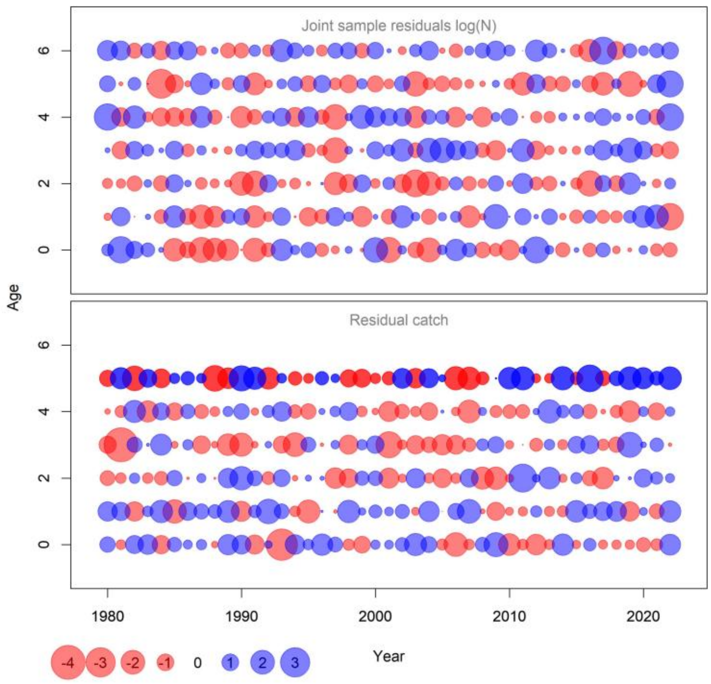

Figure 3. Process residuals for SAM Base Model

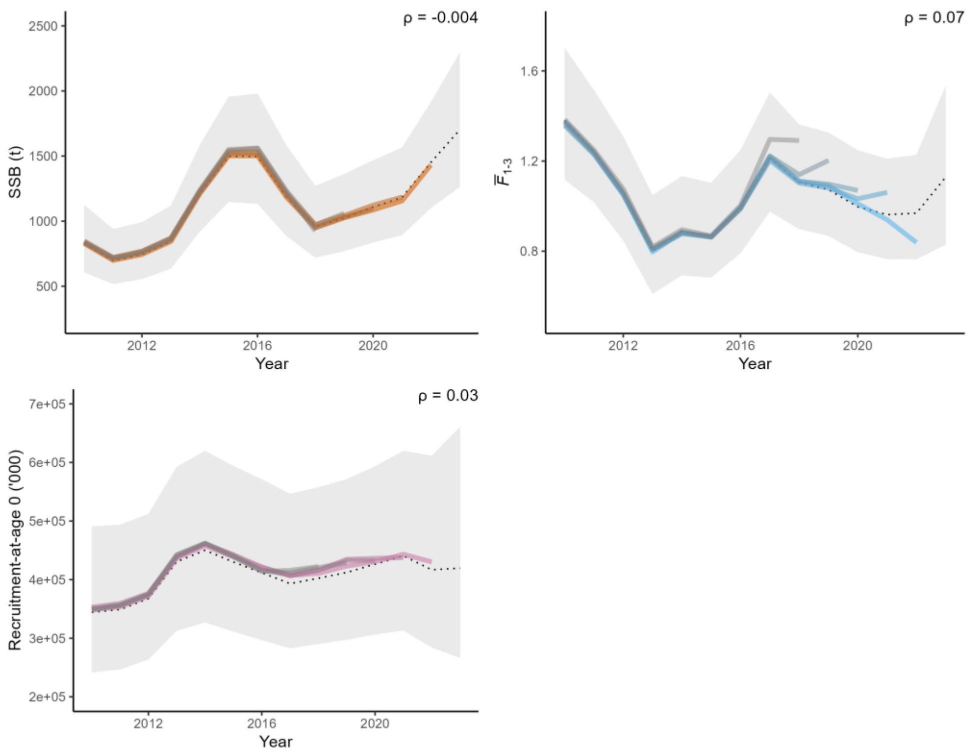

Figure 4. Retrospective pattern over five peels for the Base Model (2010-2023)

2.2 Exploring Model Implementations

2.2.1 Recreational Data Scenarios

SAM implementations with the base model configuration were run for each of the recreational data scenarios described in (Radford *et al*, 2024). These models all had similar fits to the base case, in terms of the diagnostics described above (Section 2.1). The stock development was similar across recreational scenarios (Fig. 5), with an upward re-scaling of catch, SSB, and recruitment in the earlier part of the time-series for scenarios where commercial catches were proportional to SSB. $\bar{F}_{1\text{-}3}$ closely overlapped for all scenarios.

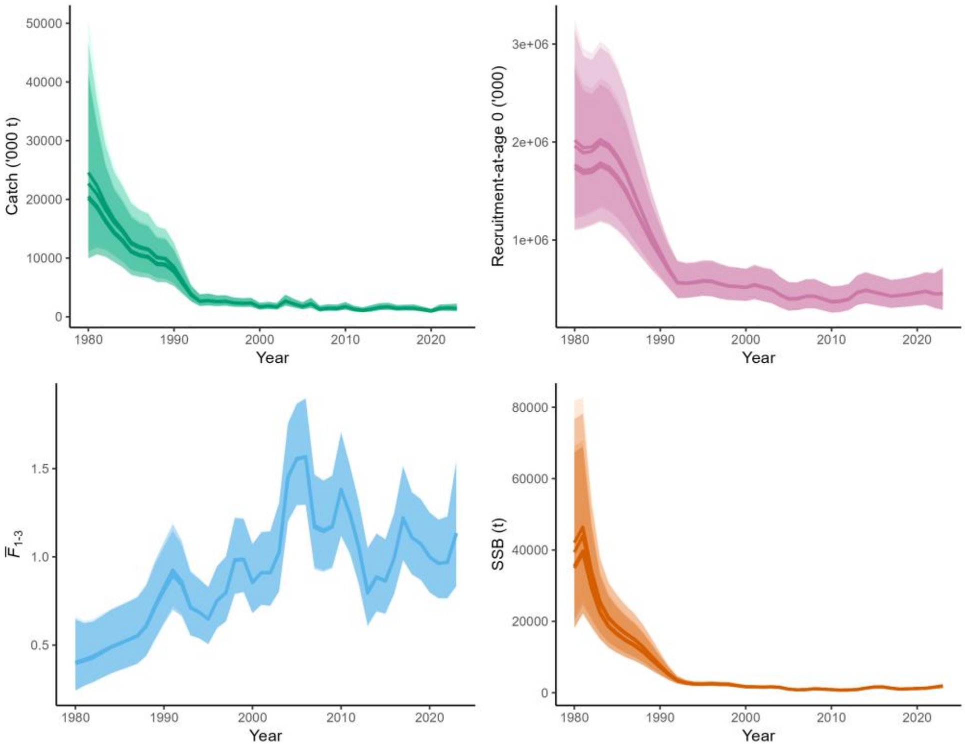

Figure 5. SAM stock development based on four different recreational catch scenarios.

2.2.2 Catch Data Uncertainties

During the course of the benchmark workshop, in order to explore the failure of many model runs to closely fit the catch numbers-at-age data between ~1991-1999, some additional investigations were conducted. This period was the focus of these investigations because working group estimates of landings were partially corrected using sample-based estimates of landings at a number of Irish Sea ports for those years (WKIrish2, 2016). During that period the officially reported landings of whiting were thought to be inaccurate due to misreporting. An attempt was made to prepare a model run where the variances for the catch data were fixed in order to force the model to closely follow the catch data, but this run failed to converge. In addition, a model was run with catch data removed for that period (see. "whg.27.7a_WKBNSCS_1_rec_sensNoCatch90_99" on stockassessment.org), and while that removed the positive residuals during the 1900s (as there was no data to fit to), the negative residuals from 2000-2015 persisted.

2.2.3 Fishing Mortality Process Coupling

Prior to the benchmark meeting, an array of what were considered plausible $\overline{F}$-coupling matrices were tested in the base model configuration (Table 2). All diagnostics were considered when determining the best candidate fit, including comparison of AICs and log-likelihoods, inspection of retrospective patterns, and data conflicts (as determined by the leave-one-out analysis). All models had one observation ahead residual profiles with similar issues to the base case. Model Alternate #2 have the lowest AIC, with minimal data conflicts (leave-one-out analysis runs within the model estimate envelopes; Fig. 6), and acceptable retrospective peels.

Table 2. Summary of model fit quality for $\overline{F}$-coupling runs

Covariance Structure Configuration	Coupling Matrix Configuration	*Leave-One-Out convergence*	Log Likelihood	AIC
Base Model	[0, 1, 2, 3, 4, 5, 5]	✗	-810.27	1658.54
Alternate 1*	[0, 1, 2, 3, 4, 5, 6]	✗	-852.45	1742.89
Alternate 2	[0, 1, 2, 3, 4, 4, 4]	✓	-891.18	1820.36
Alternate 3	[0, 1, 2, 3, 3, 3, 3]	✓**	-895.17	1828.33
Alternate 4	[0, 1, 2, 2, 2, 2, 2]	✓**	-906.20	1850.39
Alternate 5	[0, 1, 1, 1, 1, 1, 1]	✓**	-916.15	1870.29
Alternate 6	[0, 1, 1, 2, 2, 2, 2]	✓**	-893.21	1824.43
Alternate 7	[0, 1, 1, 1, 2, 2, 2]	✓	-896.27	1830.54
Alternate 8	[0, 1, 1, 1, 1, 2, 2]	✓**	-900.84	1839.69
Alternate 9	[0, 1, 1, 1, 1, 1, 2]	✓**	-892.30	1822.60
Alternate 10	[0, 1, 2, 2, 2, 2, 3]	✓**	-880.81	1799.62
Alternate 11	[0, 1, 2, 2, 2, 3, 3]	✓**	-892.39	1822.78
Alternate 12	[0, 1, 2, 2, 3, 3, 3]	✓**	-892.59	1823.18
Alternate 13	[0, 1, 2, 3, 3, 3, 3]	✓**	-895.16	1828.33

* Did not converge

** One or more leave-one-out runs diverged outside of the model confidence envelope

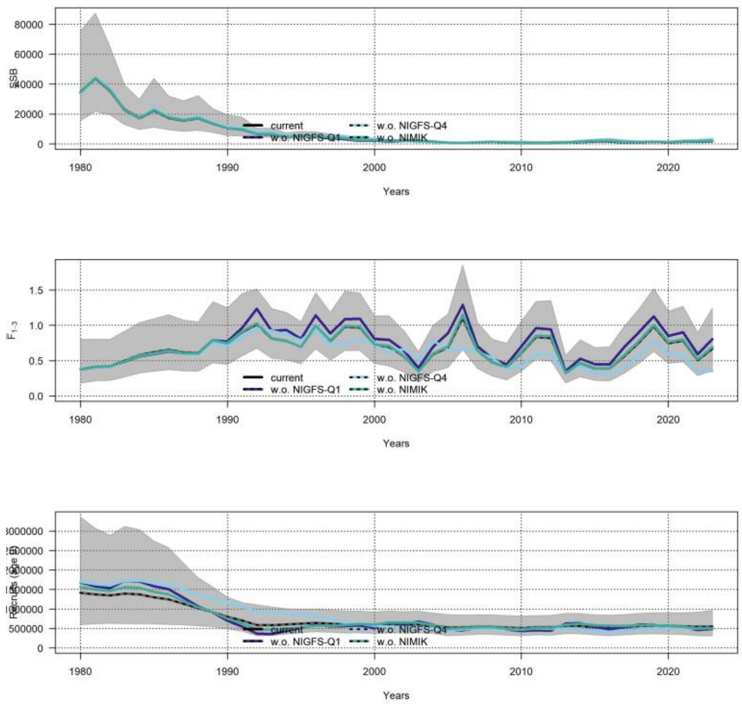

Figure 6. Leave-one-out runs for $\overline{F}$-coupling model Alternate #2.

2.2.4 Fleet Covariance Structure

Alternate fleet covariance structures were tested, whereby the commercial fleet had an independent fleet covariance structure, and the survey fleets were sequentially assigned an autocorrelated (AR1) covariance structures (Table 3). For each fleet covariance structure combination, a different coupling matrix was tested, and the best fit was selected as in Section 2.2.3. With each successive fleet covariance structure combination the quality of model fit improved, i.e. all of the best model fits had and autocorrelated covariance structure for both modelled index fleets.

The best fitting fleet covariance structure had an AR1 structure for the Q1 modelled fleet (coupling matrix [0, 1, 1, 2, 2], no age zero index) and Q4 modelled fleet indices (coupling matrix [3, 4, 4, 4, 4, 4]). Estimates from the model with the best fitting fleet covariance structure were reasonably similar to the base case model (Fig. 7), although the decline in recruitment, SSB, and particularly catch, were not as precipitous as in the latter. Patterns in fleet residuals for the best alternate fleet covariance configuration remained similar to those of the Base Model (Fig. 8). However, the bias in the six+ group of the modelled Q4 index was now reduced. Retrospective peels for this model were reasonably robust to removal of up to five years of recent data (Fig. 9), and the estimates based on conditional simulations from the model compared well with the model (Fig. 10). The leave-one-out analysis indicated that there were conflicts between datasets using this model configuration (Fig. 11).

Table 3. Fleet covariance structure combinations tested

	Commercial Fleet	Modelled Q1 Index	Modelled Q4 Index	MIKnet Index
Base Model	Independent	Independent	Independent	Independent
Alternate 1	Independent	AR1	Independent	Independent
Alternate 2	Independent	Independent	AR1	Independent
Alternate 3	Independent	AR1	AR1	Independent

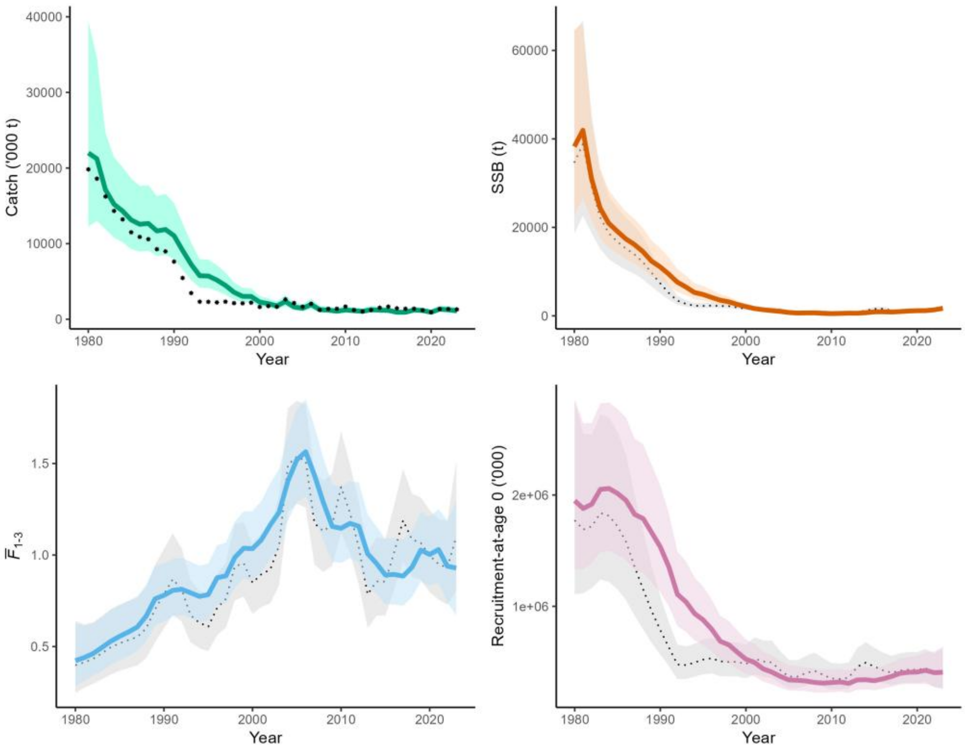

Figure 7. Comparison of SAM stock development using the Base Model configuration (*black* lines with *grey* confidence bands) with the model using the best fit fleet covariance structure.

