BENCHMARK WORKSHOP ON ANGLERFISH AND HAKE (WKANGHAKE; outputs from 2022 meeting)

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i Executive summary

The benchmark workshop on anglerfish (*Lophius budegassa, Lophius piscatorius*) and hake (*Merluccius merluccius*) (WKANGHAKE) was the first ICES benchmark entirely dedicated to assessment models run with the integrated model Stock Synthesis (SS) software. Besides the data workshop, which was held in November 2021, several online sessions were held on a continuous basis with all participants, including the reviewers and chairs between November 2021 and February 2022. Those sessions were focused on model development through constant online feedback between stock assessor teams, reviewers, and chairs. The continuous feedback resulted in several key issues being resolved before the actual benchmark meeting took place in February 2022 and was of great benefit to both the assessment teams and the reviewers. Four stocks, pertaining to the ICES assessment working group WGBIE (Working Group for the Bay of Biscay and the Iberian Waters Ecoregion) were assessed during the benchmark. These were: Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters; hke.27.8c9a); Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay; hke.27.3a46-8abd); White anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay; mon.27.78abd); and Black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay; ank.27.78abd). For all stocks a final model was developed and agreed to be appropriate to determine stock status and provide short-term catch forecast. The extensive exploration of input data and model configurations carried out during the benchmark also resulted in several recommendations regarding on how to improve the estimation of biological parameters to be used in the models, and the possibility of developing area-based models in future benchmarks which would likely allow conflict resolutions in survey indices observed in most of the models.

ii Expert group information

Expert group name	Benchmark workshop on anglerfish and hake (WKANGHAKE)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Massimiliano Cardinale, Sweden
	Giuseppe Scarcella, Italy
Meeting venue and dates	23–25 November 2021, online meeting (20 participants)
	14–18 February 2022, online meeting (20 participants)

1 Introduction

Benchmark workshop on anglerfish and hake

The benchmark workshop on anglerfish (*Lophius budegassa, Lophius piscatorius*) and hake (*Merluccius merluccius*) (WKANGHAKE) was chaired by Giuseppe Scarcella (CNR) and Massimiliano Cardinale (SLU) and reviewed by invited external experts Lisa Ailloud (NOAA), Matthew Smith (NOAA), and Dean Courtney (NOAA). The benchmark participants met online 23–25 November 2021 for a data workshop, and 14–18 February 2022 for a five-day assessment methods workshop. For all stocks in this benchmark, it was proposed to use Stock Synthesis (SS) as the assessment method. See also the work presented in WKTADSA[1] that was done in preparation of this benchmark for further details on model development. WKANGHAKE worked to:

1. As part of the data workshop:
   a) Publish an ICES data call for information on length and maturity data from sampled catches for hake to assist in validating the maturity ogive. Collate and analyse submitted data;
   b) Consider the quality of data proposed for use in the assessment;
   c) Examine the raising of discards in collaboration with representatives from WKMIXFISH;
   d) Make a proposal to the benchmark on the use and treatment of data for each assessment, including discards, surveys, life history, fishery-dependent, recreational, etc.;
   e) Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality.
2. In preparation for the assessment methods workshop:
   a) Following the data workshop, produce working documents to be reviewed during the benchmark assessment workshop at least 14 days prior to the meeting.
3. As part of the assessment methods workshop, agree to and thoroughly document the most appropriate:
   a) Method for conducting the stock assessment;
   b) Method and values for fisheries and biomass reference points that follow the best available science (i.e. taking into consideration the recommendations made by WKREF1 and WKREF2) and are in line with ICES guidance (see ICES Technical Guidelines on reference points[2]);
      (i) If additional time is needed to conduct the work and agree to reference points, a short additional reference point workshop will be scheduled to conduct this work.
   c) Method for conducting the short-term forecast.
4. As part of the assessment methods workshop, knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. A full suite of diagnostics (regarding data, retrospective behaviour, model

[1] ICES. 2021. Workshop on Tools and Development of Stock Assessment Models using a4a and Stock Synthesis (WKTADSA). ICES Scientific Reports. 3:33. 197 pp. https://doi.org/10.17895/ices.pub.8004

[2] ICES. 2021. ICES fisheries management reference points for category 1 and 2 stocks. Technical Guidelines. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021, Section 16.4.3.1. https://doi.org/10.17895/ices.advice.7891

fit etc.) should be examined as a whole to evaluate the appropriateness of any model developed and proposed for use in generating advice.

5. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach see WKLIFE X[3] should be put forward by the benchmark;

6. Update the stock annex as appropriate; and

7. Develop recommendations for future improvements of the assessment methodology and data collection.

The following four stocks, pertaining to the ICES assessment working group WGBIE (Working Group for the Bay of Biscay and the Iberian Waters Ecoregion), were selected for the benchmark, listed here with the corresponding section in the report:

- Section 2: Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay; hke.27.3a46-8abd).
- Section 3: Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters; hke.27.8c9a).
- Section 4: Black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay; ank.27.78abd).

Section 5: White anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay; mon.27.78abd).

[3] 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 X). ICES Scientific Reports. 2:98. 72 pp. http://doi.org/10.17895/ices.pub.5985

2 Greater North Sea, Celtic Seas, and northern Bay of Biscay hake

Merluccius merluccius in subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d, Northern stock; hke.27.3a46-8abd

2.1 Introduction

In the data workshop and the benchmark process several issues that can compromise the quality of the assessment of the northern stock of European hake were identified. Between the data workshop and the final benchmark meeting these issues were addressed. This section is structured as follows. First, for each issue, a subsection has been added explaining how it was addressed, its impact on the perception of the stock and/or assessment model performance and the final decision on whether or not to introduce it in the final model configuration. After presenting how the issues have been addressed, a section with the final model configuration has been added, with a deep analysis of the model performance and estimated stock perception. The final section concerns the development of the reference points.

2.2 Maturity

The maturity ogive currently in use was calculated in the benchmark carried out in 2010 using data from Bay of Biscay and using a knife-edge curve with L_{50} = 42.85 cm (ICES, 2010). In the data workshop, time-series of L_{50} estimated using AZTI's data from the Bay of Biscay was presented. The L_{50} showed an increasing trend in the most recent years that could be due to both a change in the way resting individuals is assigned and/or a real trend in the biological process of maturation. After the working group, a deeper analysis was conducted using the data call and DATRAS. There were differences in the estimated L_{50} between laboratories that were difficult to explain. It seemed that resting individuals, difficult to distinguish from immature ones, are assigned systematically as immatures in some cases, which leads to higher L_{50} estimates. It is known that maturity stage of hake is difficult to determine after the main spawning peak in the first quarter occurs. Thus, it is recommended to calculate the maturity ogives using only data in the spawning period (i.e. January-May). This implies that only data for the Bay of Biscay is available as the rest of the data comes from research surveys that take place in autumn.

Figure 2.1 shows the temporal trend of L_{50} in the spawning period in the Bay of Biscay. There are two clear periods, from 2000 to 2011 and from 2012 to 2021. Before 2011, L_{50} is well below the value used currently in the assessment. After 2011, the values for females are close to the historical value used. The way resting individuals is classified changed in 2014, which is assumed to have a minor impact in the first quarter. Thus, the change could represent a real change in the maturation process, which could be related to the increased biomass level. However, there was not enough time to test its impact on the stock assessment and model performance during the benchmark.

Benchmark Decision: Use the same L_{50} as used in the past, similar to the one observed for females in recent years.

Benchmark Recommendations: It is recommended that the WGBIOP revise the maturity data available for northern hake and calculate a maturity ogive, for females, to be used in the assessment of the stock and together with the RCG defines an adequate sampling protocol.

Furthermore, it is recommended that they revise the maturity data collected for this stock. When using only first quarter data, the maturity data only covers the Bay of Biscay, which represents only the southern part of the stock distribution and, therefore, a broader spatial coverage is needed. Moreover, if WGBIOP thinks that maturity data outside the first quarter is not reliable, it would be more efficient to concentrate the sampling during the first quarter while ensuring a good spatial coverage along the spatial distribution of the stock.

Figure 2.1. Estimated L_{50} over time. Dashed line = L_{50} used in the assessment.

2.3 Length-weight relationship

The length weight relationship used in the base case, $W_{(g)} = \alpha \cdot TL_{(cm)}^{\beta}$, has parameters α = 0.00513 and β = 3.074 and was estimated in the 1980s. In a working document presented during the data workshop (see Annex 3: Working documents) a trend in the estimated mean at length over time was observed (Figure 2.2). It was initially proposed to use 3-year blocks based on the mean value in each block. The impact of using the 3-year block approach was tested and it was estimated to be very low.

Benchmark Decision: As there was no time to analyse the stock specific length-weight data for Northern hake during the benchmark and the impact of the 3-year block was limited, it was decided to use the length-weight relationship calculated for the Southern hake stock (α =6.59e-06, β = 3.16826) because, initially, the biological part was common for both stocks.

Benchmark Recommendation*:* To carry out an interbenchmark workshop as soon as possible to revise the biological components of the model.

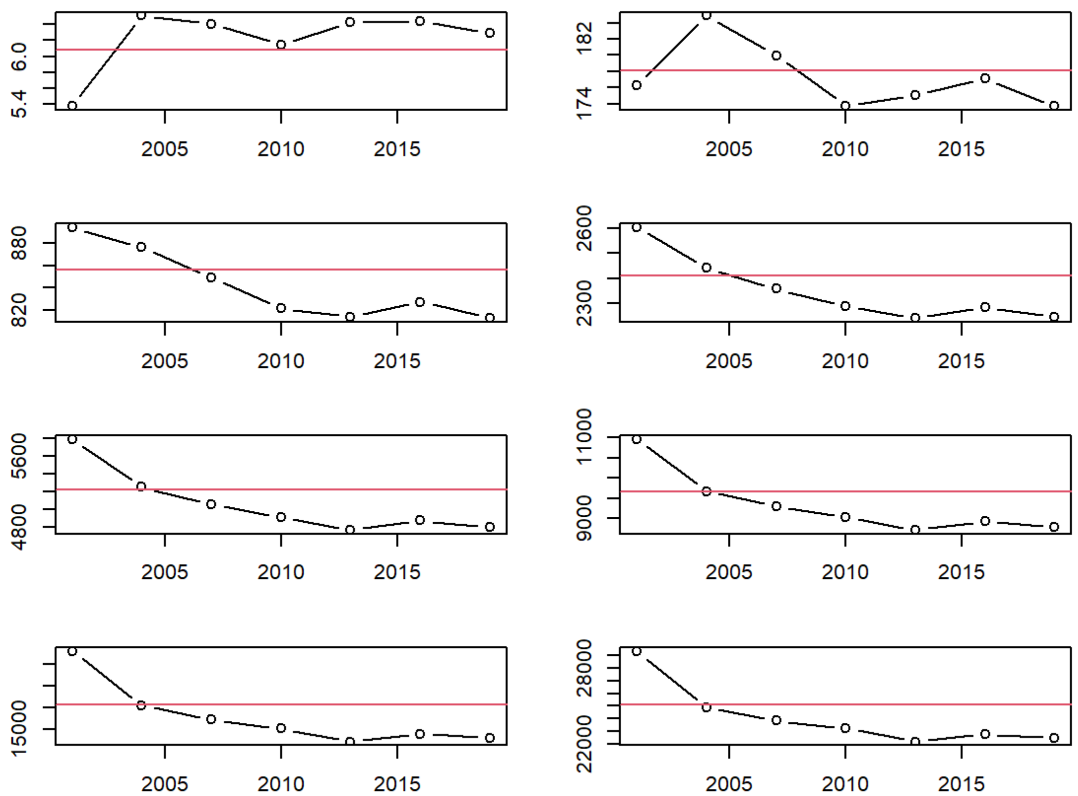


Figure 2.2. Estimated weight-over-time for lengths of 10, 20, 30, 40, 50, 60, 70 and 80 cm (from left to the right, and top to the bottom).

2.4 Growth parameters

In the 'base case' configuration L_{inf} and K were both fixed to L_{inf} = 130 cm and K = 0.17 yr^{-1}. De Pontual *et al*. (2013) based on tagging data proposed L_{inf} = 125 cm and K = 0.17 yr^{-1}. In a working document presented during the workshop, (see annex 3: working documents) proposed to calculate L_{inf} based on a meta-analysis on different hake species and life invariants for the Southern hake stock. In this case, L_{inf} is derived from maturity ogives. As maturity for northern hake stock needs further analysis as initially, the growth parameters for both males and females were borrowed from the southern hake stock.

Benchmark Decision: As there was no time to analyse the conditioning of the biological part of the model during the benchmark it was decided to maintain the same values used initially in the sex-disaggregated model.