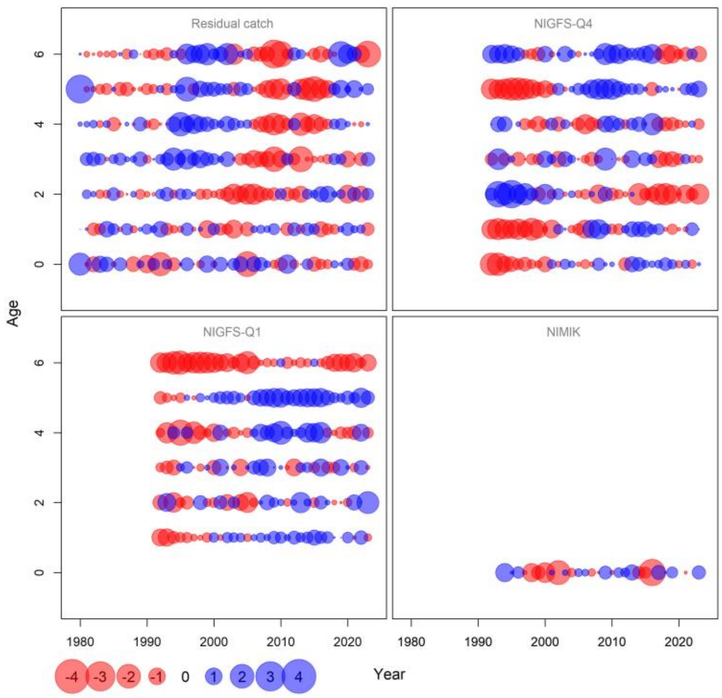

Figure 8. One-observation-ahead fleet residuals for best alternate fleet covariance configuration

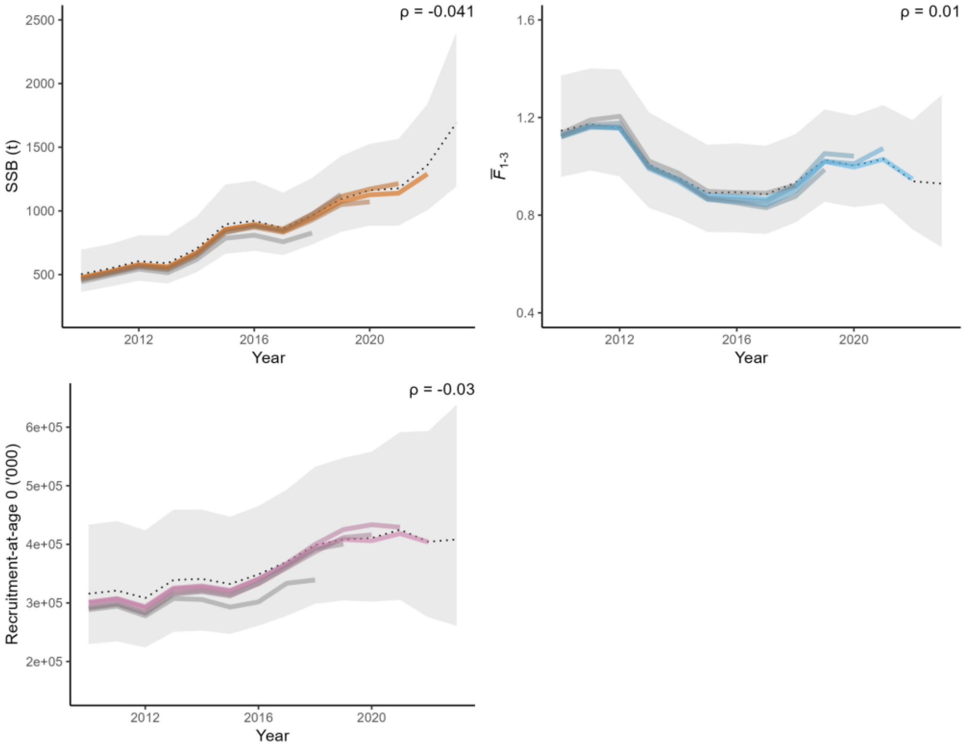

Figure 9. Retrospective pattern for the best alternate fleet covariance configuration

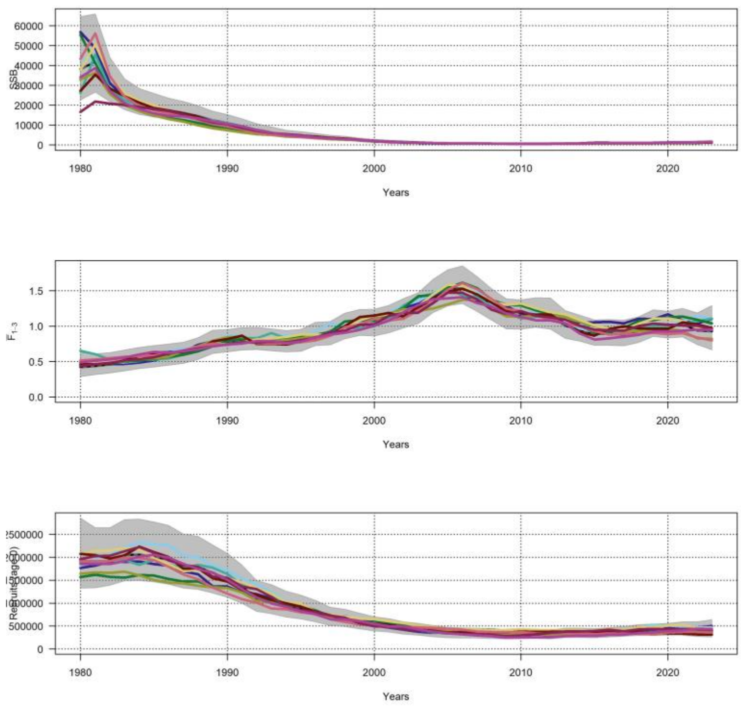

Figure 10. Stock development reproduced using conditional simulations for the best alternate fleet covariance configuration

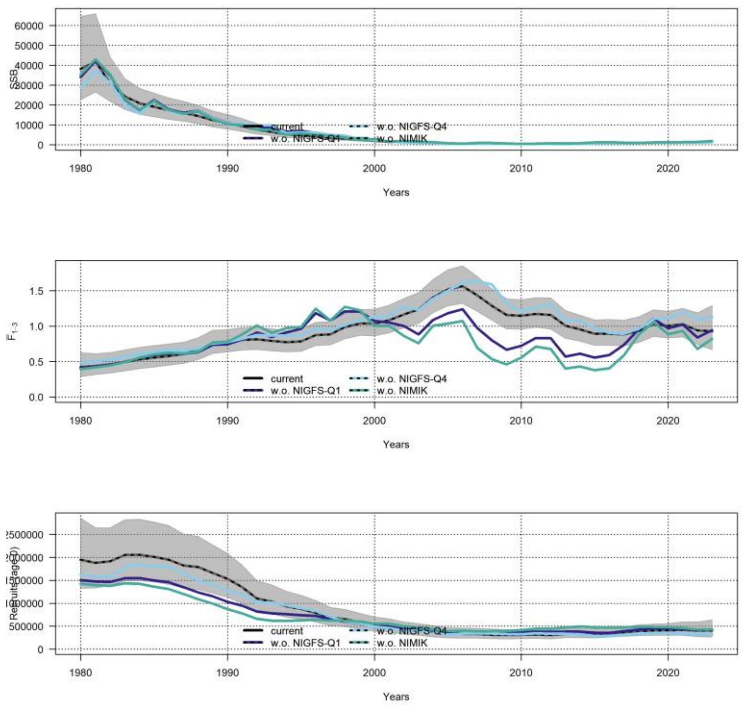

Figure 11. Leave-one-out analysis for the best alternate fleet covariance configuration

2.2.5 Survey Catchability Coupling

A number of survey catchability-at-age coupling configurations were compared to the Base Model. In alternative model runs, survey catchabilities were coupled based on combinations of plausible coupling vectors for each modelled survey index fleet. The best fitting survey catchability coupling configuration was selected as in Section 2.2.3. The best fitting model had the following coupling vectors: [0, 1, 2, 2, 2, 3] Q1 modelled fleet, and [4, 5, 6, 6, 7, 8, 9] for the Q4 modelled fleet. Estimates from the model with the best fitting fleet covariance structure were very similar to the base case model (Fig. 12). Patterns in fleet residuals for the best alternate fleet covariance configuration remained similar to those of the Base Model (Fig. 13). However, the biases in modelled index residuals appeared to be largely dealt with using this configuration. Retrospective peels for this model were reasonably robust to removal of up to five years of recent data (Fig. 14), and the estimates based on conditional simulations from the model compared well with the model (Fig. 15). The leave-one-out analysis indicated that there were conflicts between datasets using this model configuration (Fig. 16).

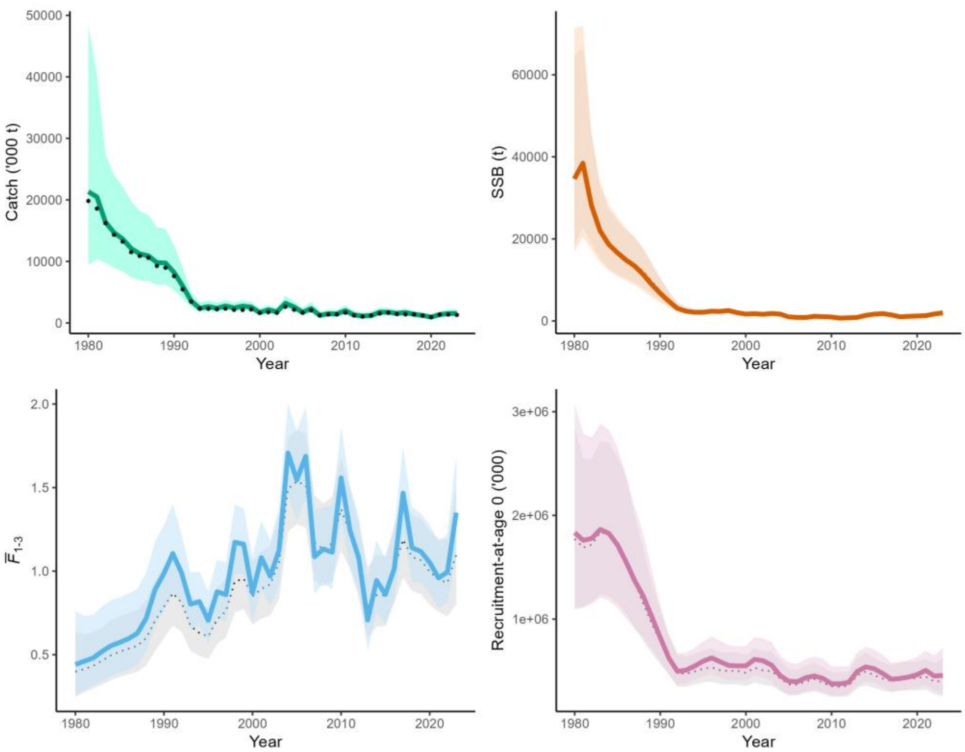

Figure 12. Comparison of SAM stock development using the Base Model configuration (*black* lines with *grey* confidence bands) with the model using the best fit survey catchability coupling configuration.

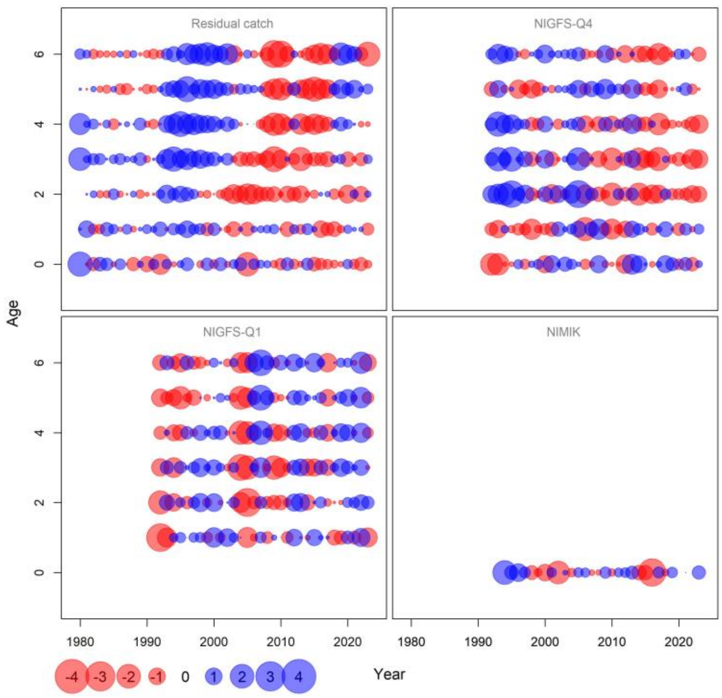

Figure 13. One-observation-ahead fleet residuals for best survey catchability coupling configuration.

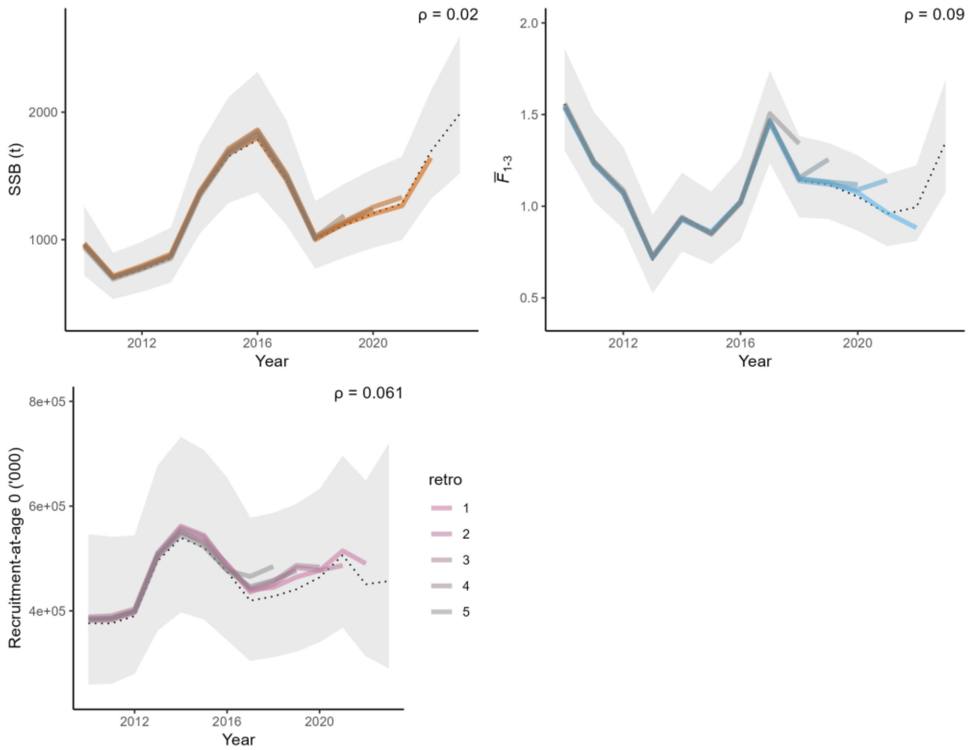

Figure 14. Retrospective pattern for the best survey catchability coupling configuration.

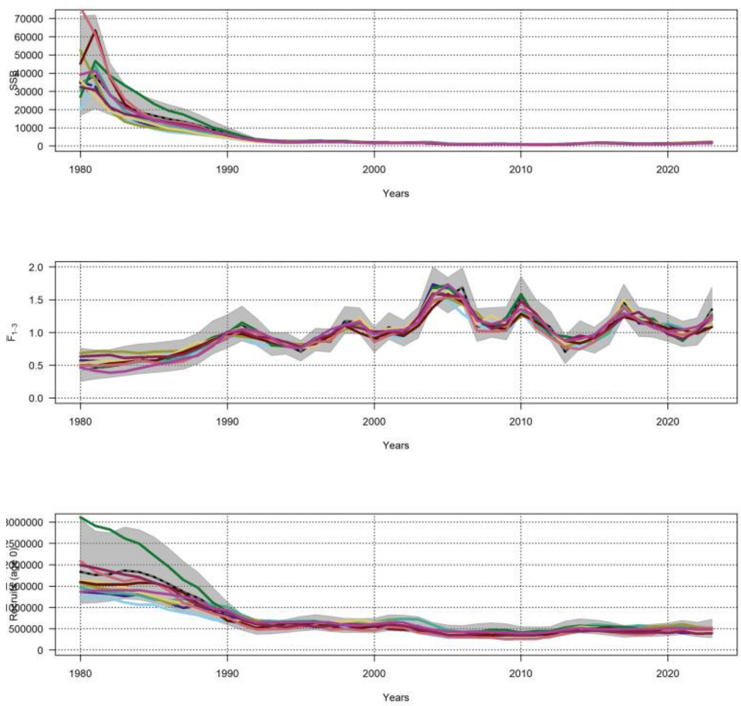

Figure 15. Stock development reproduced using conditional simulations for the best survey catchability coupling configuration.

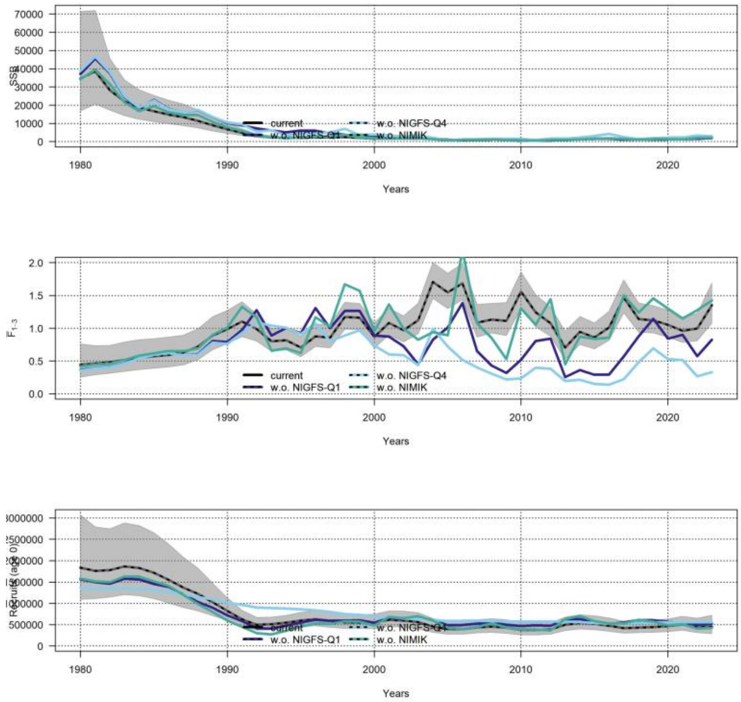

Figure 16. Leave-one-out analysis for the best survey catchability coupling configuration.

2.2.6 Final Model Explorations

The final model was constructed by combining the best fitting configurations from the above sensitivity analyses. At the benchmark workshop, there was a request to implement the uncoupled $\bar{F}$-coupling matrix in the final model to investigate whether it would yield a more realistic estimates selectivity-at-age profile compared to the best fitting coupling matrix (Fig. 17). It was decided that the decoupled F selectivity-at-age profile was more representative of the impression of fishery development as recorded in the sampling data (Fig. 18). In this model, there were increases in selectivity-at-age for ages zero, one, and two, from the early 2000s until~2010, after which estimates stabilised and then declined from 2015 onwards. Selectivity-at-age three remained relatively stable throughout, and declined for ages four and upwards from relatively early in the modelled period until the late 2010s.

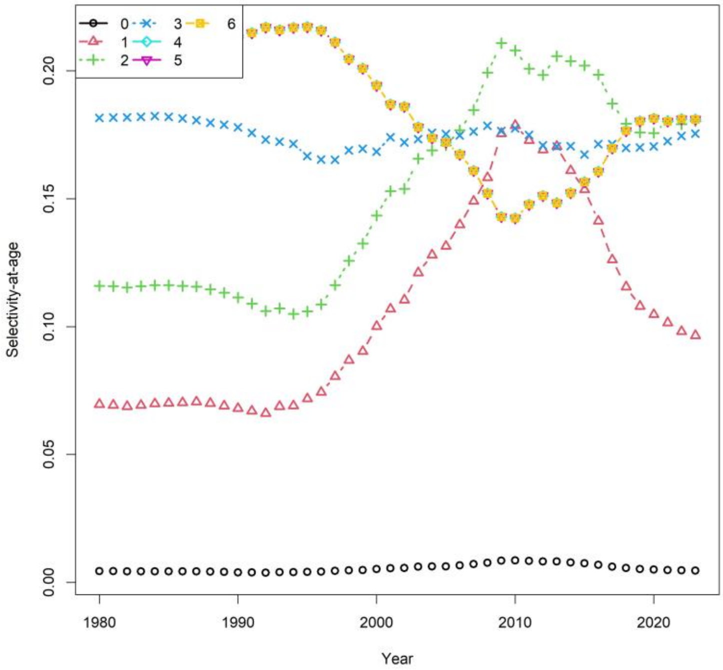

Figure 17. Selectivity-at-age for the final model configuration with $\overline{F}$-coupling model Alternate #2.

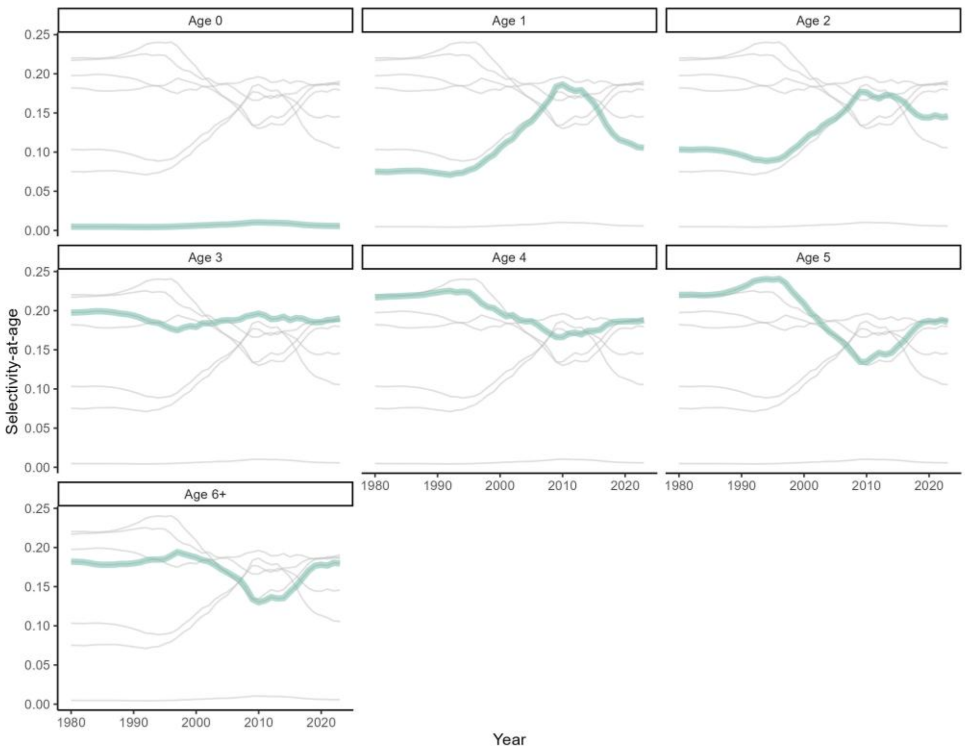

Figure 18. Selectivity-at-age profile for the final model with an uncoupled $\overline{F}$ process.

Similarly, there was a request that the survey catchability coupling be further explored, as the profiles of estimates of survey catchability-at-age from the best fit coupling matrix were not entirely as might be expected (Fig. 19). For the modelled Q1 index, catchability appeared sensible, with an increase between ages one and two, and a decrease between ages five and six+, i.e. smaller fish are more difficult to catch (likely due to physical size), as are the largest fish (due to lower numbers, escapement, etc.). Estimates of catchability-at-age for the modelled Q4 index, however, seemed to make less sense, with values increasing across each age class from three upwards, suggesting that survey caught fish more efficiently as they increase in age. A fully decoupled matrix was tested (as with the $\overline{F}$-coupling, above), which resulted in a similar catchability-at-age profile for the Q4 modelled index (Fig. 20). This configuration also provided an arguably less realistic estimate of catchability-at-age six+ for the modelled Q1 index, which had a slightly higher mean than that for age five. It was suggested that these estimates of catchability would realistically encompass a combination of processes along with catchability, and as the changes did not otherwise affect the fit or impression of stock development, that the best fit matrix should be maintained for the final model.

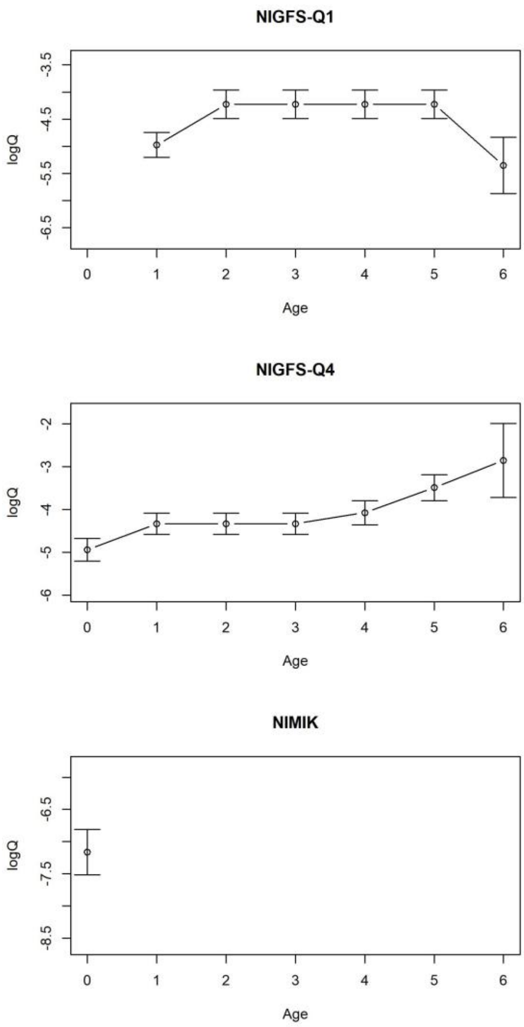

Figure 19. Estimates of survey catchability-at-age from the final model

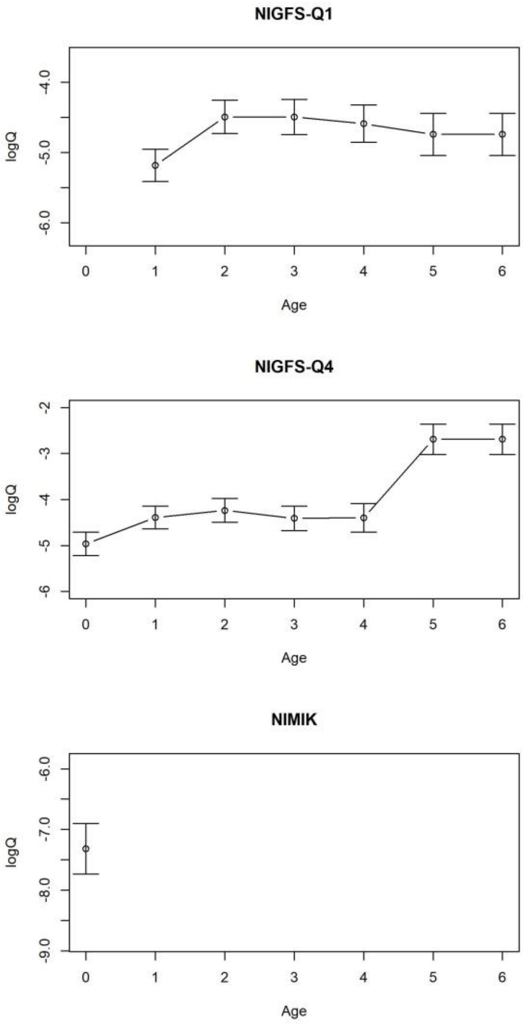

Figure 20. Estimates of survey catchability-at-age from the best fit model with decoupled survey catchability.

3 References

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whg.27.7a Eqsim - WKBNSCS 2025

Hans Gerritsen

06/02/2025

The ICES approach to setting Reference Points

This Markdown document outlines the steps involved in estimating PA and MSY reference points for Whiting in area 7a as part of the WKBNSCS benchmark 2025. It follows the current technical guidelines: https://ices-library.figshare.com/articles/report/ICES_Guidelines_for_Benchmarks/22316743?file=39704431.