Benchmark Recommendation*:* To carry out an interbenchmark workshop as soon as possible to revise the biological components of the model.

2.5 Natural mortality

In the base case model configuration, the natural mortality (M) value was equal to 0.4 for all ages. However, this value did not have any strong scientific support. In the final run, a sex-dependent natural mortality vectors were used, with higher natural mortality rate at younger ages, and constant mortality beginning at age 5. The vector of sex-separated values was based on the methods used to estimate natural mortalities in the assessment of the Adriatic and Sicilian European hake (FAO, 2019a, b). The differences obtained in the stock perception using a constant mortality or a variable one is shown in Figure 2.3. The performance of the model in terms of model fit was similar. The recruitment was significantly higher to compensate the higher fishing mortality, but the overall trend was similar. In recent years, the drop in the biomass was sharper.

Benchmark Decision: In the final run, a sex-dependent natural mortality was used with higher natural mortality rate at younger ages and constant mortality since age 5. These values were the same as the ones used in the southern hake stock.

Benchmark Recommendation: To carry out an interbenchmark workshop as soon as possible to revise the biological component of the model.

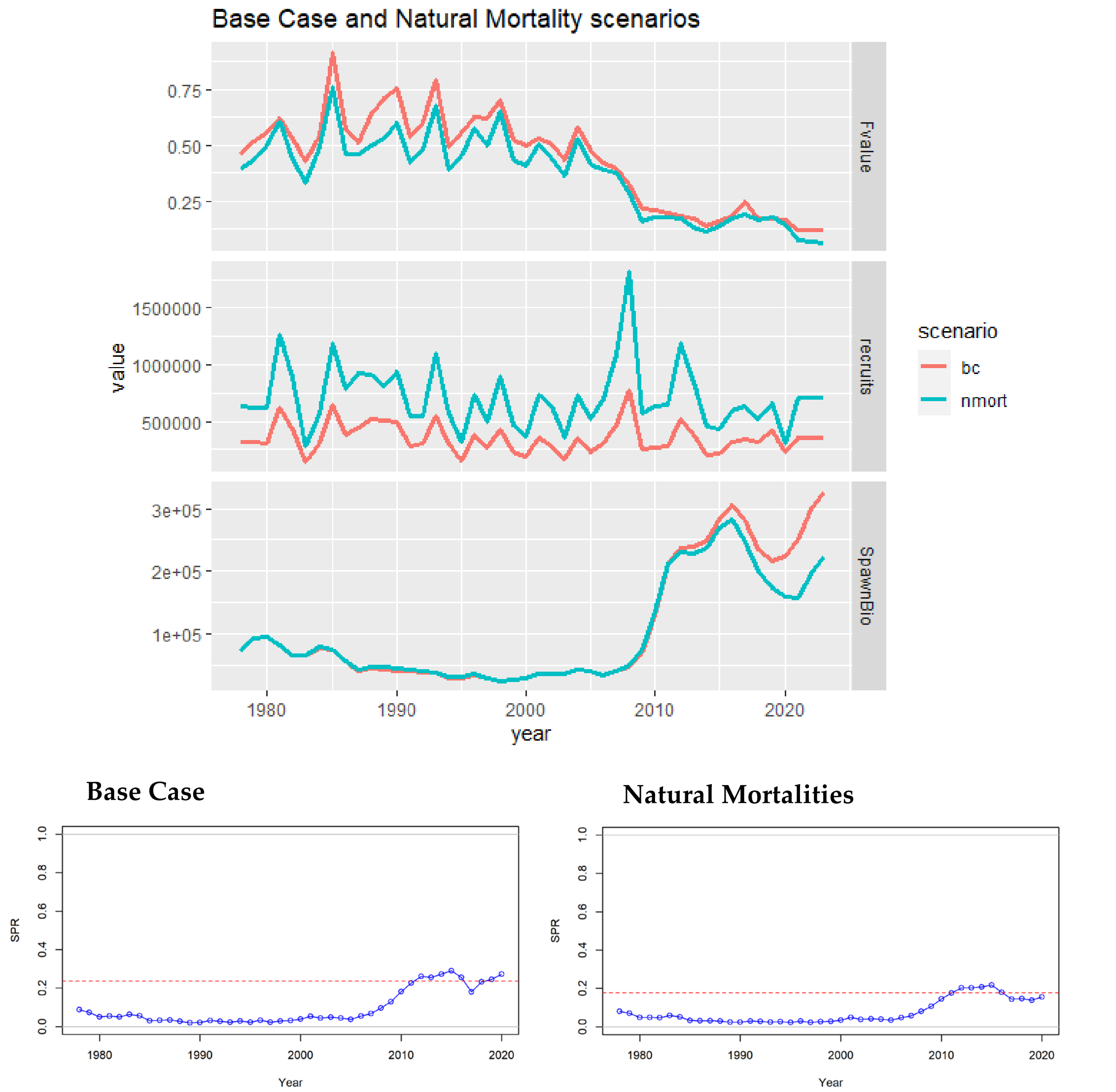


Figure 2.3. Time-series of stock status indicators in the Base Case fit and the case with age-dependent natural mortality (top) and SPR time-series relativo to SPR0, horizontal red line corresponds to SPR at MSY (bottom).

2.6 Steepness

Steepness was equal to 0.99 in the 'Base Case' which is not biologically realistic. As sigmaR is big enough to give flexibility to the model to estimate recruitment deviations adequately, the impact of different steepness values in the historical development of the stock is low. However, steepness does impact on the estimation of virgin biomass, reference points and projections. Steepness was estimated by the model and provided a relatively precise estimate (0.9; Figure 2.4), slightly above the value used for the Southern hake stock, 0.88, that was taken from the literature (see section 3 in this report).

Benchmark Decision: Steepness is estimated by the model in the current configuration.

Benchmark Recommendation*:* Monitor the robustness of the estimation of steepness to changes in biological parameters or addition of new year data.

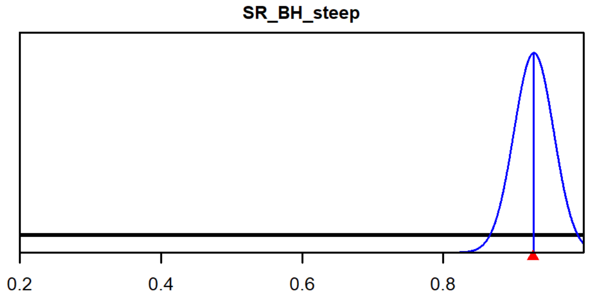


Figure 2.4. Estimate of the probability distribution of steepness.

2.7 Initial condition

Using total catches of European Hake from ICES reports, and assuming the same distribution of catches among stocks (south and north) and fleets as in the early years of the time-series (1946–1977) Total catches of northern European hake were reconstructed back to 1946 by fleet. The objective was to obtain a better estimation of the virgin biomass. However, the results obtained were pretty similar to those obtained using data from 1978. Hence, it was decided not to extend the time-series back to 1946 because it required making a lot of assumptions and there was no real gain observed.

Benchmark Decision: Do not extend the time-series of catches.

Benchmark Recommendation*:* No recommendation.

2.8 Weight of the likelihood components

The amount of length data in the model (9 fleets + 8 surveys, 4 seasons, annual length–frequency distribution (LFD) data since 1978, seasonal since 1990) produces a big imbalance in the proportion between the different likelihood components of the model, with 97% of the likelihood coming from the LFD. This makes the model a bit ‘insensitive’ to other data sources, especially the survey indices. We tested the Dirichlet (Thorson, 2017) and McAllister and Ianelli (1997) approaches, for assigning weights to the likelihood components, but they had little impact on the results presumably because the sample size used as input data are not a real sample size but only a relative weighting between fleets and surveys. Alternatively, the LFDs were down-weighted by multiplying all the LFDs by 0.1 in one scenario, and by multiplying the survey LFDs by 0.1 and the fleet LFDs by 0.01 in another scenario. The run test and the retrospective patterns improved when LFDs were down-weighted by 0.1 but the hindcasting was worse. The diagnostics were better in the scenario where all LFDs were multiplied by 0.1.

Benchmark Decision: All the LFD-s were multiplied by 0.1

Benchmark Recommendation: Continue investigating the correct way of weighting the likelihood components.

2.9 IAMS survey

A new Irish survey starting in 2016 was presented during the data workshop. This index has a wide coverage along Celtic Sea and targets bigger individuals than EVHOE and IE-IGFS. Furthermore, it provides sex-disaggregated data. Thus, the index could be useful to have more information on big individuals and sex ratio for sex-separated model. The introduction of the index had little impact on the overall performance of the model and the estimates but it was decided to keep it within the model as the time-series will increase in future and the value of the index will increase.

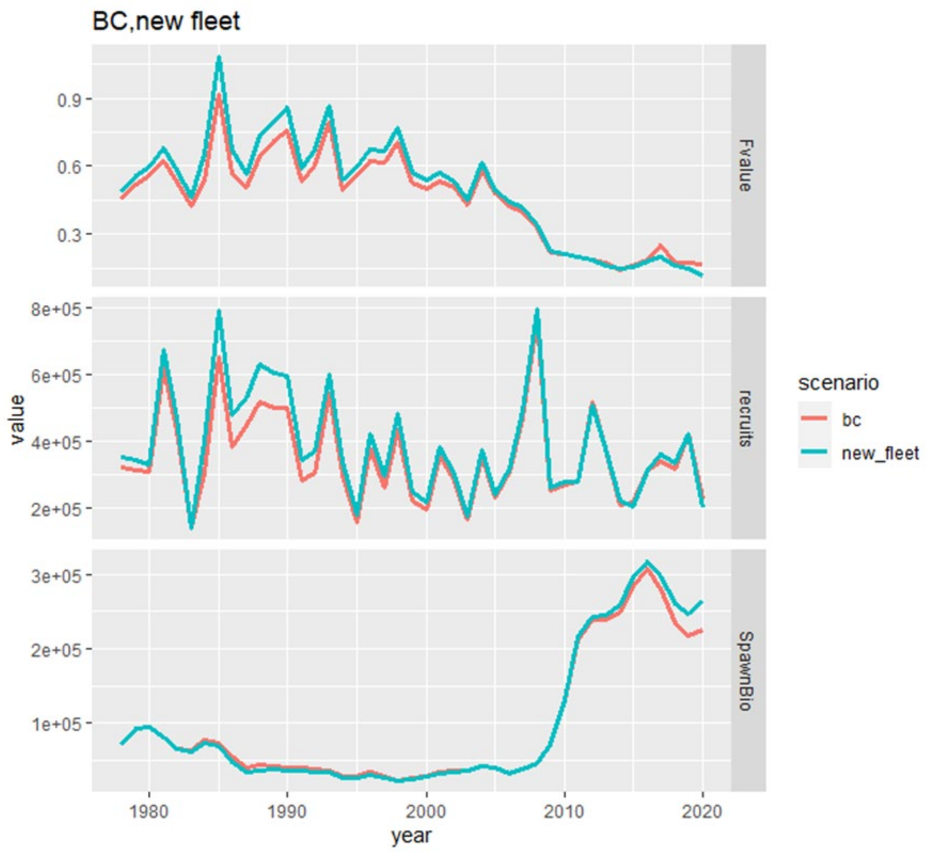
Benchmark Decision: Inclusion of the index in the final configuration of the model.

Benchmark Recommendation: None.

2.10 Disaggregation of the OTHER fleet

OTHER fleet, that accounts for catches in the northern part of the stock distribution (ICES divisions 3, 4 and 6), was a minor fleet in the past. However, with the expansion of the stock its contribution to the total catch is currently around 30%. This fleet includes catches from different gears like trawlers and gillnetters. During the workshop it was considered necessary to disaggregate this fleet into two segments, Trawlers and Non-Trawlers. The disaggregation was only possible since 2013 when InterCatch was first used for reporting catch data. The disaggregation of the fleet produces a similar fit, in terms of model performance, with a lower decrease in biomass in the most recent period (Figure 2.5).

Benchmark Decision: Disaggregation of the OTHER fleet in two new fleets since 2013.



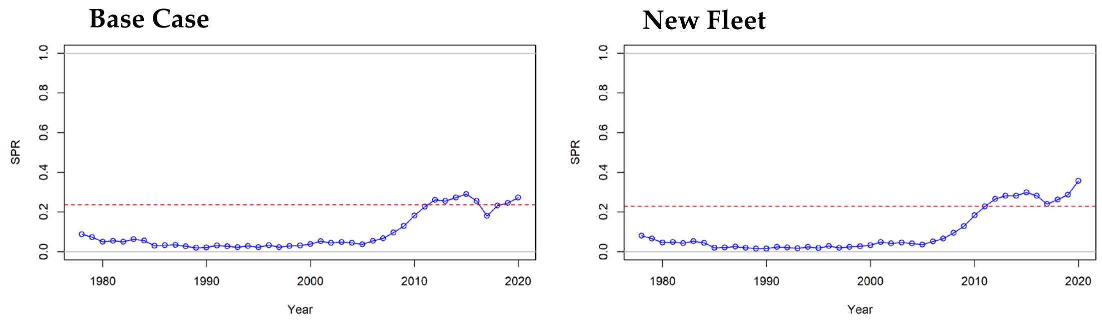


Figure 2.5. Time-series of stock status indicators in the Base Case fit and the case with the OTHER fleet dissagregated (top) and SPR time-series relativo to SPR0, horizontal red line corresponds to SPR at MSY (bottom).

2.11 Discards

In the assessment of northern European hake stock, discards were not raised externally but they were taken from InterCatch and directly introduced in the model even if discards are estimated internally by SS, they could be underestimated. During the data workshop, it was proposed to check the data and raise the discards externally in some cases where no samples are available but where discards are likely to occur. The code developed by Marine Institute in Ireland was applied to raise discards from 2014 to 2020. The values obtained were more similar to what was observed before 2014. As LFD did not change, the impact of total discards in the assessment were minimal.

Benchmark Decision: Introduce the externally raised discards in the model input.

2.12 Selectivity and fishing mortality

Several scenarios of selectivity and fishing mortality (F) were tested. Using blocks or random walks from year 1998, for Spanish fleet in the first case and for all the fleets in the other. Fishing mortality method 4 (i.e. a fleet-specific parameter hybrid F approach) was tested using method 2 only for 2 fleet or for all of them. The scenarios were compared using performance statistics (run test, Mohn's rho and hindcasting test).

Benchmark Decision: F method 4 was selected, with hybrid method for SPTRAWL7, TRAWLOTH, FRNEP8, SPTRAWL8, NSTRAWL and OTHERS) and parametric for GILLNET, LONGLINE and OTHIST. For selectivity a random walk since 1998 for selection and retention was used for all the fleet.

2.13 Sex disaggregated configuration

Hake is a dimorphic species with very different growth pattern by sex, while females reach more than 130 cm it is rare to observe males above 80 cm. The sex-disaggregated model with similar model configuration provided better estimates than the sex-aggregated model with better diagnostics, especially retrospective pattern. The differences in the stock indicators were small and the trends were almost identical. See Figure 2.6.

Benchmark Decision: Use the sex-disaggregated configuration in the final configuration

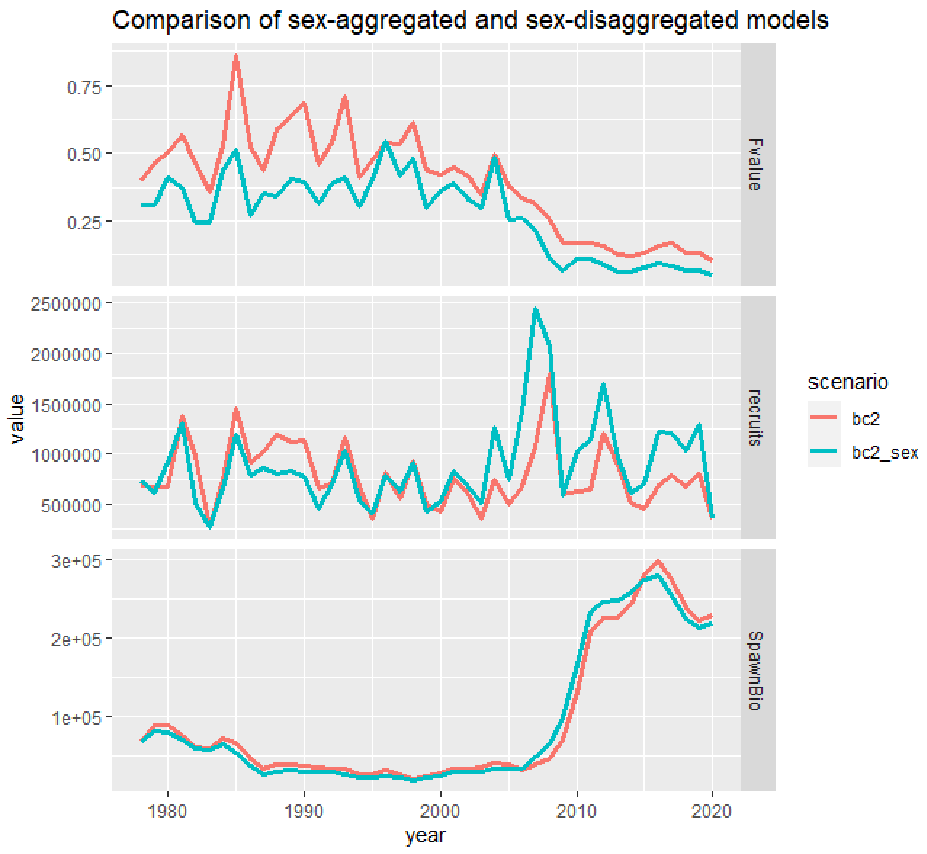


Figure 2.6. Time-series of stock status indicators in the Base Case fit and a similar model but disaggregated by sex (top) and SPR time-series relativo to SPR0, horizontal red line corresponds to SPR at MSY (bottom).

2.14 Analysis of the final configuration

Figure 2.7 compares the stock indicators using the last accepted model configuration (ICES, 2019a) and that developed during the benchmark. The main differences in recruitment come from the age-dependent natural mortality, with greater mortality currently observed on larger individuals. For SSB and F the trends are very similar.

All the abundance indices passed the run test and only one of their LFDs failed. In the commercial fleets, only two of the LFDs passed but there were not big patterns observed in general (Figures 2.8–2.12).

Table 2.1 shows the MASE statistic (Carvalho *et al.*, 2021) for the surveys and the length–frequency distributions. Among the scientific surveys, the EVHOE index has the best predictive power. On the other hand, Porcupine and IGFS had a moderate predictive power. For IAMS, the MASE was large but this is likely due to the shortness of the time-series.

In terms of retrospective pattern (Carvalho *et al.*, 2017), the fit was quite stable from year to year with a very low Mohn's rho value and no directional trend in the peels (Figure 2.13), which is significantly better compared to the results in the last assessment of this stock.

In the jitter analysis, half of the fits converged to a similar log-likelihood where differences were < 0.001 in percentage (Figure 2.14). In terms of indicators, all the runs gave quite similar results (Figure 2.14). However, the likelihood of the Base model configuration was not the lowest one. In the other half of the runs, there was a set of runs with a log-likelihood somewhat above the log-likelihood of the base model configuration and which produced a similar stock perception. The rest of the runs did not converge or did not produce sensible results.

Figure 2.15 shows the parameters that vary the most in the jitter. In general, there are two sets of values with the parameters all related to the shape of the selectivity curves and the extra standard deviation (SD) in abundance indices. The extra SD in abundance indices had very little variation so the impact was very low. In the parameters related with selectivity curves, three are related with IAMS and other three with RESGASCQ-2. These parameters are highly correlated in general, so even if the differences in the values are high, the impact was very limited because probably the effect cancels out. There was only one parameter for RESGASQ-4 survey, but the variation was very low.

Table 2.1. Hindcast indicators, by fleet/survey and joint. The lower the indicator, the better. The value for IAMS is incorrect because there was a bug in the code due to the short time-series.

Index	Season	MASE	MAE.PR	MAE.base	MASE.adj
EVHOE	4	0.69499829	0.60947167	0.87693981	0.69499829
PORCUPINE	3	1.08199357	0.38695456	0.3576311	1.08199357
IGFS	4	1.0051	0.55140025	0.54860238	1.0051
IAMS	1	9.88704541	2.23840752	0.22639802	9.88704541
joint		**1.79811695**	**0.89351615**	**0.49691771**	**1.79811695**
SPTRAWL7	3	1.41147638	0.1025314	0.07264125	1.02531405
TRAWLOTH	3	1.05696154	0.05594858	0.05293341	0.55948581
FRNEP8	3	2.83480347	0.06577269	0.02320185	0.65772695
SPTRAWL8	3	1.18949944	0.09932706	0.08350325	0.99327065
GILLNET	3	0.366817	0.07538834	0.20552031	0.366817
LONGLINE	3	1.00698727	0.03868664	0.0384182	0.3868664
NSTRAWL	1	1.7091354	0.11424396	0.06684313	1.14243961
OTHERS	1	1.3934256	0.10789964	0.07743481	1.07899642
EVHOE	4	0.69751383	0.14165756	0.20308925	0.69751383
PORCUPINE	3	0.82086067	0.09605108	0.11701265	0.82086067
IGFS	4	0.64257888	0.21073119	0.32794602	0.64257888
IAMS	1	0.96546592	0.14052274	0.14554914	0.96546592
joint		**0.8869052**	**0.10278662**	**0.11589359**	**0.8869052**

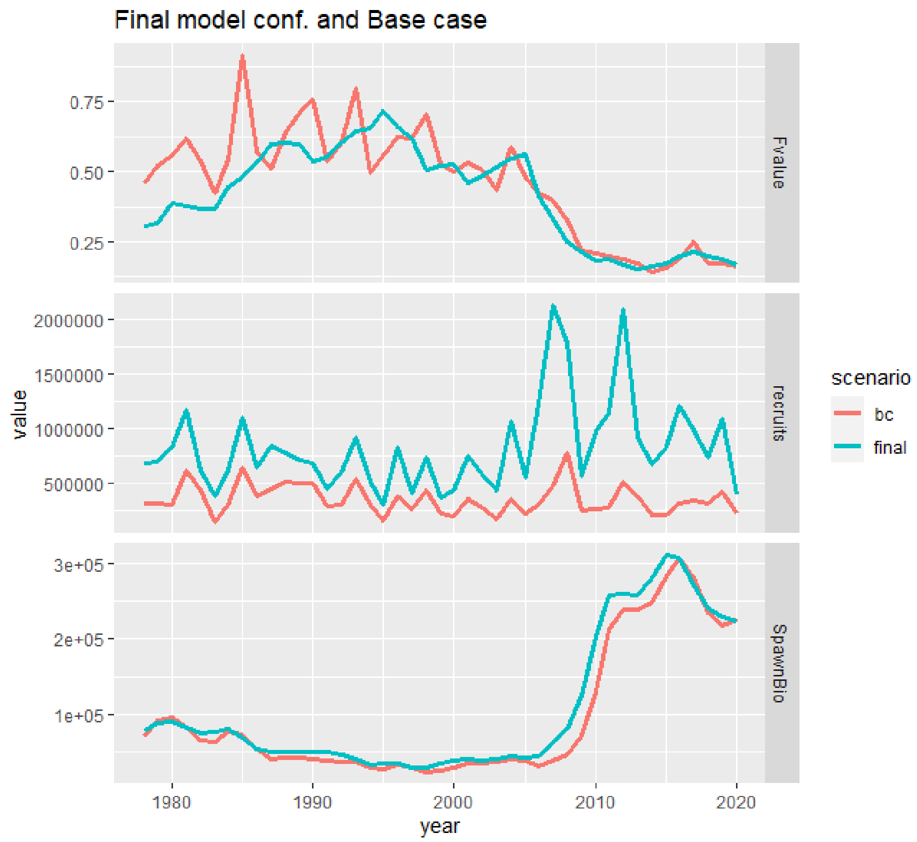


Figure 2.7. Time-series of stock status indicators in the Base Case fit and the final model configuration (top) and SPR time-series relativo to SPR0, horizontal red line corresponds to SPR at MSY (bottom).