Get the data in FLR

```
library(stockassessment)
library(FLCore)
library(msy)
library(icesAdvice)
library(ggplot2)
library(ggplotFL)
library(dplyr)
library(FLfse)

# load the fit of the final model
SAMfit <- fitfromweb('whg.27.7a_WKBNSCS_1_rec')

stockObs <- SAM2FLStock(SAMfit,catch_estimate = F)
stockEst <- SAM2FLStock(SAMfit,catch_estimate = T)

stock0 <- stock <- stockEst

# check fbar range
stock0@range['minfbar']
```

```
## minfbar
##       1
```

```
stock0@range['maxfbar']
```

```
## maxfbar
##       3
```

```r
# check that F is ok
# it is not, because of the process error in SAM
all(harvest(stock0) ==  harvest(stock.n(stock0), catch=catch.n(stock0), m=m(stock0)))
```

```
## [1] FALSE
```

```r
## deal with NA
#stock0@catch.n[is.na(stock0@catch.n)] <- 1e-6
#stock0@landings.n[is.na(stock0@landings.n)] <- 1e-6
#stock0@discards.n[is.na(stock0@discards.n)] <- 1e-6
#stock0@range['plusgroup'] <- stock0@range['max']

## eqsr_fit cannot deal with 0 group
stock0 <- trim(stock0,age=1:stock@range['max'] )
```

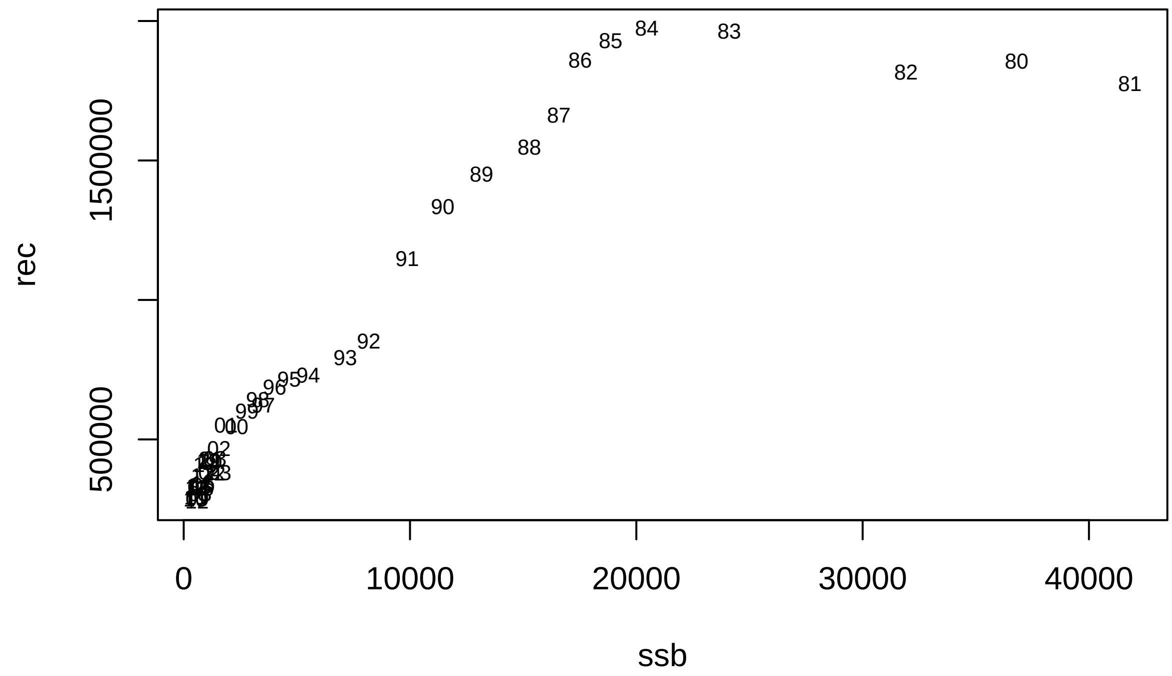
Step 1. Identifying approptiate data

Evidence for a regime shift in the Irish Sea during the 1990s was presented at the workshop. Evidence that this regime shift affected whiting includes: changes in stock weights and spr0 over time; changes in food availability and predation pressure.

The stock-recruit pattern appears to change from the early time period with a changepoint after 1991. In order to include as much of the time series, the decision was made to truncate it to 1992 onwards. It should also be noted that stock-recruit data from the early period are quite uncertain, supporting this decision to truncate.

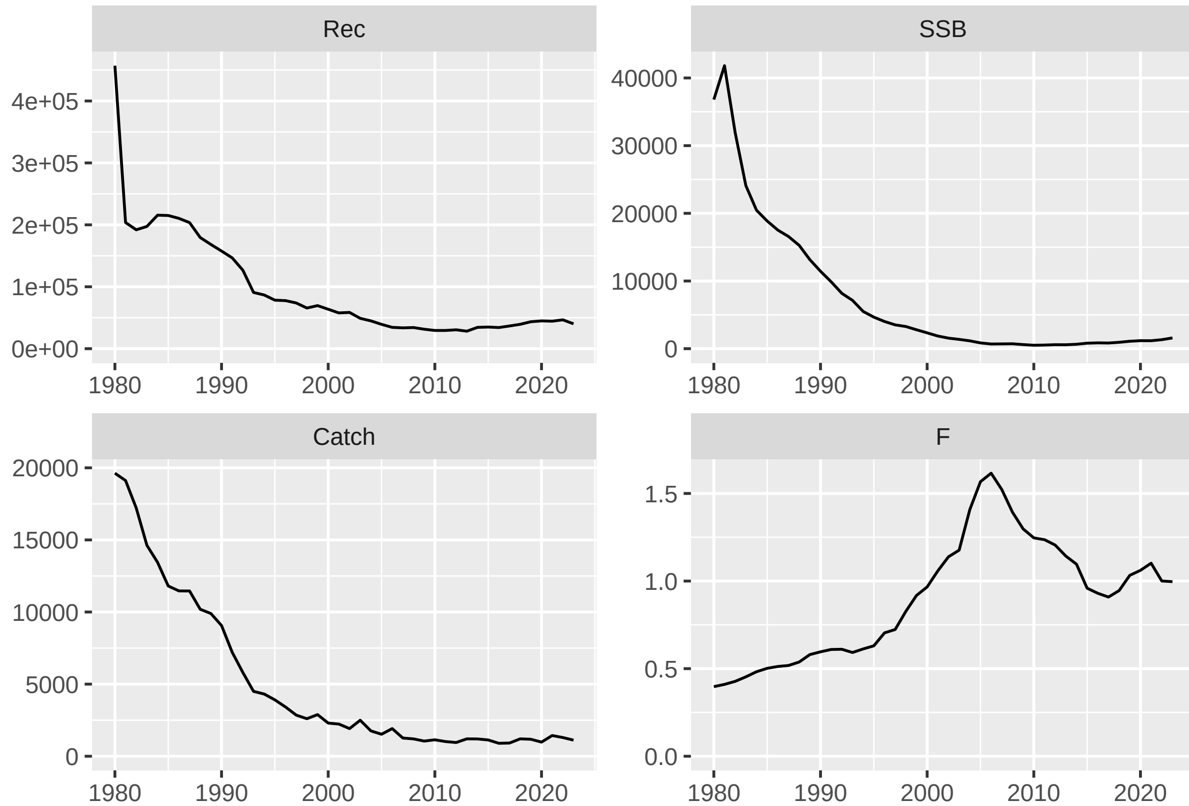
Additionally, recruitment in the last year is considered to be poorly estimated so these are also excluded. The period considered for fitting the SR is therefore 1992-2022.

```r
plot(c(ssb(stock)),c(rec(stock)),cex=0,xlab='ssb',ylab='rec')
text(c(ssb(stock)),c(rec(stock)),substring(stock@range['minyear']:stock@range['maxyear'],3,4),cex=0.7)
```



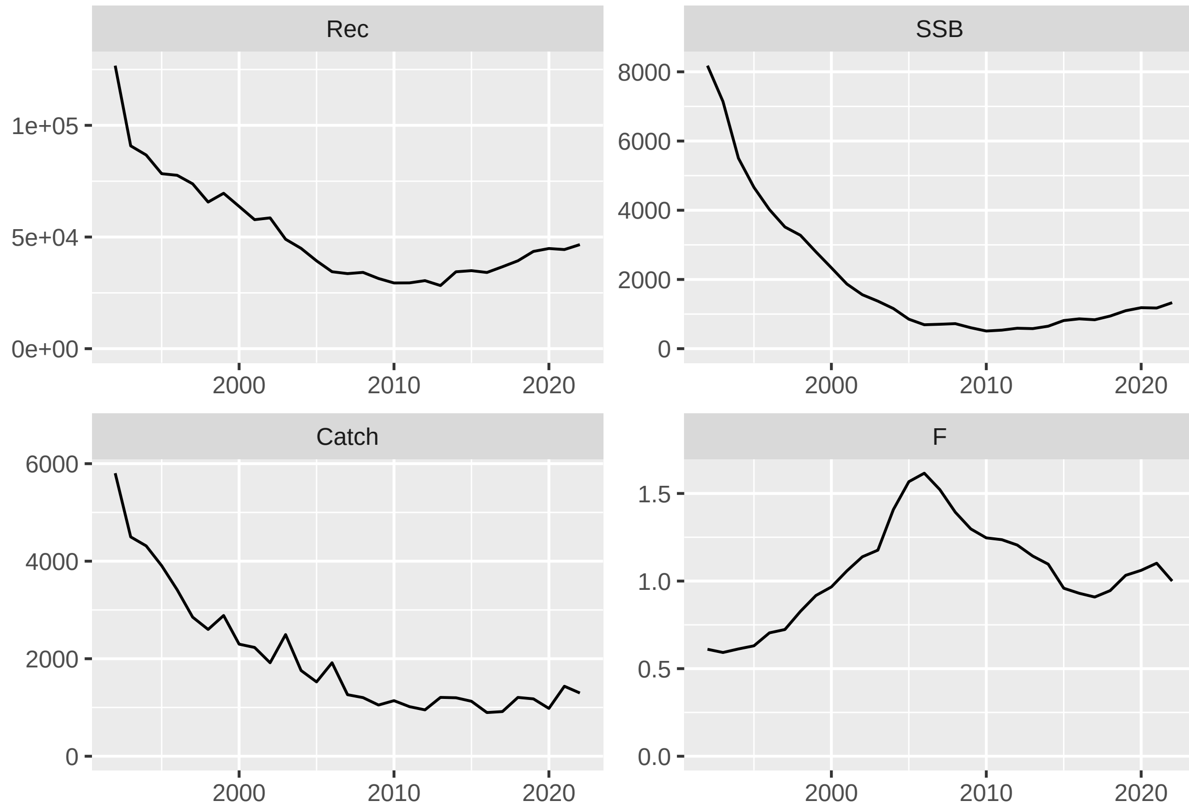
This is the stock development over the full time series.

```
plot(stock0) + facet_wrap(~qname, scales="free")
```



... And the truncated time series.

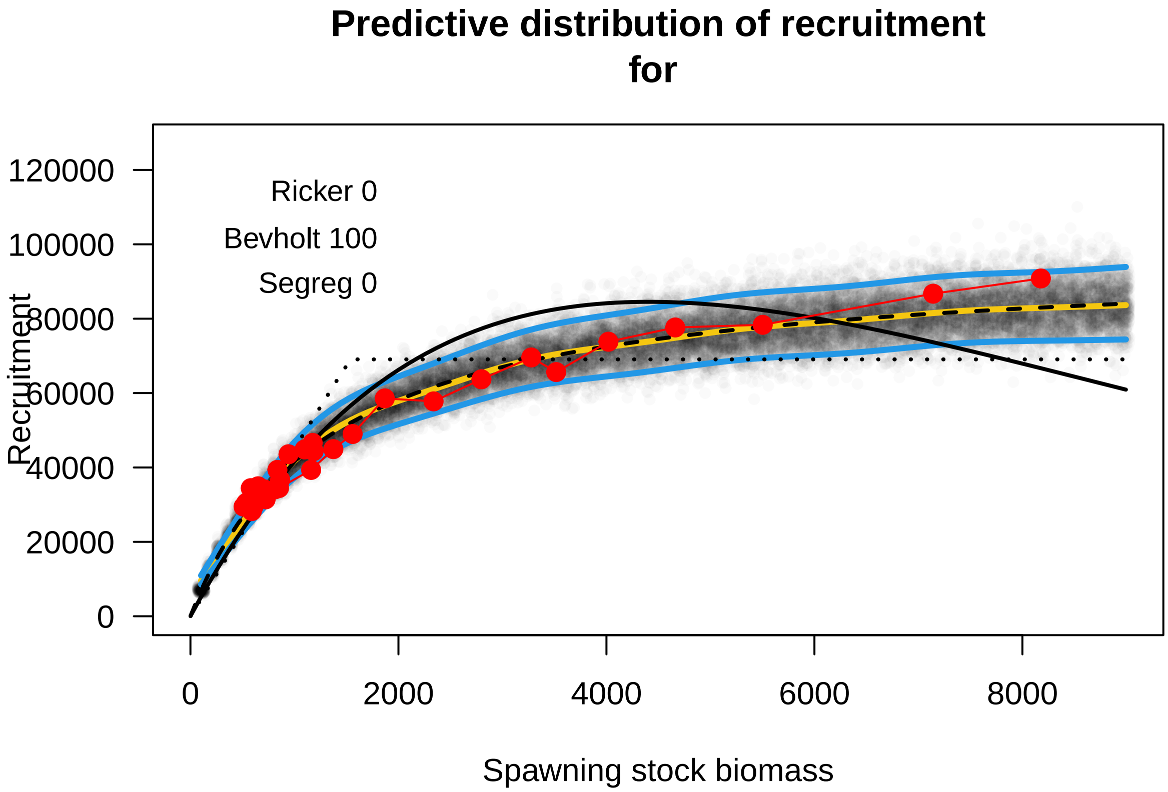
```
stock <- window(stock0,start=1992)
# also remove last year as there is no/little information on recruitment (now age 1)
stock <- window(stock,end=stock@range['maxyear']-1)
plot(stock) + facet_wrap(~qname, scales="free")
```



Explore stock-recruit

Neither Ricker, nor segreg fit the data well; the best fit is for Beverton-holt in 100% of the iterations.

```r
set.seed(1)
nsamp <- 1000 #increase number of samples for final run (e.g 1000)
fit_temp <- eqsr_fit(stock, nsamp = nsamp, models = c("Ricker","Bevholt","Segreg"))
fit_temp$sr.det$n[is.na(fit_temp$sr.det$n)] <- 0
fit_temp$sr.det$prop <- 100*fit_temp$sr.det$n/sum(fit_temp$sr.det$n)
eqsr_plot(fit_temp)
```

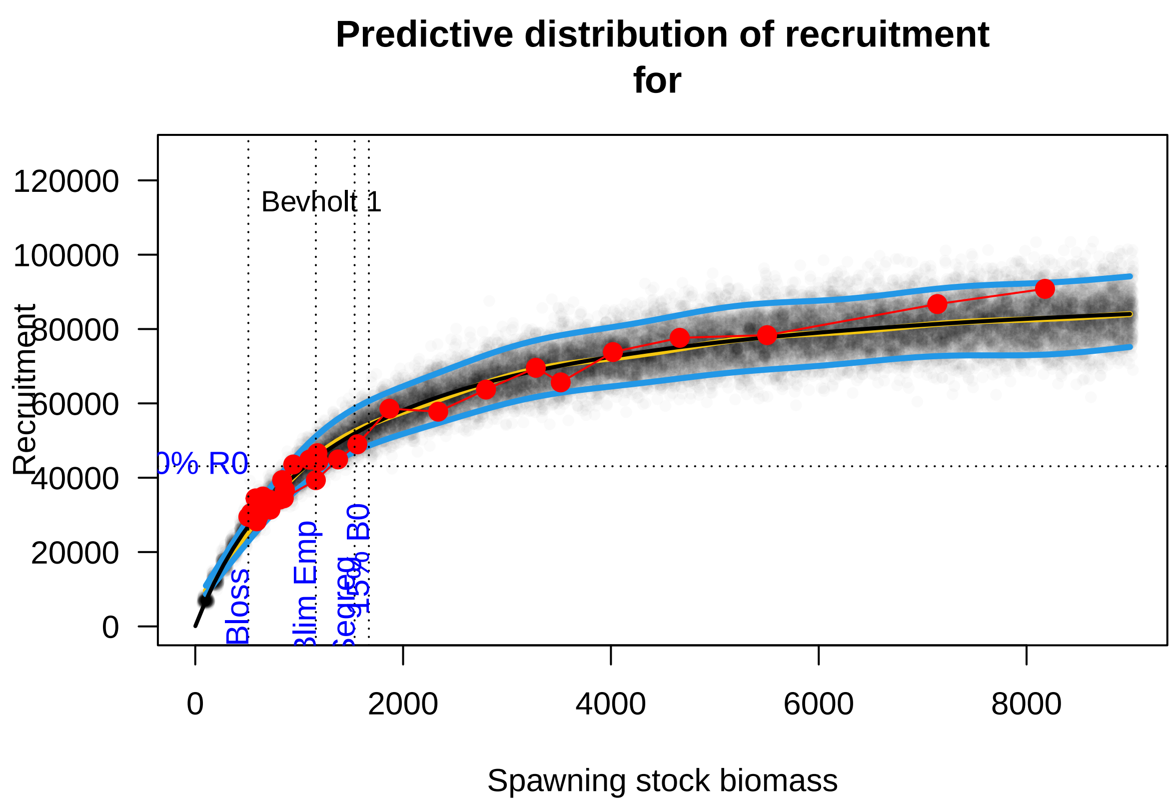


Step 2. Stock type and step 3. Blim

This SR relationship does not fall into any of the SR types described in the ICES guidelines. Blim could be based on Bloss but the group did not consider this to be very precautionary. Blim based on the breakpoint in a segmented regression is another option but there is no clear breakpoint in the data. An alternative would be to take the SSB with the median recruitment value (B emperical) or the SSB that would result in a reduction in R0 of 50%. Both of these options are quite arbitrary. WKNEWREF2 collated information on Blim as a proportion of B0 for stocks where B0 was well defined. For gadoids, the mean Blim/B0 ratio is 15%. WKNSCS decided that this reference point may be appropriate. However considering the uncertainty around the potential reproductive capacity of the stock; this decision needs to be reviewed on a regular basis for appropriateness.

```
fit.segreg <- eqsr_fit(stock, nsamp = nsamp, models = c("Segreg"))
fit <- eqsr_fit(stock, nsamp = nsamp, models = c("Bevholt"))

BlimSegreg <- subset(fit.segreg$sr.det,model=='Segreg')$b

# WKNEWREF empirical rule
# Minimum SSB level that resulted in a recruitment higher that the median.
q <- 0.5
BlimEmp <- min(ssb(stock)[,which(rec(stock)>quantile(c(rec(stock)),q))])


library(FLRef)
sr <- srrTMB(as.FLSRs(stock, models=c("bevholtSV")),spr0(stock))
```

```r
rp <- computeFbrps(stock = stock, sr = sr[[1]], proxy = 'sprx', f0.1 = TRUE, verbose = FALSE)
B0 <- c(rp@refpts['B0','ssb'])
R0 <- c(rp@refpts['B0','rec'])

Bloss <- min(c(ssb(stock)))

{eqsr_plot(fit);
abline(v=Bloss,lty=3);
text(Bloss,0,'Bloss',pos=3,cex=1,col='blue',srt=90);
abline(v=BlimSegreg,lty=3);
text(BlimSegreg,0,'Segreg',pos=3,cex=1,col='blue',srt=90);
abline(v=BlimEmp,lty=3);
text(BlimEmp,5000,'Blim Emp',pos=3,cex=1,col='blue',srt=90);
abline(v=0.15*B0,lty=3);
text(0.15*B0,13000,'15% B0',pos=3,cex=1,col='blue',srt=90);
abline(h=0.5*R0,lty=3);
text(700,0.5*R0,'50% R0',pos=2,cex=1,col='blue');
}
```




```r
# we choose 15% of B0
Blim <- max(BlimEmp,0.15*B0)
```

B0 is 11,138 Blim is set at 15% of B0: 1,670

step 4. Other PA reference points from Blim

```
idx <- names(SAMfit$sdrep$value) == "logssb"
years <- SAMfit$data$years
sigmaSSB_sam <- SAMfit$sdrep$sd[idx][years==max(years)]
sigmaSSB_sam
```

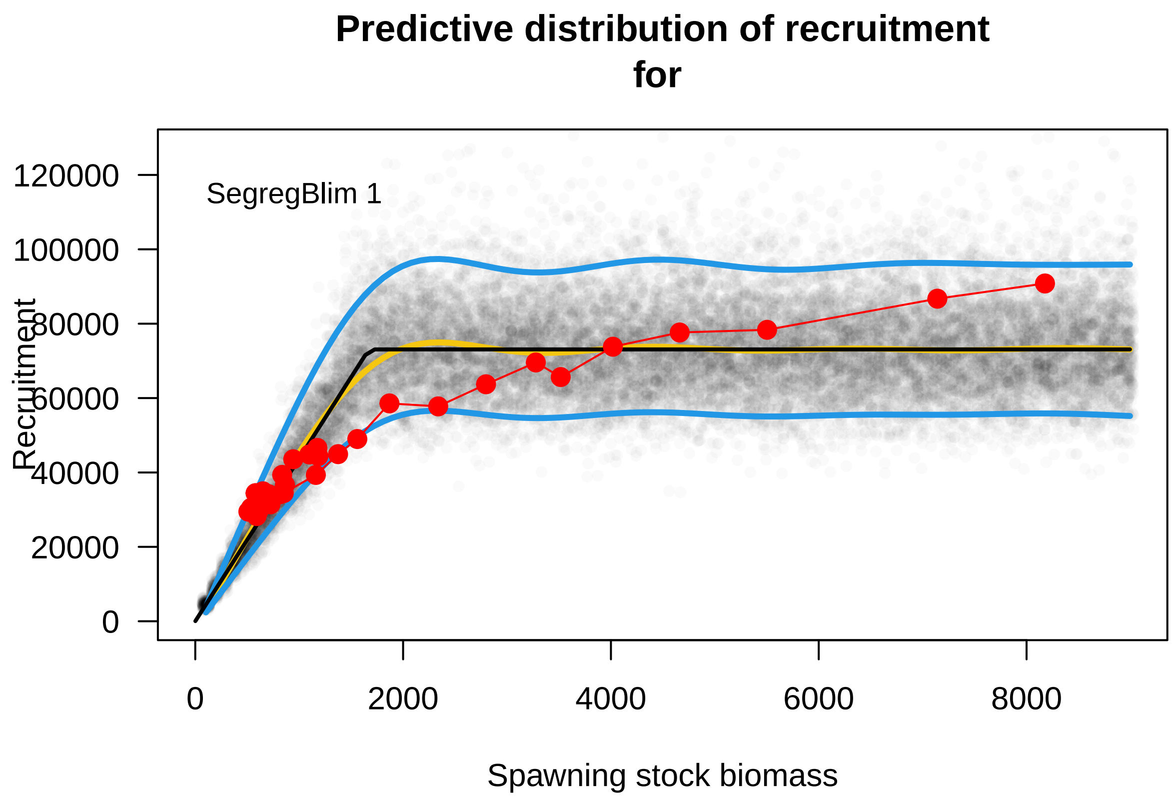
```
## [1] 0.1630493
```

```
# this is lower than 0.2 so we take a more conservative value of 0.2

sigmaSSB <- 0.2 # default

Bpa <- round(Blim * exp(1.645 * sigmaSSB))
#abline(v=Bpa,lty=4)
#text(Bpa,0,'Bpa',pos=3)
```

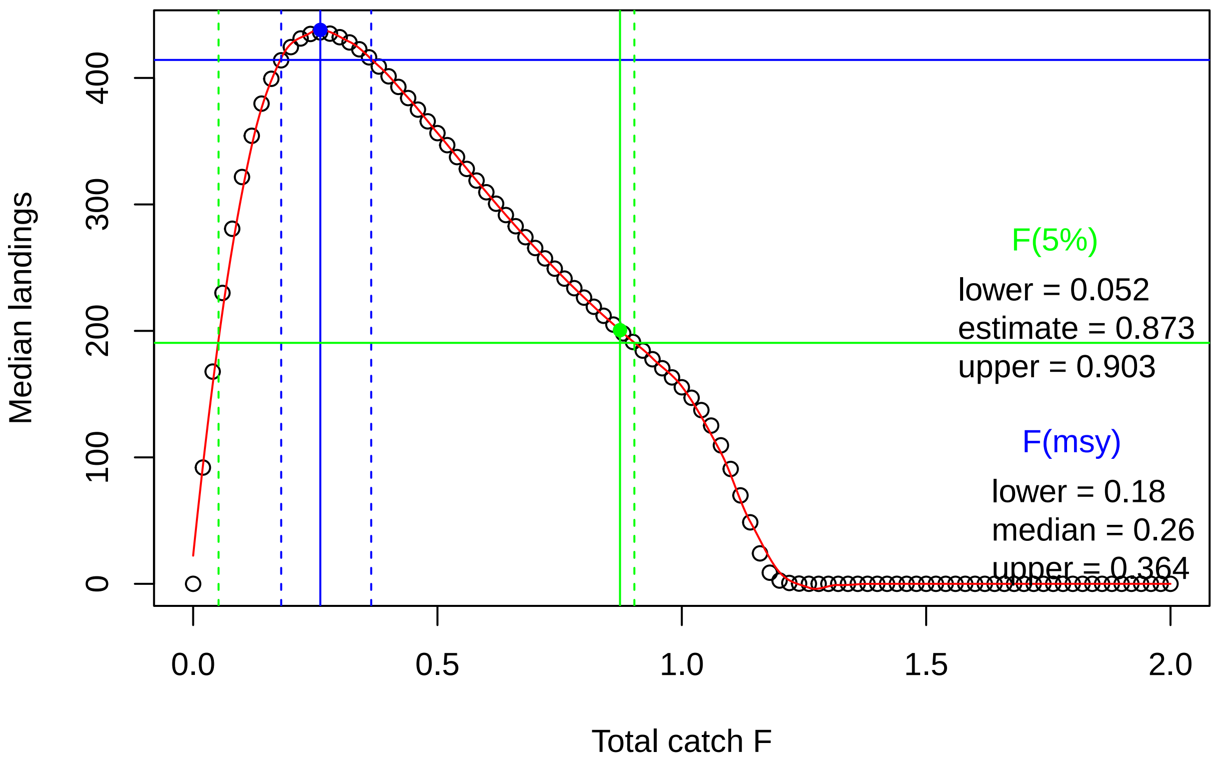
Bpa is Blim plus assessment error: The model estimates assessment error to be 0.16. This may be an under-estimate so we use the defauls of 0.2 resulting in a Bpa of 2,322

Flim is no longer used as a reference point in the ICES framework. It is included here for completeness. The preferred method is simulating a stock with a segmented regression SR relationship, with the point of inflection at Blim, thus determining the F = Flim which, at equilibrium, yields a 50% probability of SSB > Blim. Note that this simulation should be conducted based on a fixed F (i.e. without inclusion of a Btrigger) and without inclusion of assessment/advice errors. This means Btrigger, Fcv, and Fphi should all be set to zero

```
SegregBlim  <- function(ab, ssb) {
  log(ifelse(ssb >= Blim, ab$a * Blim, ab$a * ssb))
  }
fit_segregBlim <- eqsr_fit(stock,nsamp=nsamp, models = "SegregBlim")
eqsr_plot(fit_segregBlim)
```




```
# choice of bio.years and sel.years are the defaults (last 5 years) may want to change that
sim_segregBlim <- eqsim_run(fit_segregBlim,
                            Fcv=0, Fphi=0, SSBcv=0,
                            Btrigger = 0, Blim=Blim,Bpa=Bpa,
                            Nrun=200, Fscan = seq(0,2,len=101),verbose=F)

Flim <- round(sim_segregBlim$Refs2['catF','F50'],3)
eqsim_plot_range(sim_segregBlim, type="median")
```



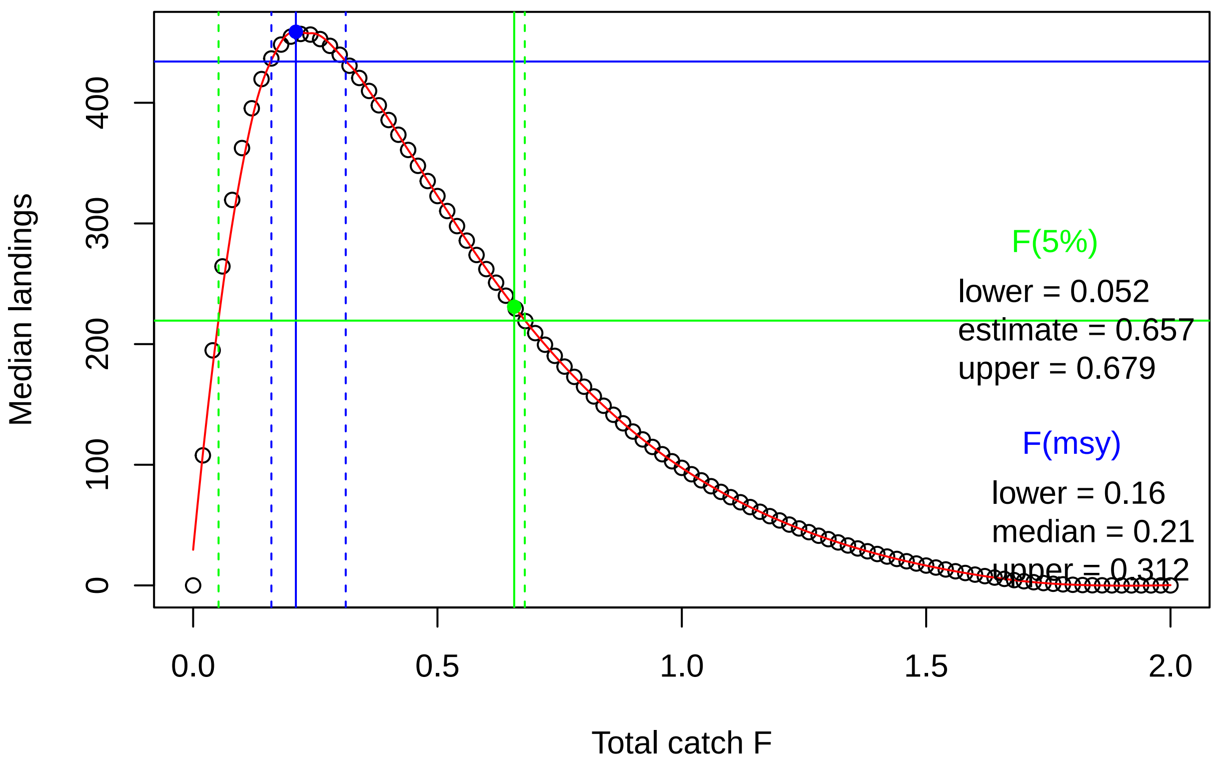
Flim is estimated at 1.062. Fpa is no longer estimated from Flim, it is now Fp05, see later

Step 5. Fmsy and Btrigger

FMSY should initially be calculated based on an evaluation with the inclusion of stochasticity in a population (i.e. recruitment, M, maturity, growth) and fishery (e.g. selectivity) as well as assessment/advice error. This is a constant F, which should provide maximum yield without biomass constraints (without MSY Btrigger). Error is included as this is the condition analogous to management strategy evaluations (MSEs) that will prevail in practice. Note that in order to ensure consistency between the precautionary and the MSY frameworks, FMSY is not allowed to be above Fpa; therefore, if the FMSY value calculated initially is above Fpa, FMSY is reduced to Fpa.

```
## Forecast error (see Guidance document for details on calculation of these values)
# F
cvF  <- 0.212                                 # Default = 0.212
phiF <- 0.423                                 # Default = 0.423
# SSB
cvSSB <- 0                                    # Default = 0
phiSSB <- 0                                   # Default = 0


sim_noTrig <- eqsim_run(fit,
                            Fcv=cvF, Fphi=phiF, SSBcv=cvSSB,
                            Btrigger = 0, Blim=Blim,Bpa=Bpa,
                            Nrun=200, Fscan = seq(0,2,len=101),verbose=F)
```