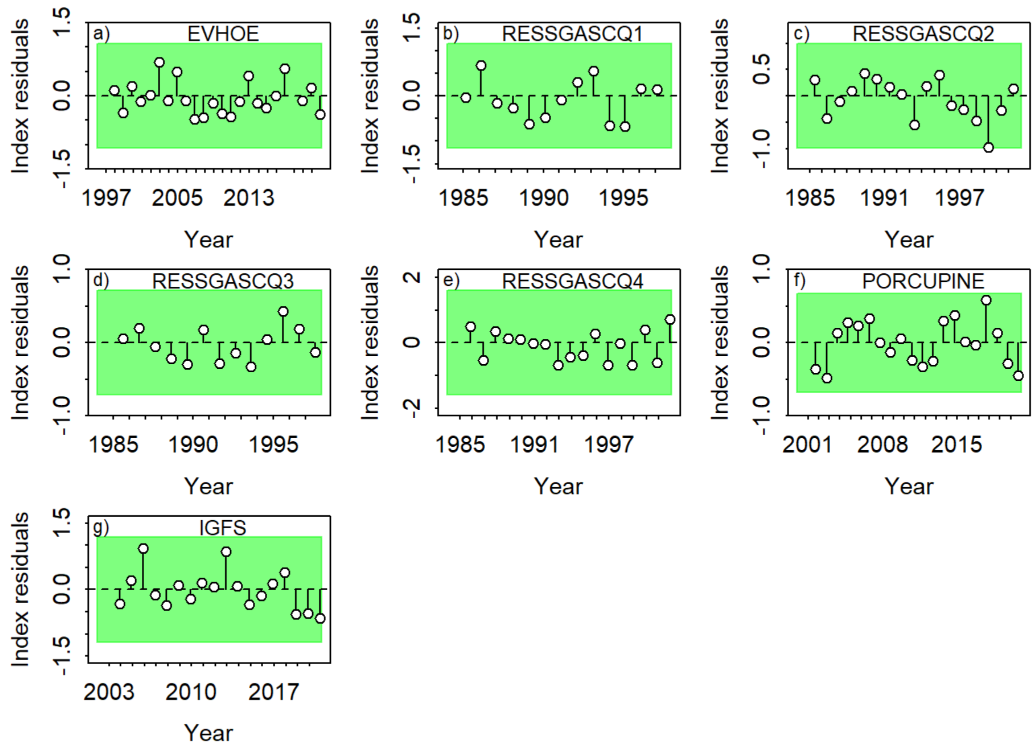


Figure 2.8. Residuals of the surveys, green bands mean the data has passed the run test and red ones indicate it has not passed.

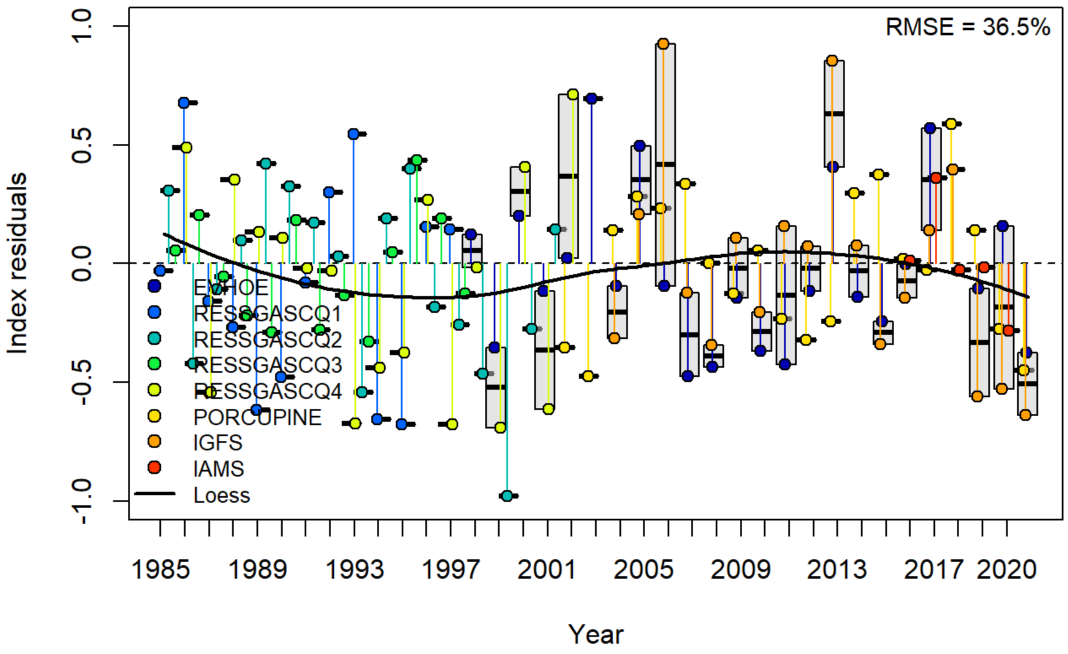


Figure 2.9. Joint residuals of the surveys, an RMSE value below 30% indicates a low conflict between the different surveys.

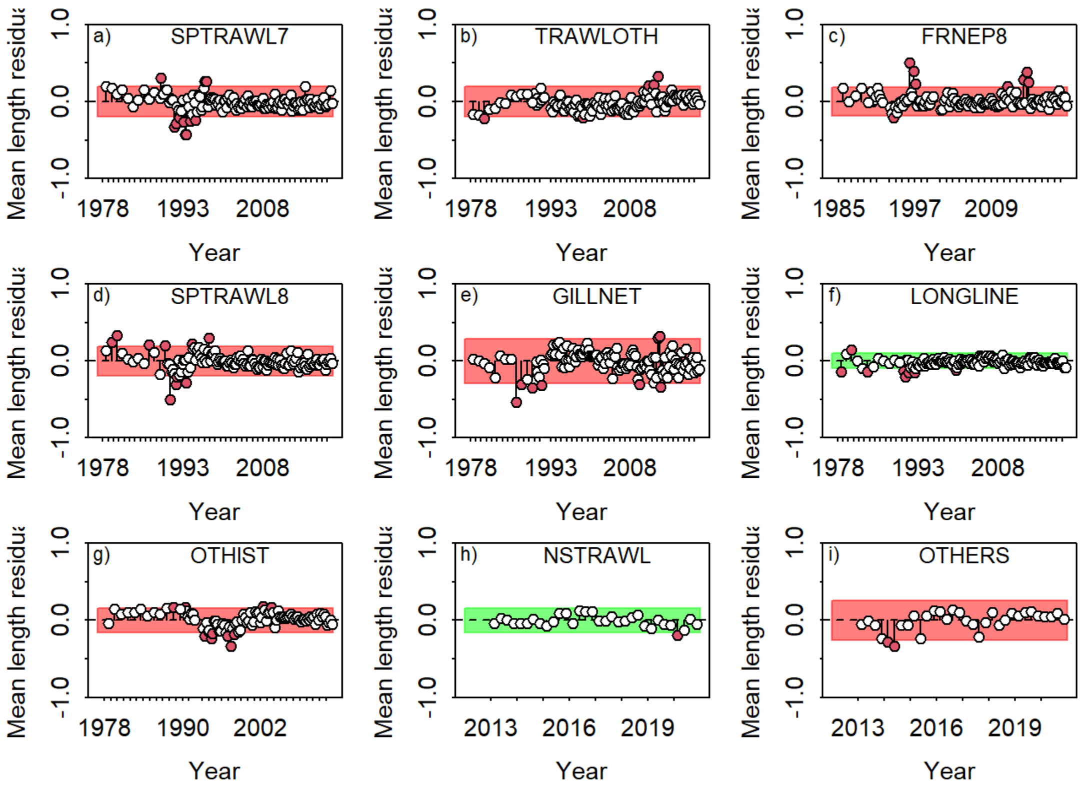


Figure 2.10. Residuals of the fleets' length-frequencies. Green bands mean the data has passed the run test and red ones indicate it has not passed.

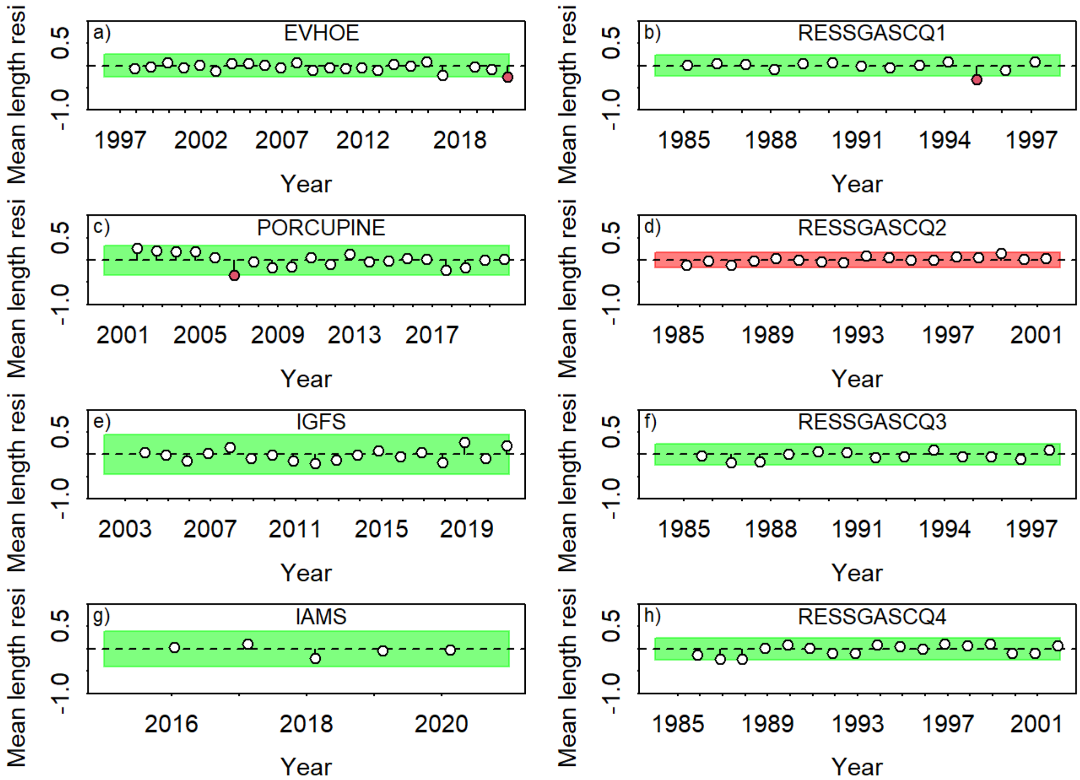


Figure 2.11. Residuals of the surveys' length-frequencies. Green bands mean the data has passed the run test and red ones indicate it has not passed.

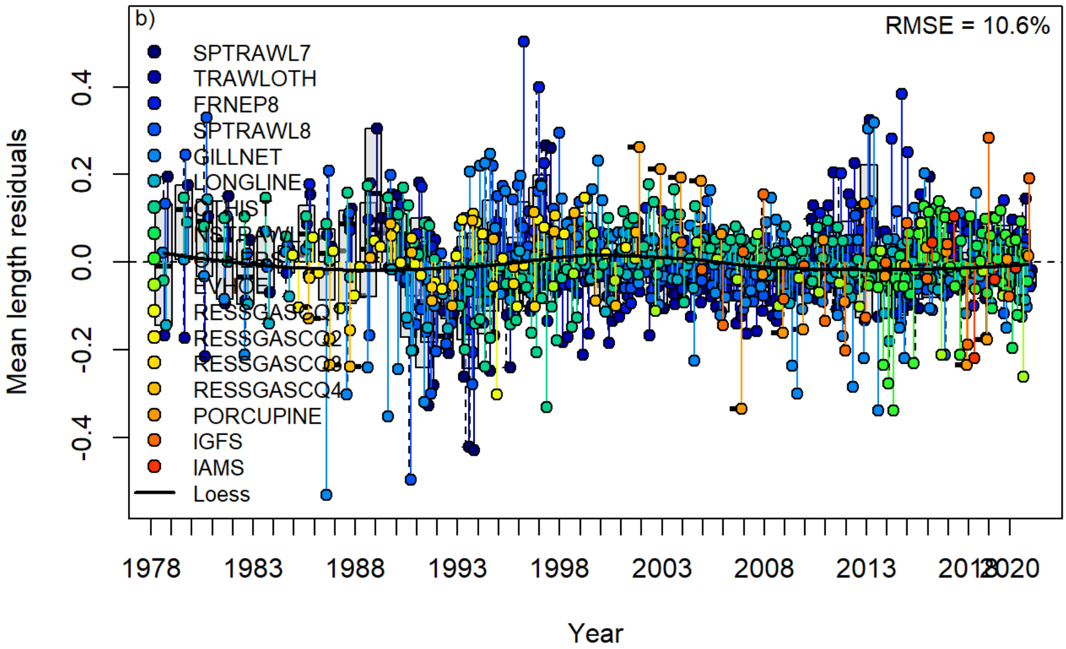


Figure 2.12. Joint residuals of the surveys, an RMSE value below 30% indicates a low conflict between the different surveys.

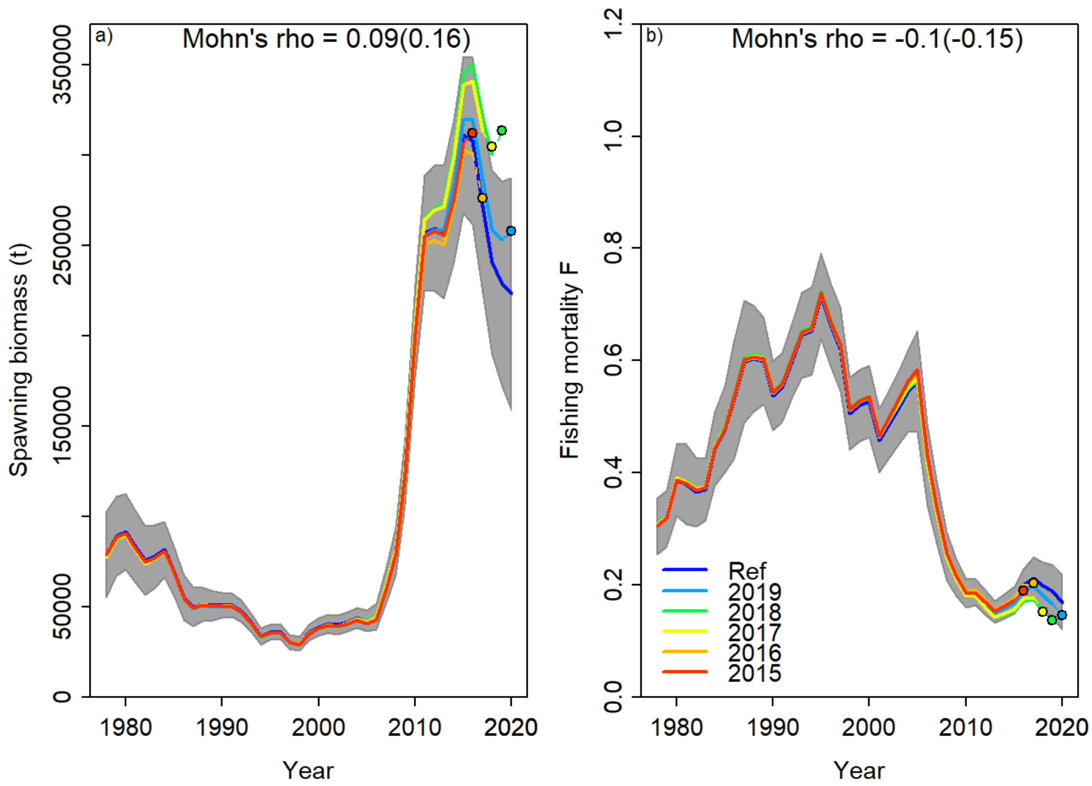


Figure 2.13. Retrospective analysis of SSB and fishing mortality together with the confidence intervals and the Mohn's rho value.

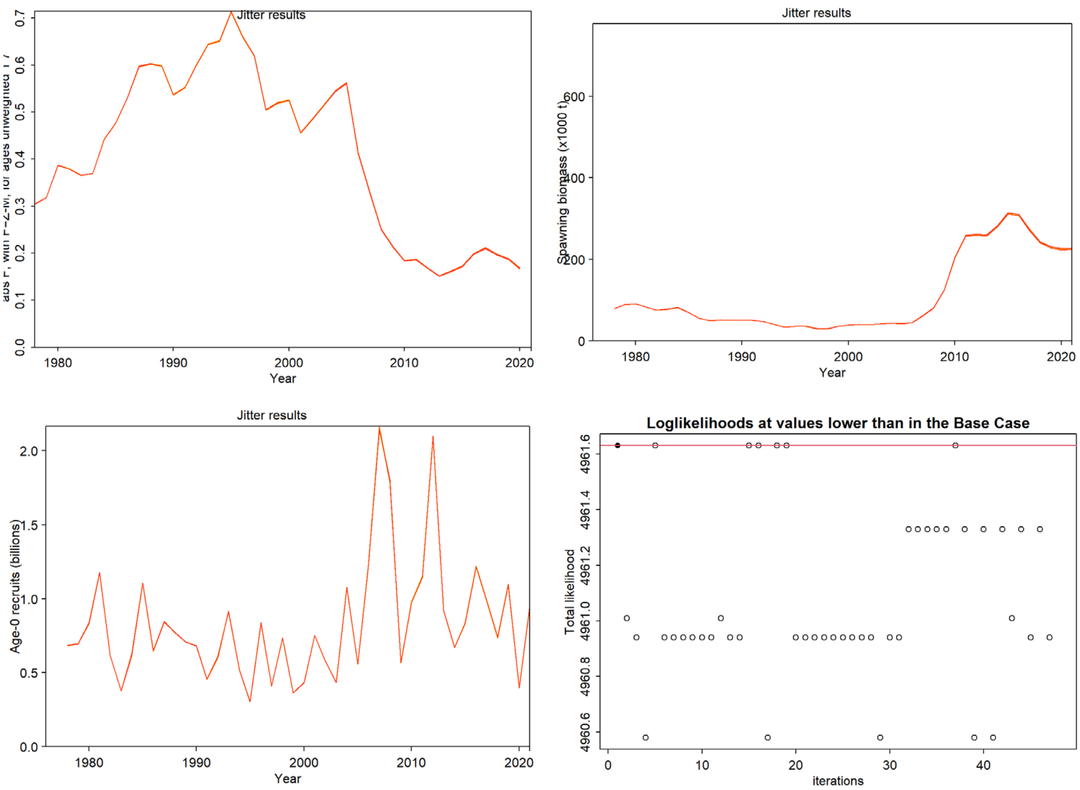


Figure 2.14. Jitter analysis with the iterations with the same or lower log-likelihood value. In the first three plots the time-series of fishing mortality, SSB and recruitment are shown. In the last scenario, the value of the log-likelihood, the black dot and the horizontal red line, correspond to the log-likelihood of the final fit.

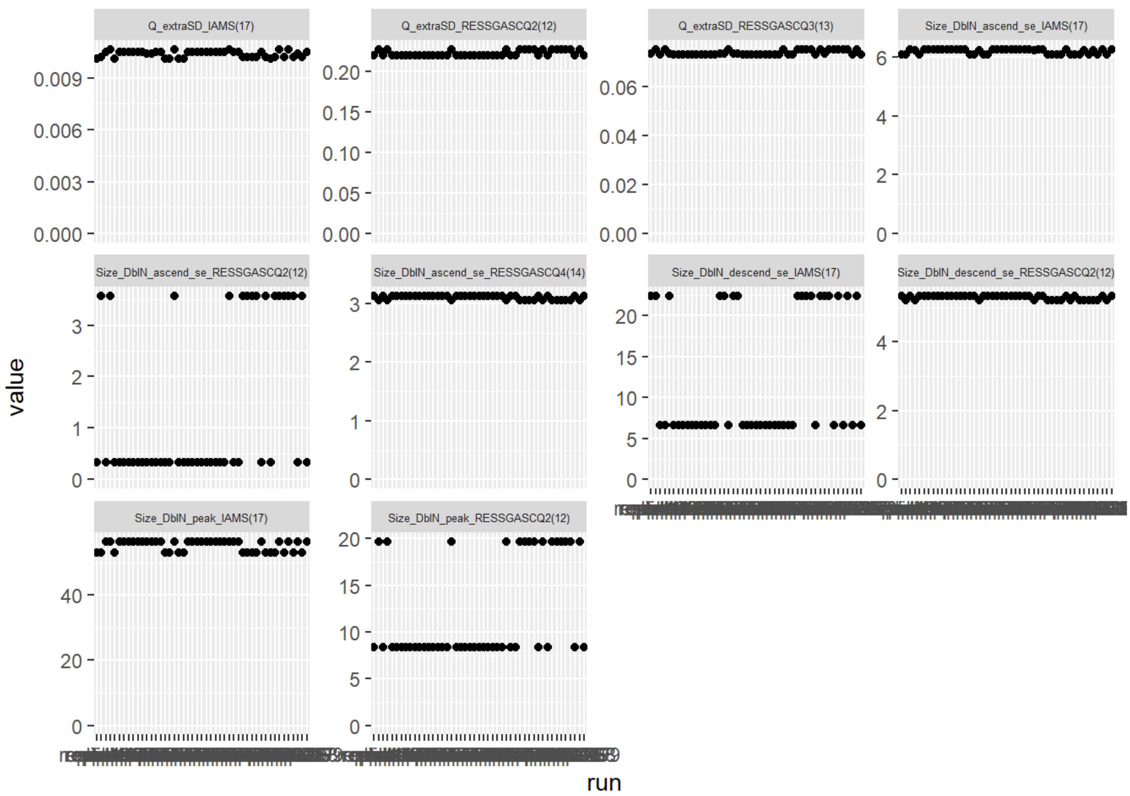


Figure 2.15. Value of the parameters which estimated value has a CV higher that 1% in the jitter analysis.

2.15 Reference points

2.15.1 Introduction

The reference points previously evaluated for northern hake are given in Table 2.2. These were recalculated during the ICES Working Group for the Bay of Biscay and Iberian Waters Ecoregion, WGBIE (ICES, 2019b), after a benchmark workshop (ICES, 2019a).

Given the new revision of the assessment configuration during current workshop, the reference points were reviewed again following the latest ICES Advice technical guidelines on reference point estimation for category 1 and 2 stocks[4].

2.15.2 Software

Two complementary methods were used for the reference points estimation. First, the SS software that allows inferring MSY reference points (with associated uncertainty). And, next the *EqSim* functions (under the *msy* R package provided by ICES), for checking the compliance of MSY reference points with the ICES precautionary criterion (less than 5% probability of SSB < B_{lim} in the long term) and the calculation of other reference points that rely on risks calculation, such as F_{lim} and F_{p05}.

Currently adopted SS model for northern hake is sex-separated, with 4 seasons and 2 spawning events, where recruits are generated based on a Beverton and Holt stock–recruitment

[4] ICES. 2021. ICES fisheries management reference points for category 1 and 2 stocks; Technical Guidelines. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021, Section 16.4.3.1. https://doi.org/10.17895/ices.advice.7891.

relationship which considers female only SSB. Additionally, it models several fleets. However, *EqSim* only deals with stock data with both sexes combined and one fleet running in yearly steps. Therefore, the SS output has been collapsed (to both sexes stock spawning at the beginning of the year, exploited by a single fleet) and the maturity has been recalculated for getting female-only SSB.

2.15.3 Precautionary reference points

B_{lim}

The stock shows a wide dynamic range of SSB, and evidence that recruitment is or has been impaired (Figure 2.16). So, in this case, B_{lim} is the breakpoint of the segmented regression fitted using the recruitment and the female only SSB (as in SS) estimated from revised assessment, B_{lim} = 62 086 t.

B_{pa}

The ICES basis for advice requires that a precautionary safety margin incorporating the uncertainty in actual stock estimates leads to a precautionary reference point B_{pa}, which is a biomass reference point designed to avoid reaching B_{lim}. Consequently, B_{pa} was calculated as B_{lim} * exp(1.645 σ_{SSB}) where σ_{SSB} = 0.147 was taken as the SS3 estimate of the log spawning biomass uncertainty in the most recent year (2020); B_{pa} = 79 071 t.

F_{lim}

F_{lim} is derived from B_{lim} and is determined as the F that on average would bring the stock to B_{lim}. This value is derived from long-term simulations (with *EqSim*) as the F that in stochastic equilibrium will result in median(SSB) = B_{lim}. The value estimated was F_{lim} = 0.73 year^{-1}.

F_{pa}

F_{pa} was set at F_{p05}. This value is derived from long-term simulations (with *EqSim*) as the F which combined with MSY $B_{trigger}$ (under the ICES MSY advice rule) fulfilling the precautionary criterion of having less than 5% probability of SSB < B_{lim} in the long term. F_{pa} = 0.54 year^{-1}.

2.15.4 MSY reference points

The ICES MSY framework specifies a target fishing mortality, F_{MSY}, which over the long term, maximizes yield, and also a spawning biomass, MSY $B_{trigger}$, below which fishing mortality is reduced proportionately relative to F_{MSY} (ICES MSY advice rule). The ICES basis for advice notes that, in general, F_{MSY} should be lower than F_{pa}, and MSY $B_{trigger}$ should be equal to or higher than B_{pa}. The values of F_{MSY} should be checked using stochastic simulation to ensure that expected errors in the advice do not result in >5% probability of SSB < B_{lim}.

Given the SS estimates for MSY-related values, a stochastic evaluation using equilibrium stochastic simulations was carried out using *EqSim* for checking the precautionary criteria.

2.15.4.1 Configuration of the simulations

Definition of the stock recruitment model

The form of the Beverton and Holt stock–recruit model is assumed as estimated in SS, so we force the SR function to have the same steepness and R_0 and calculate the recruitment variability (σ_R). All the stock recruitment pairs since 1987 were used as a basis to estimate σ_R for the simulations. The latest recruitment estimate (2020) was considered too uncertain and excluded from the time-series.