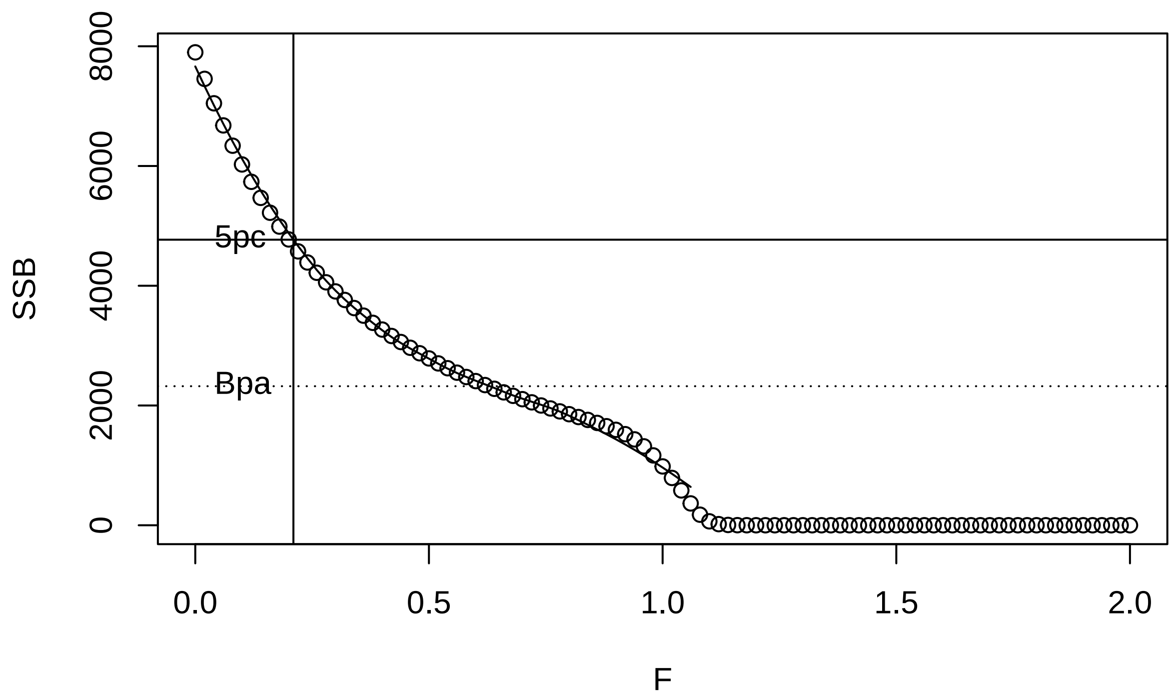
```r
Fmsy_tmp <- round(sim_noTrig$Refs2["lanF","medianMSY"],3)
eqsim_plot_range(sim_noTrig, type="median")
```



Fmsy is initially estimated as 0.21.

MSY Btrigger should be selected to safeguard against an undesirable or unexpected low SSB when fishing at FMSY. For most stocks that lack data on fishing at FMSY, MSY Btrigger is set at Bpa. However, as a stock starts to be fished consistently with FMSY, it is possible to move towards implementation of a value for MSY Btrigger that reflects the 5th percentile definition of MSY Btrigger. In this case the stock has not been fished near Fmsy so Bmsy5pc is not appropriate here, but is included for completeness.

```r
data.05<-sim_segregBlim$rbp
x.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$Ftarget
b.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$p05
plot(b.05~x.05, ylab="SSB", xlab="F")
abline(v=Fmsy_tmp)
i <- which(x.05<Flim)
b.lm <- loess(b.05[i] ~ x.05[i])
lines(x.05[i],c(predict(b.lm)),type='l')

Bmsy5pc <- round(predict(b.lm,Fmsy_tmp))
abline(h=Bmsy5pc)
abline(h=Bpa,lty=3)
text(0,Bmsy5pc,'5pc',pos=4)
text(0,Bpa,'Bpa',pos=4)
```

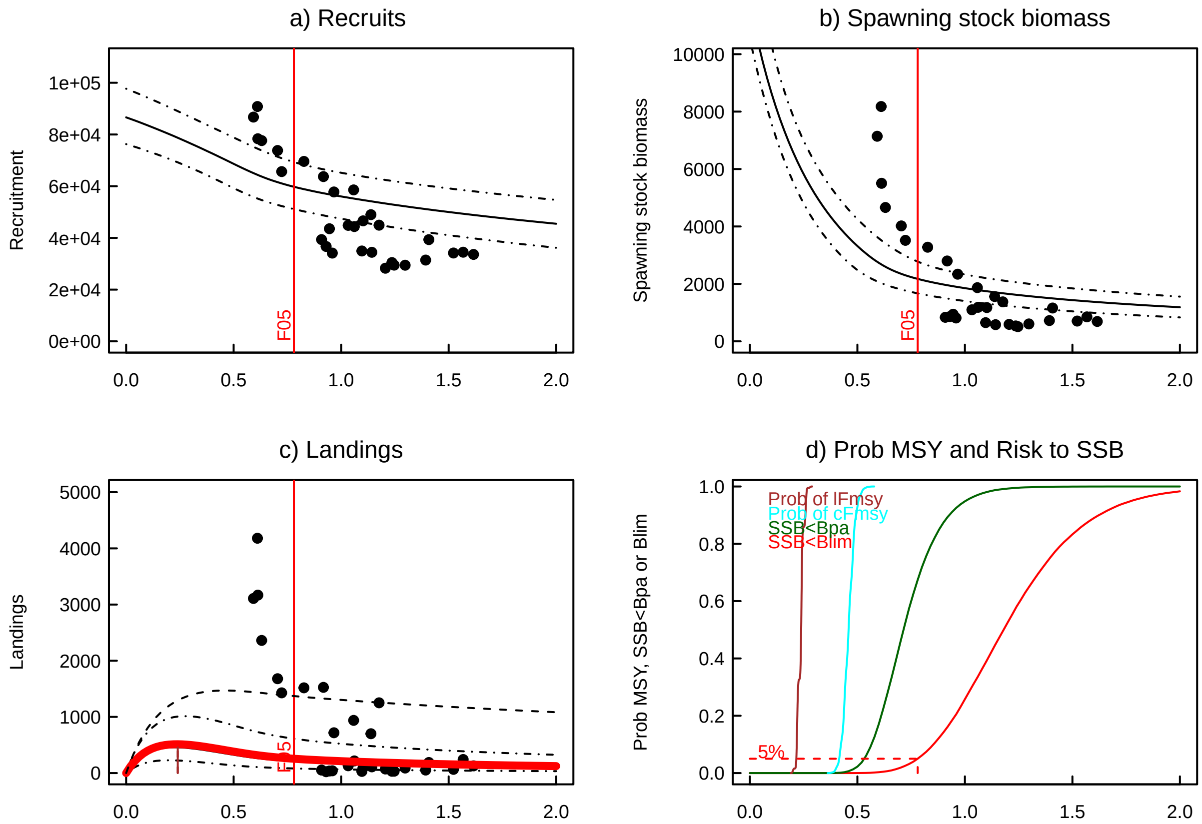


We will use Btrigger = Bpa =2,322 because Bmsy5pc is not appropriate here because the stock has not been fished at Fmsy for 10 years (Bmsy5pc = 4,769).

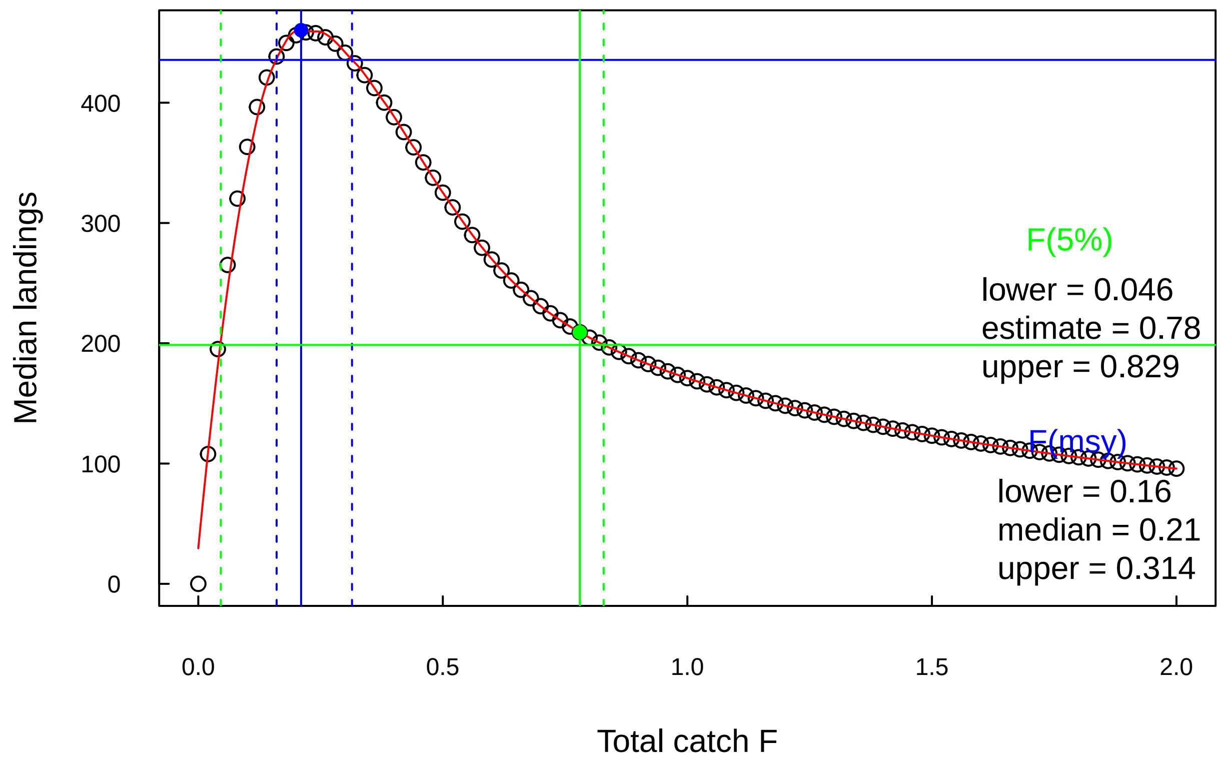
```
Btrigger <- Bpa
```

The ICES MSY AR should be evaluated to check that the FMSY and MSY Btrigger combination fulfills the precautionary criterion of having less than 5% annual probability of SSB < Blim in the long term. The evaluation must include realistic assessment/advice error and stochasticity in population biology and fishery selectivity.

```
sim_Trig <- eqsim_run(fit,
                          Fcv=cvF, Fphi=phiF, SSBcv=cvSSB,
                          Btrigger = Btrigger, Blim=Blim,Bpa=Bpa,
                          Nrun=200, Fscan = seq(0,2,len=101),verbose=F)
eqsim_plot(sim_Trig,catch=F)
```




```
eqsim_plot_range(sim_Trig, type="median")
```




```
Fp05 <- round(sim_Trig$Refs2["catF","F05"],3)
```

If the precautionary criterion evaluated in point 3 is not met, then FMSY should be reduced from the value calculated above until the precautionary criterion is met (i.e. reduce FMSY to FMSY = Fpa). Fpa is Fp05 and is estimated at 0.78 so there is no need to cap Fupper.

```
Fmsy <- round(min(sim_Trig$Refs2["lanF","medianMSY"],Fp05),3)
Fupper <- round(min(sim_Trig$Refs2["lanF","Medupper"],Fp05),3)
Flower <- round(min(sim_Trig$Refs2["lanF","Medlower"],Fp05),3)
```

Reference point table

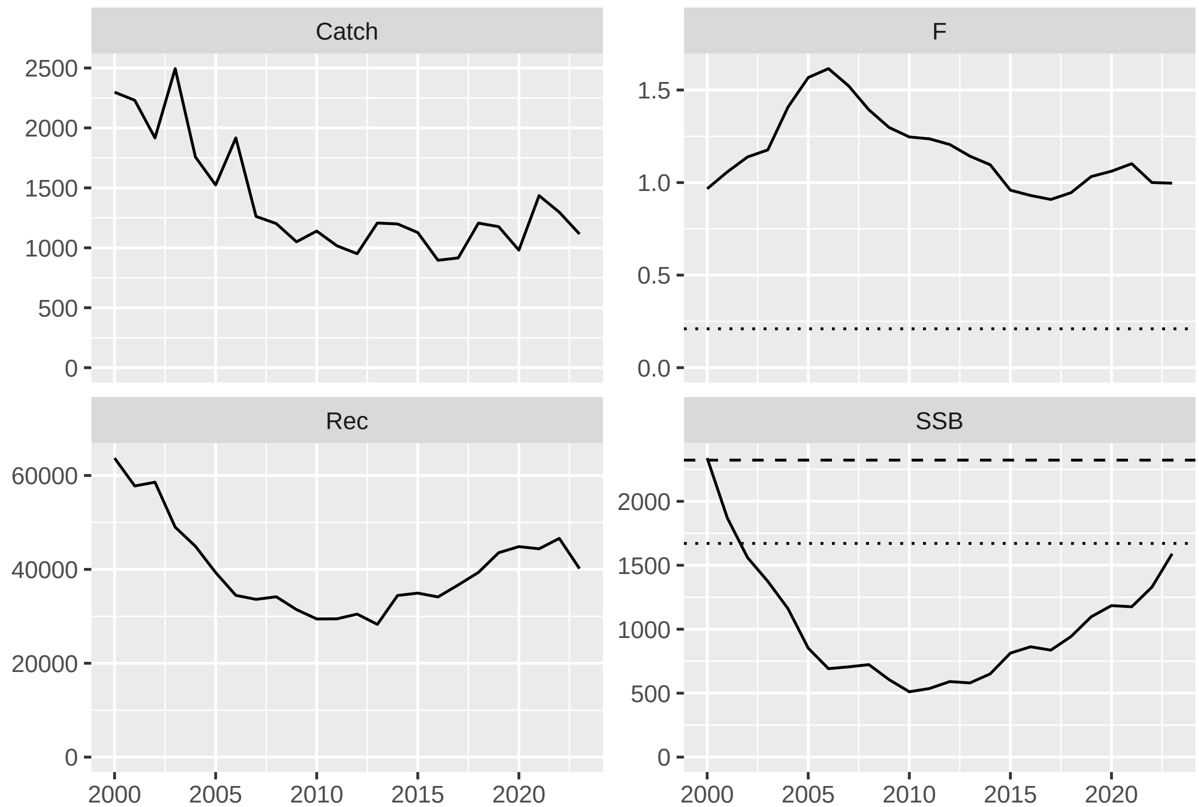
The estimated reference points are shown below.

Reference Point	Value	Rationale
Blim	1,670	0.15*B0; average Blim/B0 for gadoids (WKMSYREF2)
Bpa	2,322	Blim with assessment error
MSY Btrigger	2,322	Bpa
Flim	Not used (1.062)	F with 50% probability of SSB>Blim (segreg without Btrigger)
Fpa	0.78	F with 95% probability of SSB>Blim (BH with Btrigger)

Reference Point	Value	Rationale
Fmsy	0.21	Stochastic simulations
FmsyLower	0.16	Stochastic simulations
FmsyUpper	0.314	Stochastic simulations
Bmsy5pc	Not used (4,769)	5% probability of SSB < Blim

Current stock status: F is well above Fmsy and SSB is just below Blim.

```r
plot(window(stock0,start=2000) ) + facet_wrap(~qname,scales='free_y') +
  geom_hline(aes(yintercept=Fmsy),data=data.frame(qname='F'),lty=3) +
  geom_hline(aes(yintercept=Blim),data=data.frame(qname='SSB'),lty=3) +
  geom_hline(aes(yintercept=Btrigger),data=data.frame(qname='SSB'),lty=2)
```



Sensitivity to SR assumption

In order to investigate the sensitivity of the reference point estimates to the stock-recruit relationship; an SR was fitted to the full time series; this resulted in an Fmsy estimate of 0.20, so this reference point was not sensitive to truncating the time series. The B0 estimate, however, was considerably higher, resulting in a Blim = 0.15B0 = 3,151t. Note that this is still a lot lower than the Blim reference point before the benchmark of 10,000t.