Simulations' setup

The default setting for the biological vectors (weights-at-age, proportion mature at age, proportion natural and fishing mortality occurring before spawning…) is a 5-year window in which values for the simulation period are taken by resampling. According to ICES guidelines, the simulations should represent the current productivity state of the stock and make no inference on the direction of future changes. Based on this guideline, the mean values for the last 5 observed years were considered appropriate.

In the absence of an estimate of F_{cv} and F_{phi}, *EqSim* assumes default values of 0.212 and 0.423 respectively. These values were used.

The simulations were based on 1000 replicates of the stock, used the value of B_{lim} and B_{pa} defined above and considered MSY $B_{trigger} = B_{pa}$ (see rational below).

The detail of the configuration of the simulation is given in the table below.

```
sim_Trig <- eqsim_run( fit_bh,
                       Fcv = 0.212, Fphi = 0.423, SSBcv = 0,
                       rhologRec = rho,
                       Btrigger = Btrigger, Blim = Blim, Bpa = Bpa,
                       Nrun = 1000, Fscan = Fscan, verbose = F)
```

2.15.4.2 Simulation output and F_{MSY} estimation

Simulations were first run implementing no assessment error and not implementing the ICES MSY advice rule (i.e. setting MSY $B_{trigger} = 0$ in the simulations) in order to estimate F_{lim}. The F value for which the median of the SSB across replicates was equal to B_{lim} was 0.73 (Figure 2.17).

MSY reference points were extracted from SS yield-per-recruit simulations (Figure 2.18), where: $F_{MSY} = 0.24$ year^{-1}, $B_{MSY} = 163\ 929$ t and MSY = 78 855 t. The F_{MSY} ranges were calculated as those F values associated with yield that is 95% of the peak of the yield curve (Figure 2.18) with lower and upper values estimated at 0.147 and 0.37 year^{-1}, respectively.

Following ICES guidelines, MSY $B_{trigger}$ should be set equal to B_{pa} in the case of the northern hake, for which fishing mortality has been higher than F_{MSY} in most of the historical period.

Finally, simulations were run implementing assessment errors and the ICES MSY advice rule using a MSY $B_{trigger} = B_{pa}$ (79 071 t) to check if the candidate F_{MSY} value from SS (0.24) and the F_{MSY} ranges (0.217, 0.37) were still found to be precautionary, which was the case as F_{p05} was estimated at 0.704 (Figure 2.19 and 2.20).

2.15.5 Conclusions

Proposed revision of the reference points is shown in Table 2.3.

2.16 Forecast assumptions

The following are default forecast options. The ICES Working Group should evaluate these annually and adapt as necessary:

- Mean weights-at-age, maturity-at-age: average last 3 year;
- Discard proportions-at-age: average last 3 years;
- Exploitation pattern: average last 3 years;
- F status-quo average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year;
- F in the intermediate year: F *status-quo;*

- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship;
- Recruitment estimates in the last 2 data year(s): The recruitment has a big retrospective pattern and the last two years are significantly corrected as new data comes into the model. This correction has a big impact in the short-term forecast and hence in the catch advice. Thus, recruitment deviations in last two assessment years should be turned off and the recruitment estimates should correspond to the values predicted by the stock–recruitment model.

2.17 References

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2.18 Figures and tables

Table 2.2. Current northern hake reference points.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	56000	B_{pa}	ICES (2019b)
	F_{MSY}	0.26	Stochastic simulations on a segmented regression stock–recruitment relationship	ICES (2019b)
Precautionary approach	B_{lim}	40000	The breakpoint of the segmented regression stock–recruitment relationship	ICES (2019b)
	B_{pa}	56000	1.4 × B_{lim}	ICES (2019b)

Framework	Reference point	Value	Technical basis	Source
	F_{lim}	Undefined	F_{lim} (0.84) is no longer considered appropriate given the estimate of F_{pa}	ICES (2021)
	F_{pa}	1.02	$F_{p.05}$ with AR: The F that provides a 95% probability for SSB to be above B_{lim}.	ICES (2019b; 2021)
Management plan	F_{MGT}	Not defined		
	SSB_{MGT}	Not defined		
	MAP MSY $B_{trigger}$	56000	MSY $B_{trigger}$	ICES (2019b), EU (2019)
	MAP B_{lim}	40000	B_{lim}	ICES (2019b), EU (2019)
	MAP F_{MSY}	0.26	F_{MSY}	ICES (2019b), EU (2019)
	MAP range F_{lower}	0.180	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).	ICES (2019b), EU (2019)
	MAP range F_{upper}	0.40	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).	ICES (2019b), EU (2019)

Table 2.3. Proposed revision of the northern hake reference points after the 2022 benchmark.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	79071	B_{pa}
	F_{MSY}	0.24	SS simulations
Precautionary approach	B_{lim}	62086	The median of the segmented regression stock–recruitment relationship breakpoint (Type 2 stock recruitment)
	B_{pa}	79071	$\exp(1.654 \times \sigma) \times B_{lim}$, $\sigma = 0.147$.
	F_{lim}	0.73	The F that provides a 50% probability for SSB to be above B_{lim}.
	F_{pa}	0.54	$F_{p.05}$ with ICES MSY AR: The F that provides a 95% probability for SSB to be above B_{lim}.
Management plan	F_{MGT}	Not defined	
	SSB_{MGT}	Not defined	
	MAP MSY $B_{trigger}$	79071	MSY $B_{trigger}$
	MAP B_{lim}	62086	B_{lim}
	MAP F_{MSY}	0.24	F_{MSY}
	MAP range F_{lower}	0.147	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).

Framework	Reference point	Value	Technical basis
	MAP range F_{upper}	0.37	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).

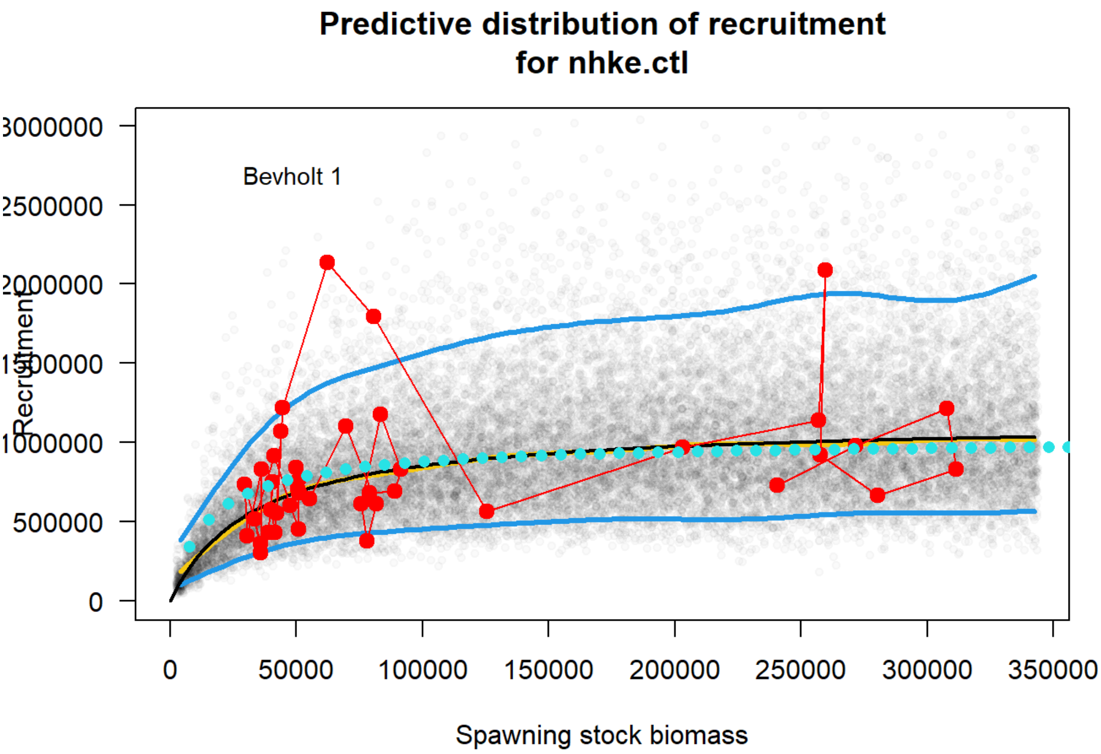

Figure 2.16. Northern hake stock recruitment model used for stochastic simulations. SS estimates of the stock–recruitment pairs used for model fitting are depicted in red (1978–2019). Black lines show the average Beverton and Holt model. The grey dots represent simulated values, the yellow line represents the median and the blue lines the 5% and 95% percentiles for the simulated values.

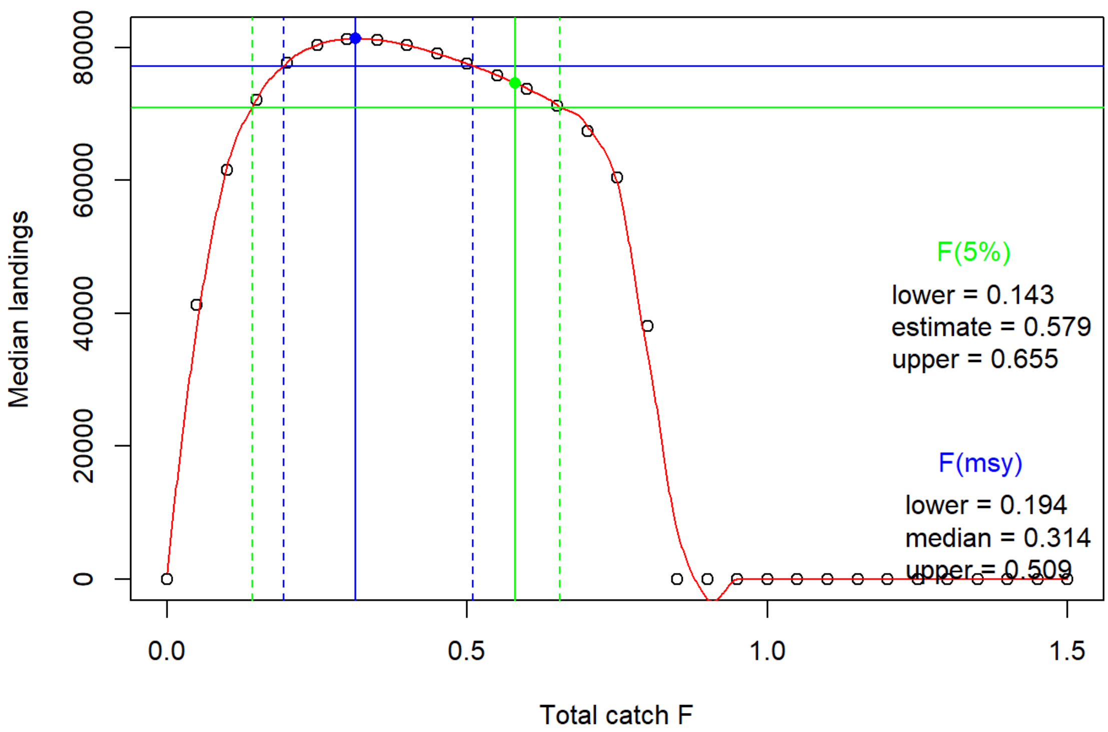

Figure 2.17. Northern hake. Median (across 1000 iterations) for the mean yield at stochastic equilibrium as a function of the fishing mortality applied. Blue vertical line corresponds to Fmsy (with dashed line representing the Fmsy range limits). Green vertical lines represent the fishing mortality at which p(SSB<B_{lim})>5%. Simulations run without assessment error and not implementing ICES MSY advice rule.