WD 3.8 Whiting in Division 7.a Reconstruction of Recreational Catches

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Abstract

Marine recreational fishing (MRF) is an important but historically underrepresented component of total fishing mortality. For whiting in the Irish Sea (whg.27.7.a), the shift from a landings-based fishery to one dominated by bycatch and a reduction in stock size mean that MRF's contribution to overall fishing mortality could be increasing, and so it is key to quantify. Here, historical recreational catches were reconstructed to provide a time series for stock assessment models. Catch data from 2016–2023 were compiled from national surveys. Due to the absence of whiting specific post-release mortality (PRM) estimates, a precautionary PRM rate of 35.1% was applied.

To extend the time series before 2016, four reconstruction scenarios were developed. Scenario 1 assumed removals were proportional to spawning stock biomass (SSB), assuming constant catchability, producing high historical estimates due to higher early timeseries SSB's. Scenario 2 capped scenario 1's removals at 1995, where the SSB was similar to those observed in recent years. Scenario 3 modified scenario 1's estimates by assuming that anglers have a maximum catch of whiting before the stop fishing. Finally, scenario 4 assumed constant removals based on estimates from 2016-23.

Scenario 1 yielded the highest estimates and Scenario 4 the lowest, with Scenarios 2 and 3 producing intermediate trends. The reliance on SSB in Scenarios 1–3 could introduce circularity into the model inputs when including MRF data into the model, whereas Scenario 4 potentially underestimates past effort-and stock size-abundance driven variations in total catches.

Whilst this document represents a significant step in understanding the recreational whiting fishery, the lack of understanding in the survey biases and whiting specific PRM values add uncertainty. These findings highlight the need for continuous data collection, improved PRM research, and refined reconstruction approaches to integrate MRF into stock assessments and fisheries management effectively.

Introduction

Marine recreational fishing (MRF) is an important component of fisheries exploitation, yet it has historically been underrepresented in stock assessments. While commercial landings have traditionally been the focus of fisheries management, increasing evidence suggests that recreational removals can constitute a significant proportion of total fishing mortality, particularly for certain species and regions (Radford *et al.*, 2018). As a result, the inclusion of MRF data in stock assessments is essential to ensure accurate estimates of total removals and to develop effective management strategies (Hyder *et al.*, 2017).

As fish stocks decline, the relative importance of recreational removals may increase due to motivations beyond simply catch. When commercial landings decrease due to stock depletion or regulatory restrictions, MRF can become a larger component of total removals, even if absolute recreational catches remain stable. This shift highlights the need to incorporate MRF data into assessments, particularly for stocks undergoing changes in exploitation patterns. Whiting in the Irish Sea (whg.27.7.a) provides a relevant case study, as the fishery has transitioned from a landings-based fishery to one dominated by bycatch, and is one of the top five species in terms of number caught be recreational fishers.

One of the key challenges in assessing recreational removals is accounting for the high proportion of fish that are released. MRF often involves substantial catch-and-release activity (Ferter *et al.*, 2013) making it necessary to estimate post-release mortality (PRM) to determine total fishing mortality. Even modest PRM rates can contribute significantly to overall removals, where large amounts of fish are released. Given the absence of species-specific PRM estimates for whg.27.7.a, a precautionary approach is required to ensure that recreational impacts are not underestimated.

Despite the clear need for MRF data in stock assessments, historical recreational catch data are often sparse or incomplete. For whg.27.7.a, recreational removals are only available for 2016–2023, necessitating reconstruction to provide a continuous timeseries for the assessment model. Given the potential importance of recreational removals in the overall stock dynamics, this study aims to reconstruct historical recreational catches for whg.27.7.a using a range of plausible assumptions. The results will provide insight into the role of recreational fishing in total removals that can be used to support stock assessment and management decisions.

Methods

Data collation

Table 1 presents a breakdown of the data provided in response to the ICES benchmark data call for selected North sea and Celtic sea stocks (WKBNSCS) which included whg.27.7.a. Ireland contributed a single year of catch data (2022) from their offsite logbook survey, which includes both catch records and length measurements. England and Wales provided catch and length estimates from 2016 to 2023. These data were collected using an offsite survey as part of the Sea Angling Diary Project (www.seaanglingdiary.org). The same approach was used for data collection in Scotland and Northern Ireland from 2016-21, but these nations withdrew from the survey in 2022 and no further data were generated.

Most of the reported catch originates from the UK (Table 2). A large proportion of the catch was released in both England and Wales. The relative standard errors (RSEs) for all countries and components of the catch were within acceptable limits (Table 3).

Given the high release rates, it is important to account for PRM. No primary literature specific to the study species was identified, meaning that extrapolation from another species is required. As a precautionary approach, this study applied the upper 95% confidence limit of post-release mortality from the Gulf of Maine cod fishery, which is 35.1% (Capizzano *et al.*, 2016) for the approach used for Northern Shelf cod (ADD REF HERE).

Figure 1 illustrates the length distributions for all years and countries combined. Rounding bias is evident, with disproportionately high percentages of recorded lengths ending in 0 or 5. In general, larger fish were more likely to be retained than returned (Figure 1).

Table 1: An overview data provided as part of the data call for whg.27.7.a. Key for data provided: C = Kept & released, L = Length data. Green = Offsite, Grey = Onsite, +/- = Level of bias.

Year	Country				
	Ireland	England	Wales	Northern Ireland	Scotland
2012		C, L			
2013					
2014					
2015					
2016		C, L +	C, L +	C, L +	C, L +
2017					
2018					
2019					
2020					
2021					
2022					
2023	C, L				
2024					

Table 2: The tonnage of whg.27.7.a kept and returned for each of the years where data were provided.

Year	IE		UK		England + Wales	
	Kept	Returned	Kept	Returned	Kept	Returned
2016			30.591	251.437		
2017			35.311	281.392		
2018			25.137	243.873		
2019			22.414	202.141		
2020			27.689	252.515		
2021			24.347	223.512		
2022	0.1	11.6			25.847	150.247
2023					20.926	132.415

Table 3: The relative standard error, expressed as a percentage, in the kept and returned tonnages provided.

Year	IE		UK		England + Wales	
	Kept	Returned	Kept	Returned	Kept	Returned
2016			17.9	13.5		
2017			15.4	11.8		
2018			15.5	11.8		
2019			14.7	11.2		
2020			16.2	12.1		
2021			16.6	13.0		
2022	22	25.9			16.1	11.1
2023					16.9	11.2

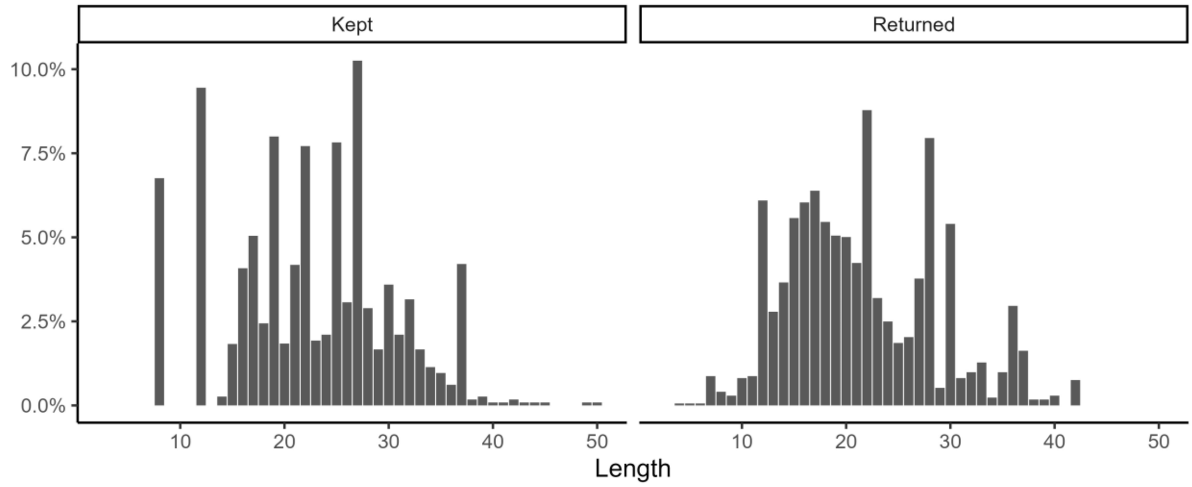

Figure 1: The percentage of fish at each length group of whg.27.7.a kept and returned

Data analysis

Reconstructing countries catches 2016-2023

To reconstruct the catches of whg.27.7.a for Scotland and Northern Ireland, an average ratio of kept and returned catches in these countries was calculated relative to the combined English and Welsh catch in matching years (2016–2021). This process is outlined in full in the WKSEABASS benchmark (Hyder *et al.*, 2025). This same method was applied to Ireland's catch data, after which the proportion of total kept and returned tonnages attributed to Ireland relative to the UK was calculated.

To estimate removals (kept + dead returns), the total kept caches were added to the returned catches after applying the 35.1% post release mortality value (Cappizano et al. 2016).

Reconstructing the historical timeseries before 2016

Removals data are only available for the period 2016–2023. However, the SAM model used to assess whiting 27.7.a requires a continuous timeseries from 1980. This presents a challenge due to substantial changes in the fishery over this period. Historically, the spawning stock biomass (SSB) was several times higher than its current levels, and the nature of the commercial fishery has shifted from a landings-based fishery to one in which whiting is primarily bycatch . For recreational fisheries, there have been many changes due to a combination of changes in fishing effort, opportunities, and technology (REF) that cannot be incorporated in the reconstructions. Instead, four potential reconstruction scenarios were developed to account for potential changes in stock abundance, fishery dynamics, and recreational fishing behaviour from 1980 onwards.

In **Scenario 1**, it was assumed that recreational catches were directly proportional to the spawning stock biomass (SSB) as estimated in the previous ASAP assessment model. This approach accounts for the possibility that catch rates increase when fish abundance is higher. The proportional relationship was calculated similarly to the reconstruction of country-specific removals: total SSB was summed for the period 2016–2023, and total recreational kept and returned tonnage for the same period were also summed. The ratio of recreational catches to total SSB was then applied to years without recreational data to estimate removals.

SSB was substantially higher at the beginning of the timeseries meaning that the linear assumption led to unrealistically high estimates of recreational removals in the early years. To address this issue, **Scenario 2** was developed. Since SSB declined sharply around 1995 to levels comparable to today, this scenario followed the same reconstruction approach as Scenario 1 but assumed that recreational removals remained constant before 1995. This adjustment allows for some variation in catch rates in response to fish abundance while preventing unrealistically high estimates of removals in the early part of the timeseries.

A key uncertainty is whether changes in stock abundance primarily affect retention rather than overall catch levels. In other words, recreational fishers may have a maximum quantity of whiting they catch before ceasing to fish or targeting other species. This idea was tested in **Scenario 3**, which set an upper limit on retained and released whiting based on observed data. This upper limit on the per-angler catch was based on the average weight of whg.27.7.a kept and released per angler per year based on the 2016–2020 Sea Angling Diary data. This cap was then applied to the catches estimated in Scenario 1. The removals were then recalculated accordingly.

Finally, recognising that the first three scenarios rely on an output from the model (SSB) to generate an input (removals), a more simplistic approach was tested in **Scenario 4**. This scenario assumes that recreational catches before the start of the dataset remain constant, using average removals from 2016-23 as a fixed estimate for earlier years.

These four scenarios provide a range of possible reconstructions for recreational removals, each incorporating different assumptions about the relationship between stock size, fishing effort, and retention behaviour.

Results

Reconstructing countries catches

Table 4 presents the results of generating a timeseries of catches from all countries with access to whg.27.7.a between 2016 and 2023. These years represent the period for which at least one country provided data. Most reported catches originated from the UK, with returned fish comprising the largest component. Across the timeseries, average removals were estimated at 113 tonnes.

*Table 4: The reconstructed recreational kept and returned tonnages for all years where data were provided in Ireland, the United Kingdom and in total. Removals are presented in the total's column calculated as the kept + returned * 0.351.*

Year	Ireland		United Kingdom		Total		
	Kept	Returned	Kept	Returned	Kept	Returned	Removed
2016	0.83	6.81	30.59	251.44	31.42	258.24	122.06
2017	0.96	7.62	35.31	281.39	36.27	289.01	137.71
2018	0.68	6.60	25.14	243.87	25.82	250.47	113.73
2019	0.61	5.47	22.41	202.14	23.02	207.61	95.89
2020	0.75	6.84	27.69	252.51	28.44	259.35	119.47
2021	0.66	6.05	24.35	223.51	25.01	229.56	105.58
2022	0.10	11.60	28.56	229.08	28.66	240.68	113.14
2023	0.63	5.47	23.12	201.89	23.75	207.35	96.53
Average	**0.65**	**7.06**	**27.15**	**235.73**	**27.80**	**242.79**	**113.01**

Reconstructing the timeseries

Figure 2 presents the timeseries of removals estimated under each reconstruction scenario. In Scenario 1, removals were estimated based on a direct proportional relationship with SSB. The calculated SSB ratios were 0.027 for the kept component and 0.237 for the released component. This scenario produced the largest estimated catches, with a maximum of 4,860 tonnes in 1981. Scenario 2 applied the same methodology as Scenario 1 but assumed that recreational removals remained constant at 424 tonnes in 1995 and earlier, reflecting the decline in SSB to levels similar to those observed today. All other values remained the same as in Scenario 1. In Scenario 3, an upper cap was applied to the kept component, estimated at 2,264 tonnes per year, while the returned component was capped at 4,053 tonnes per year. These caps were derived from the Sea Angling Diary Project, which reported an average annual catch per angler of 9.93 kept and 32.7 returned. The corresponding average weights were 0.306 kg for kept fish and 0.166 kg for returned fish. Scenario 3 produced results like Scenario 1 until 1989, when the caps were introduced. This adjustment reduced the maximum estimated catch to 2,618 tonnes. Scenario 4 took the simplest approach, applying constant removals estimate of 113 tonnes for all years prior to 2016, based on the average observed removals during the available data period.

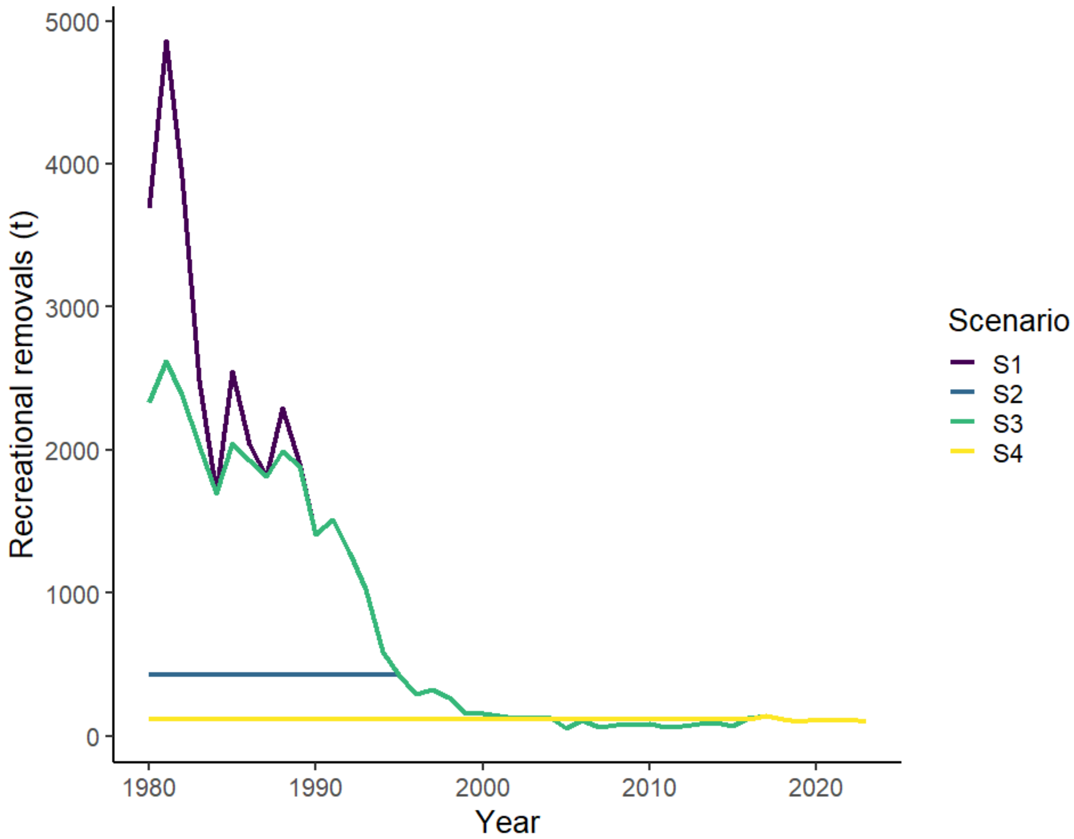

Figure 2: The catches over time calculated for the four reconstruction scenarios: S1 = Constant to ASAP SSB. S2 = Constant to ASAP SSB up until 1995. S3 = Constant to ASAP SSB, but a limit on the kept and returned catch. S4 = Average of 2016-23 removals.

Discussion

The results from the four reconstruction scenarios present a wide range of recreational catch estimates, allowing for an assessment of the sensitivity of the SAM model to variations in input data. Scenario 1 represents the highest estimates of recreational catches. Scenarios 2 and 3 offer intermediate estimates, reflecting more conservative assumptions regarding the relationship between stock abundance and recreational removals. Scenario 4 represents the most pragmatic case, assuming a constant level of recreational removals based on the most recent data.

A key challenge in using Scenarios 1–3 is that they rely on outputs from a stock assessment model (SSB estimates) to generate future input data. If one of these scenarios is selected, the removals estimates would need to be updated based on the SSB outputs from the new SAM model. Typically, an increase in recreational removals would lead to higher estimated SSB, which in turn could feed back into even higher recreational catch estimates.

One of the key challenges was assessing potential biases in the data. Expert evaluations suggested that earlier surveys may have underestimated catches, whereas more recent surveys could be overestimating them. This created a significant hurdle in producing accurate estimates, as the magnitude and direction of these biases varied over time. The variability in bias must be accounted for when synthesising data to create meaningful time series for stock assessment. In particular, the assumptions made about compliance with management measures, such as adherence to bag limits and the increase in MCRS, may not always be accurate, which introduced further uncertainty.

Despite these challenges, these scenarios provide a useful starting point to evaluate the extent to which recreational removals influence the SAM model's assessment of whg.27.7.a stock dynamics. This sensitivity testing will help determine the impact of different assumptions about recreational fishing on stock status estimates and management advice.

This document represents a substantial step forward in understanding the recreational whiting fishery. The integration of national surveys into a coherent data set for stock assessments is a challenging but necessary task. The analysis done represents a step change towards synthesising marine recreational fisheries data from diverse sources and understanding the issues, uncertainties, and biases. Currently there is a lack of knowledge regarding post-release mortality rates of whiting. Since most recreationally caught whiting are released, post-release mortality could be an important component of total whiting removals, highlighting the need for further research. A consistent time series and robust uncertainty analyses are also needed. Continued refinement of the approach should be done as more survey data is generated.

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Appendix 1 – The tonnages from all four reconstruction scenarios

Year	S1	S2	S3	S4
1980	3689.968	423.958	2330.242	113.0144
1981	4860.296	423.958	2618.085	113.0144
1982	3905.28	423.958	2383.198	113.0144
1983	2484.754	423.958	2033.819	113.0144
1984	1692.055	423.958	1692.055	113.0144
1985	2549.303	423.958	2049.695	113.0144
1986	2040.353	423.958	1924.519	113.0144
1987	1816.709	423.958	1816.709	113.0144
1988	2292.662	423.958	1986.574	113.0144
1989	1900.034	423.958	1890.007	113.0144
1990	1411.082	423.958	1411.082	113.0144
1991	1512.961	423.958	1512.961	113.0144
1992	1283.317	423.958	1283.317	113.0144
1993	1021.788	423.958	1021.788	113.0144
1994	586.7196	423.958	586.7196	113.0144
1995	423.958	423.958	423.958	113.0144
1996	291.7489	291.7489	291.7489	113.0144
1997	320.9682	320.9682	320.9682	113.0144
1998	265.4181	265.4181	265.4181	113.0144
1999	156.2067	156.2067	156.2067	113.0144
2000	153.6514	153.6514	153.6514	113.0144
2001	135.8754	135.8754	135.8754	113.0144
2002	121.0991	121.0991	121.0991	113.0144
2003	121.6546	121.6546	121.6546	113.0144
2004	129.2094	129.2094	129.2094	113.0144
2005	51.43935	51.43935	51.43935	113.0144
2006	106.6561	106.6561	106.6561	113.0144
2007	56.21665	56.21665	56.21665	113.0144
2008	72.32617	72.32617	72.32617	113.0144
2009	73.43717	73.43717	73.43717	113.0144
2010	82.76957	82.76957	82.76957	113.0144
2011	59.99405	59.99405	59.99405	113.0144
2012	68.10436	68.10436	68.10436	113.0144
2013	83.43618	83.43618	83.43618	113.0144
2014	94.43508	94.43508	94.43508	113.0144
2015	66.21566	66.21566	66.21566	113.0144
2016	122.0629	122.0629	122.0629	122.0629
2017	137.7089	137.7089	137.7089	137.7089
2018	113.7336	113.7336	113.7336	113.7336
2019	95.89335	95.89335	95.89335	95.89335
2020	119.4701	119.4701	119.4701	119.4701
2021	105.5822	105.5822	105.5822	105.5822

2022	113.1357	113.1357	113.1357	113.1357
2023	96.52841	96.52841	96.52841	96.52841

Appendix 2: Summary of national surveys

A2.1: United Kingdom

Sea Angling 2012

The Sea Angling 2012 survey programme started in 2012 to estimate fishing effort, catches (kept and released) and fish sizes for shore based and boat angling in England (Armstrong et al. 2013). The survey does not cover other forms of recreational fishing.

The surveys adopted, where possible, statistically-sound, probability-based survey designs. Two survey approaches were adopted: firstly, a stratified random survey of charter boats from a list frame covering ports in England; and secondly an on-site stratified random survey of shore anglers and private boat anglers to estimate mean catch per day, combined with annual effort estimates derived from questions added to a monthly Office of National Statistics household survey covering Great Britain.

A list of almost 400 charter boats was compiled for the charter boat survey, and 166 skippers agreed to participate. Each month over a twelve-month period in 2012 and 2013, 34 randomly selected skippers completed a diary documenting their activities, catches, and sizes of fish. A diary was completed whether any fishing took place. Data from 5,300 anglers were collected. Total annual catches were estimated by raising the monthly catches per vessel from the diaries to all vessel-month combinations in the frame and raising this to all vessels including refusals. The estimated total annual catch of sea bass for the entire coast of England was 44t (RSE 31%) of which 31t was kept. The release rate by number was 37%. The charter boat survey has potential bias due to the large non-response rate, if non-respondents have different catch rates to respondents.

The Office of National Statistics (ONS) household survey covered 12,000 households during 2012, and from this it was estimated that 2.2% of adults over 16 years old went sea angling at least once in the previous year. The surveys estimated there are 884,000 sea anglers in England. Estimation of fishing effort by shore and private boat anglers proved difficult due to the overall low number of households with sea anglers in the survey. A range of methods was explored to estimate annual and seasonal effort using the ONS data alone and combining it with observations from on-site and on-line surveys. It was not possible yet to agree on a best estimate of effort, and for that reason the estimates of total catch (cpue × effort) for shore and private boat angling were given as a range of plausible values.

The survey of anglers fishing from the shore and private boats to estimate cpue was carried out throughout 2012 using on-site interviews. A stratified random design was adopted to select shore sites and boat landing sites on a weekly basis from site lists stratified into low-activity and high-activity sites. The shore survey used roving-creel methods (collecting data from partial angling trips), and the private boat survey a roving access-point survey (data from completed trips). Visits were made to 1475 shore sites and 425 private boat sites, and 2440 anglers were interviewed. The mean daily catch rate of kept and released fish of each species was estimated based on the survey design, and sizes of caught fish were recorded. Cpue for shore angling was estimated using catches for the observed trip duration and estimates of expected total trip duration for that day. A length-of-stay bias correction was applied based on expected total trip duration. The catch-per-day estimates were combined with estimates of total annual fishing effort (days fished) obtained from the ONS survey to estimate total annual catches. Release rates, by number, were 82% for shore angling and 57% for private boats. Non-response rates were low (<10%) in this survey. The range of point estimates for shore-caught sea bass was 98–143t (total) and 38–56t (kept), and for private and rented boats was 194–546t (total) and 142–367t (kept). The relative standard errors for the individual shore and private boat estimates were high at 40–50%.

Combining the catch estimates for charter boats, private boats and shore angling, the point estimates of annual kept weights of sea bass ranged from 230t–440t, compared with total UK commercial landings of almost 900t in 2012. The combined estimates of sea bass catches had precision (relative standard error) estimates of 26%–38%for the different effort estimation methods.

Sea Angling Diary (2016-present)

The Sea Angling Diary programme has been running since 2016 with the aim of estimating the number of sea anglers, how often they fish, what they catch, and the social and economic benefits that they generate (Hyder et al. 2020; 2021; 2024). This is done through combining the outputs from two surveys: a survey of 12,000 individuals that generates estimates of the numbers of anglers and their characteristics; and sea anglers that volunteer as 'citizen scientists' to report their catches through the Sea Angling Diary. These estimates are combined accounting for differences in characteristics of sea anglers to generate the numbers and tonnages of fish kept and released by sea anglers in the UK. From 2016-21, over 5,000 sea anglers provided data on over 48,000 fishing sessions and 362,000 catch records from 216,000 hours of angling activity.

To estimate the participation and effort by UK sea anglers, questions were added to a survey of 12,000 residents (Watersports Participation Survey - WPS). Due to COVID restrictions, it was not possible to do face-to-face surveys as in 2016-19, so an online panel was used instead. The 2020 online panel generated much higher estimates than previous surveys, probably due to the different approaches. This meant that it was not possible to use the 2020 results in the analysis as it would impact on the consistency of the time series. Instead, data from the WPS from 2016-19 were modelled and used to derive estimates. This approach utilised all existing data to generate more consistent and robust results than previous annual estimates.

Catch per unit effort was generated from an offsite diary panel. For example, a total of 15,064 sessions and 107,697 individual catches across over 100 species were reported in 2020-21 by up to 900 sea anglers each year. Data from 2016-23 were used to model the number of fish kept and released by individual sea anglers each year and the weights of individual fish. Numbers of sea anglers were combined with diary panel catch per angler, to estimate total UK catches, after correcting for differences between the diary sample and the UK population.

Each year, around 7 million fish were retained and 28 million were released, representing a release rate of around 80%. Catch composition was similar between years with mackerel, whiting, lesser spotted dogfish, and sea bass the most caught fish. All results can be accessed through the UKSAIL website (https://rconnect.cefas.co.uk/sea_angling_library/).

Total catch estimates were higher than those in the English 2012 onsite survey. It is likely that a combination of survey bias, sampling error, or changes in fish abundance generated the differences. The consistent difference between the approaches indicated that it is likely due to the methods, both of which are uncertain and subject to bias. As a result, a side-by-side comparison between diary and onsite approaches is underway to validate the diary approach (www.catchwise.org).

A2.2: Ireland

The Irish Marine Recreational Angling Survey uses several sampling programmes to assess catches around the Irish coast. A full description can be found in Ryan et al. (2022; 2023) with a summary provided below.

An onsite roving creel survey of shore anglers has been done. The IMREC survey of shore anglers utilises a spatio-temporal sampling method to collect catch per unit effort (CPUE) data of sea anglers around the Irish coast. The survey incorporates spatial and temporal stratification into its design, where increased sampling effort is allocated to the places and times with greater angling effort. The spatio-temporal sampling frame consists of two spatial strata: East (ICES regions 7.a and 7.g) and West (ICES regions 7.j2, 7.b and 6.a) and two temporal strata: Winter (November to March) and Summer, (April to October). To increase the likelihood of encountering anglers during sampling, weighted angling activity strata were also written into the sampling programme. At the start of the sampling season, sampling schedules were produced which instructed samplers to visit a randomly selected PSU on a particular sampling day.

All anglers are interviewed about their catch on site and all information is uploaded and a follow up interview is requested to collect a complete picture of their angling trip. The mean catch-per-unit-effort (CPUE) of all marine recreational fisheries species caught during each shore angling trip is estimated where an angling trip is defined as one daily angler trip for shore angling. A ratio of the means estimator was used to calculate average species specific CPUE across all strata. Retained or released fish of a particular species were considered as a separate catch.

An onsite bus route access point survey of small boat anglers was also done. The IMREC survey of private small boat anglers also uses a spatio-temporal sampling method to collect catch per unit effort data around the Irish coast. The most appropriate method of collection of catch data for this survey is through a random-access point survey. Unlike the roving-creel type approach, access point surveys capture complete angling trip data as the interview occurs when the angler has completed their fishing trip. This survey also incorporated spatio-temporal stratification into its final design to maximise sampling efficiency and PSU selection procedures followed the steps described in the roving creel survey of shore anglers.

The onboard charter catch survey randomly selects and samples chartered angling trips to record species numbers, and measure lengths and weights of all captured and released fish. A sampling frame was developed from charter skippers operating around the Irish coast. As per the surveys, the sampling frame was stratified spatially (east and west coasts) and temporally (summer and winter). Surveys were selected through a well-defined random sampling frame. Samplers were assigned to randomly selected vessel trips to count and measure captured fish.

An offsite citizen science angling diary was designed to provide a simple recording platform for anglers (hereafter referred to as “diarists”) to submit catch information from their shore angling trips. This citizen science approach to data collection allows participating shore anglers to submit data on numbers of fish species caught and released or retained over the course of their daily angling trip. It followed a non-probabilistic, self-selection approach to data collection.

The IMREC Diary was launched in August 2021. The diary was open to all anglers that expressed an interest in participating in the project. Several techniques were deployed to encourage anglers to participate in the programme. To encourage participating diarists to keep submitting trips, monthly draws for angling vouchers were offered to anglers who submitted angling trips to the diary within the previous month. To further incentivise anglers to participate in the online diary, a dashboard that displays their submitted angling trips and catches on an interactive map was developed. Diarist recruitment and retention is ongoing. There is uncertainty regarding reporting bias associated with the diary. Currently this data is used to assess catch seasonality for some species of interest.