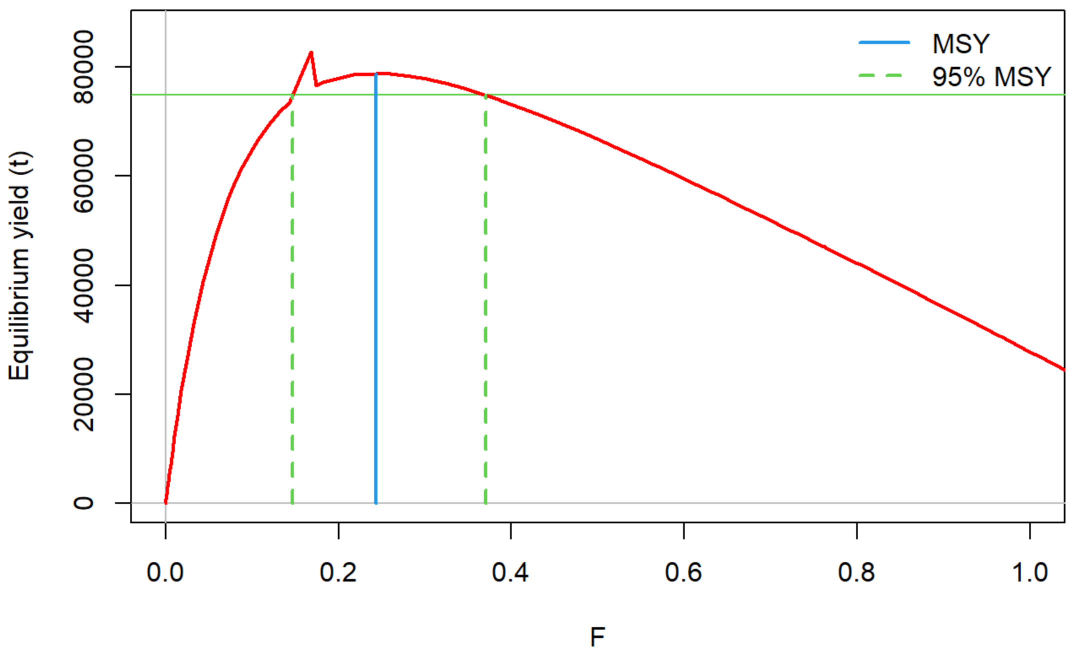

Figure 2.18. Northern hake. MSY estimates from SS3 assessment.

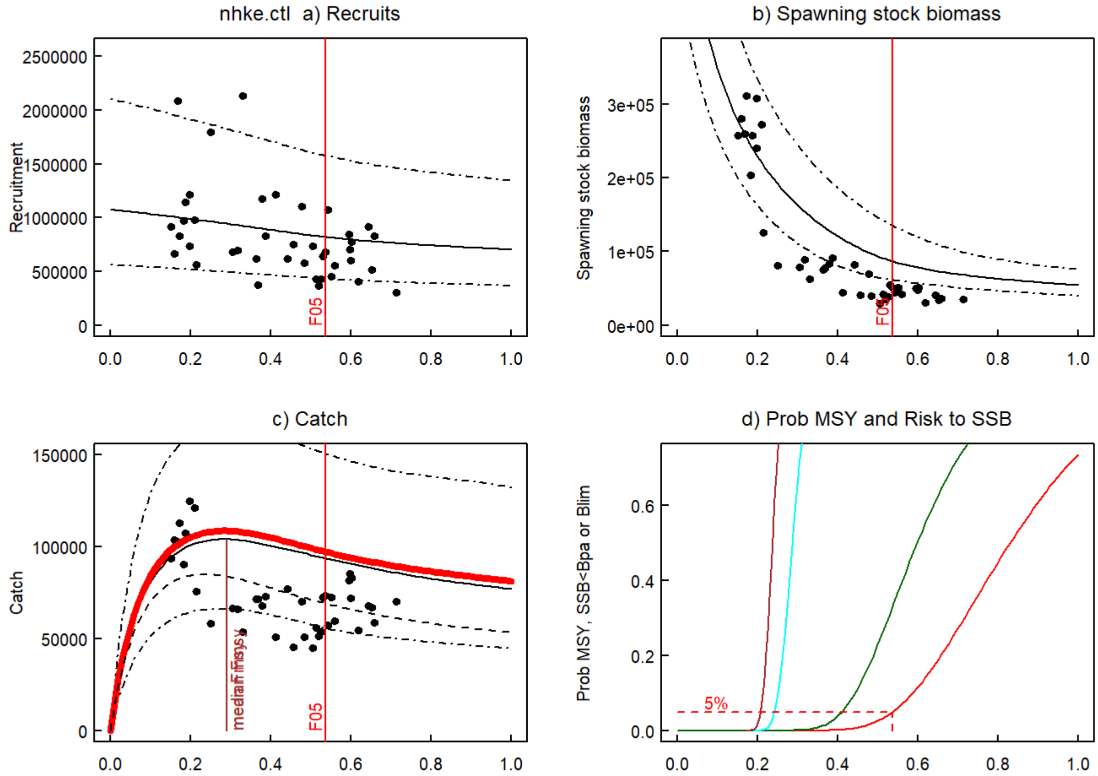

Figure 2.19. Northern hake. Simulated recruitment, SSB, yield and p(SSB<B_{lim}) as a function of the fishing mortality in the long-term simulations with *EqSim* under ICES AR. (a), (b) and (c): solid line represents the median value across the 1000 iterations, dashed lines represent 5% and 95% percentiles of the distribution, historical estimates are depicted by the black dots.

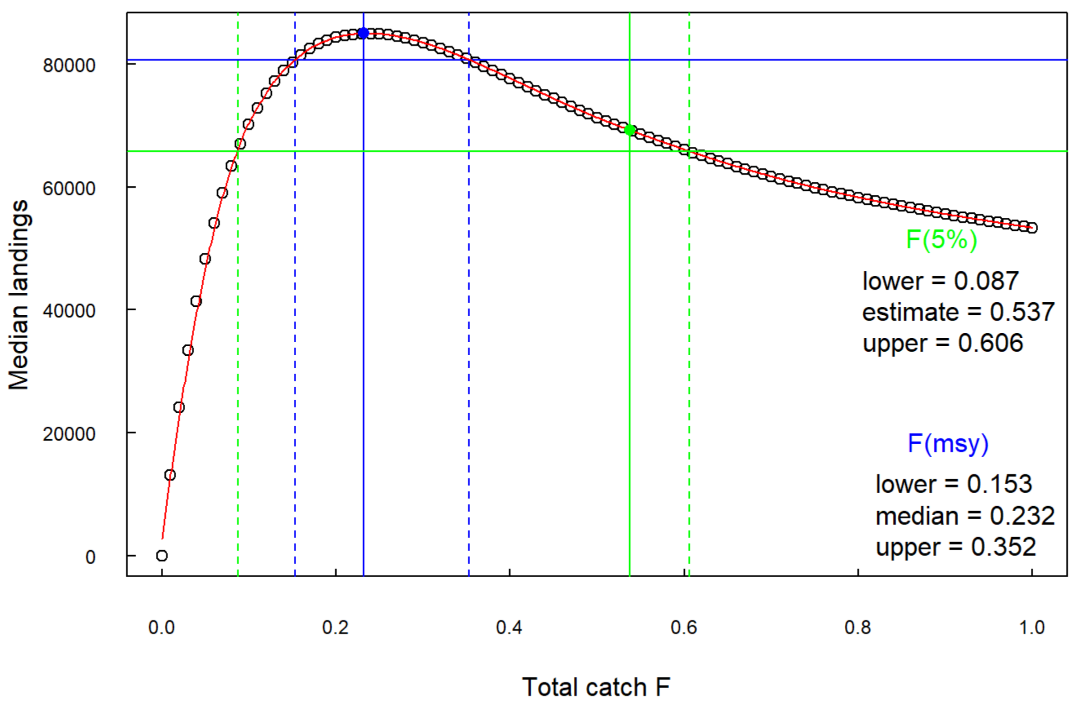

Figure 2.20. Northern hake. F_{p05} estimation in the long-term simulations with EqSim under ICES AR.

3 Cantabrian Sea and Atlantic Iberian waters hake

Merluccius merluccius in divisions 8.c and 9.a, Southern stock; hke.27.8c9a

3.1 Introduction

The last stock assessment model for the southern Atlantic hake (*Merluccius merluccius*) stock was carried out in GADGET with data from 1982 to 2019. This model was rejected in 2020 mainly due to problems with the retrospective pattern and convergence problems. Other data-limited alternatives were explored. The objective of this work is developing a Southern hake SS model able to provide catch advice in the ICES context. The initial Southern hake SS model was developed in WKTADSA[5] (ICES, 2021) with the same data and similar assumptions than those used in the WGBIE for the GADGET model. Afterwards the work continues intersessionally addressing the identified issues for both, data and models. Data news were presented in the WKANGHAKE data compilation workshop (November 2021) and a case base model, incorporating all these data, was presented the first day of the benchmark workshop on anglerfish and hake (WKANGHAKE, 2022). A final SS model was finally accepted by WKANGHAKE. The process of this development is presented here.

This section is structured as follows. (1) First, a summary of the data review and main decisions (details can be seen in the working documents); (2) then a progress of the benchmark meting were model decisions were taken; (3) a description of the final model; (4) reference points; (5) projection settings and (6) final considerations.

3.2 Data review

There are working documents with methodological details for all the new data presented.

Catch data review from 1948 to 2020 includes total catch review for the older period (1948 to 2001) for landings and discards and an extension back for length distributions.

- Catch data review from 1948 to 2020
    a) Period 1948–1971: there is only Portuguese data. Spanish was estimated based on Sp/Pt proportions.
    b) Period 1972–1981: No length distribution by fleets. Only yearly catch by country and main fleets.
    c) Period 1972–1985: Spanish catch data estimated at the beginning of the 1990s by Spanish experts. No document found about the procedure used.
    d) Discards are only routinely estimated after 2004. Before that only discards in years 1994, 1997 and 2000 were estimated.
- Catch length distribution review
    a) No length distribution available before 1982.
    b) Period 1982–1993: there are new data disaggregated by fleet that includes length distribution in a yearly basis and only until 80+ cm.

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[5] ICES. 2021. Workshop on Tools and Development of Stock Assessment Models using a4a and Stock Synthesis (WKTADSA). ICES Scientific Reports. 3:33. 197 pp. https://doi.org/10.17895/ices.pub.8004

c) Period 1994-present: the same data as usual, seasonally data with Length frequency Distribution 100+ cm.
d) Discards length distribution are only available after 2004 and in years 94, 97 and 2000.
e) Length distribution weights were initially set based on the sample size.

SS Fleets and length distribution

It was accepted to use the old time recovered of catch data (1948–1981) although their high uncertainty. Increase their weight compared with recent time-series was recommended. However preliminary SS runs showed a biomass in the first period quite instable.

Benchmark Decision: Cutting the time-series starting in 1960 helped to stabilize this first period.

The final 4 fleets used in the SS model combine fleets with similar length distributions. From lower to higher length target these fleets are: (1) the Cadiz trawl fleet alone (CdTrw); 4 trawl fleets (Trawlers), 2 artisanal fleets (Artisanal) and 2 fleets, gillnetters and longliners, targeting large fish (Volpal).

Benchmark Decision: to divide historical fleet (1960–1981) in trawlers and volpal by mirroring the selectivity (LFD) of the modern fleets and combine fleets 1982–1993 (80+ cm) with fleets 1994–2020 (100+ cm).

Total discards estimation and length distribution are available after 2003 and some years before.

Benchmark Decision: to assume that discards were negligible before 1994 when the implementation of minimum landing size of 27 cm started to be enacted. Afterwards, years without discard estimation were estimated by the SS model.

CPUE was standardized for different fleets both, in Spain (WD 13) and in Portugal (WD 12). The three Spanish trawls were standardized in and joined in one CPUE weighted by the inverse of variance for years 2003–2020 (SpCPUE_trawlers). Gillneters and longliners were also joined together (2009–2020) with the same method (SpCPUE_volpal) and Portuguese trawlers for years 1987–2020 were also standardized (PtCPUE).

Same surveys than those used in the previous GADGET assessment were used: the Spanish survey in the North (SpSurv), the Portuguese survey in the centre (PtSurv) and the Spanish survey in the Gulf of Cádiz, in the South (CdSurv). All of them performed in autumn. The length distribution for SpSurv and PtSurv were available split by sexes to help to develop a sex separated SS model.

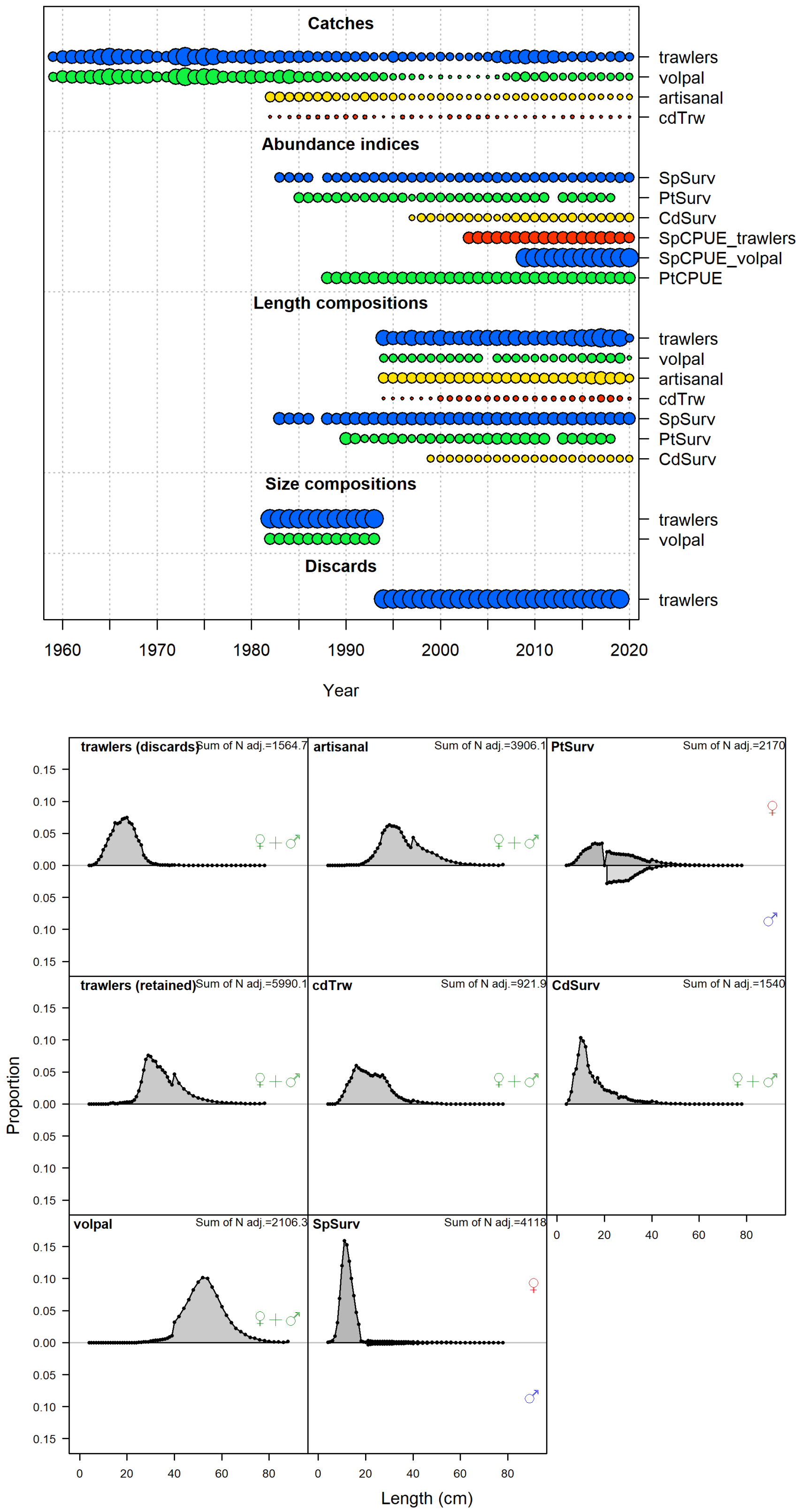


Figure 3.1. Time-series of final SS data for fleets, CPUEs and surveys (top) and length distribution for these fleets and indices, all years together (bottom).

Biological data were also reviewed. The following topics were addressed in the data workshop:

- Sex-at-length data for two surveys, Portuguese survey and Spanish survey in the North length distribution by sex was provided by both countries.
- Length weigh relationship was re-estimated and, given the low differences in time it was decided to use only a global mean for all the years (WD 10).
- Female maturity was also re-estimated including Portuguese data (WD 9) not previously used. Two options for maturity implementation were discussed: a yearly ogive (with some years joined together) or a global maturity. Finally, only a constant ogive was explored
- Life-history invariants combined with Bayesian hierarchical analysis was presented to develop posteriors for Li_{nf}, k and M by sex (WD 03).

Among these, sex-at-length survey distribution, length-weight relationship and maturity ogives were implemented in the new model as time invariant parameters. Life-history invariants analysis were not explored.

3.3 Analysis and model progress along the benchmark

A case base was presented the first day of WKANGHAKE. Main differences regarding the older GADGET model are:

- Extension of the time-series back to 1960 (no Spanish data available. It was assumed that the ratio Spain/Portugal from the 1980s was constant previous to 1982).
- Fleets separated allowing different selectivities for each group (4 groups of fleets). All of them was initially modelled as double normal.
- Sex separated dynamic since it is known that males and females have different growth patterns.

Apart of that, SS settings have quite different options than GADGET. These options will be described in the final model section.

Initially all fleets were configured as double normal allowing the shape parameters (peak, top, left slope and right slope) to be estimated. The model was presented to WKANGHAKE group and the problems identified to this base case model were the following:

- Initial conditions sensitivity. Small changes in model configuration can make the initial biomass to change from 0 to a high figure.
- Convergence problems. Same run under different starting values or some alternative setting can produce quite different results. SSB and F time-trends are quite sensitive to model setting changes.
- Fleets are not catching big individuals (>90 cm) and the population modelled is able to produce a big amount of these (~40% biomass > 90 cm). It is not realistic assuming that there is a 40% of biomass not accessible to the fishery.

The cause of having a big amount of hidden biomass can be wrong selectivity or wrong biological parameters (E.G. L_{inf} or M for older individuals).

Exploring impact of selectivity:

- Dome shaped selection can drive to huge SSB and large proportion of unfished > 90 cm
- Logistic selection drives to quite low SSB and no fish > 90 cm.
- Approach: to explore intermediate selections for the Volpal fleet (the fleet that catch larger individuals) fixing selection for older size al figures between 0 (dome shape like) and 1 (logistic shape like) and check diagnostics.

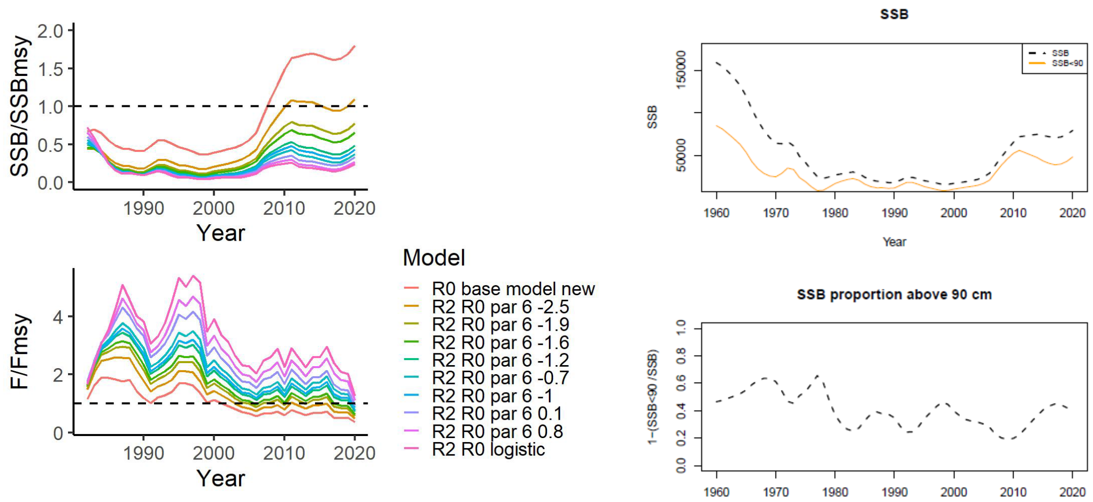


Figure 3.2. Sensitivity analysis of SSB and F trends on selectivity settings for the VolPal fleet (left) and proportion of SSB above 90 cm (right) under double normal selectivity.

Figure 3.2 (left) shows the trends on SSB/B_{MSY} and F/F_{MSY} for different VolPal selectivity configuration. The base model, with double normal selection shows the highest SSB trend and the logistic selectivity shows lower one. In between we can find intermediate selections with an additional parameter (selection at max size) fixed at different values. The large proportion of SSB above 90 cm are shown in the left plot with figures around 40% in the whole time-series.

Diagnostics for all these alternative models did not help to choose the best one because they present similar likelihoods, residuals, retrospective patters and MASE.

Main potential causes to this behaviour, i.e. strong differences in SSB and F depending on selectivity settings (logistic and double normal) can be caused by selectivity options, but also caused by biological process (growth or natural mortality).

Alternative runs to be explored:

Sensitivity to L_{inf} (90 cm to 120 cm each 10 cm) estimating the k parameter. The expected results would be that double normal and Logistic would have become more similar when reducing L_{inf} because the growth do not allow to fish to reach big amount above L_{inf}. However, this was not the case.

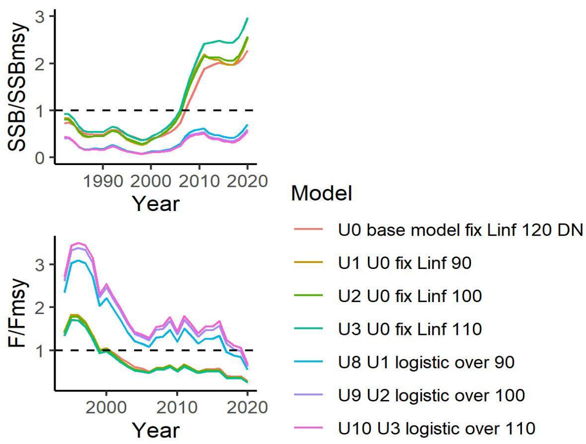
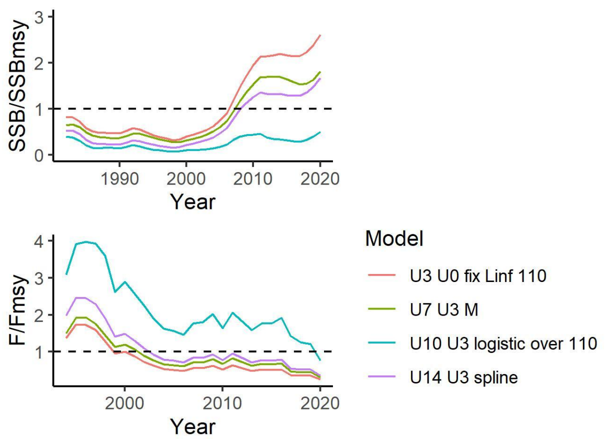


Figure 3.3. Time-trends for SSB/SSB_{MSY} and F/F_{MSY} under different combinations of selectivity (Double normal and logistic) and L_{inf} (90, 100, 110).

Figure 3.3 shows that difference in SSB and F trends under two different VolPal fleet selectivities are not affected in a significative way by the reduction of L_{inf} from 120 to 90 cm.

Benchmark Conclusion: L_{inf} is not impacting this lack of model stability

Benchmark Decision: WKANGHAKE decided to fix $L_{inf} = 110$ cm and the corresponding estimated k = 0.14, and continue analysis exploring other options. Explore sensitivity to a combination of selectivity (spline) and M, increasing the M at older ages (senescence). The range of M values explored did not provide a clear improvement.



Likelihood	Total	Logistic Linf=110	Spline Linf=110	DN Linf=110
	Total	6 247	6 192	6 163
	LD	6279	6242	6216
	Index	-32	-50	-53
Monh's Rho	SSB	0.193	-0.001	-0.065
	F	-0.187	-0.118	-0.1
MASE Index	SpSurv	2.59	3.07	2.91
	PtSurv	2.44	3.01	3.01
	CdSurv	0.82	0.79	0.68
	SpCPUE_Trw	1.3	1.31	1.21
	SpCPUE_VolPal	3.3	2.69	2.15
	PtCPUE	3.16	2.18	2.18
	Total	13.61	13.05	12.14
MASE Len Dist	trawlers	0.74	0.69	0.68
	volpal	0.36	0.4	0.43
	artisanal	0.3	0.31	0.31
	cdTRrw	0.75	0.72	0.74
	SpSurv	0.62	0.7	0.75
	PtSurv	1.55	1.7	1.75
	CdSurv	0.61	0.63	0.63
	Total	4.19	4.46	4.61

Figure 3.4 Time-trends for SSB/SSB_{MSY} and F/F_{MSY} under different combinations of selectivity (Spline and logistic) and M (senescence) with fixed $L_{inf} = 110$. Left: table with quality diagnostics for logistic, spline and double normal models.

Figure 3.4 (right) shows the impact of increasing M (senescence) and to estimate spline selectivity for Volpal fleet. Both changes reduce the SSB trend compared with those in the base case. This reduction is larger for spline than for M. There is a scientific basis to increase the M al older ages, although there is no basis to choose an amount.

Figure 3.4 (left) shows that model diagnostics (likelihood, retrospective pattern, residuals) do not help to choose a "best model", since figures are quite similar among different selectivities. This table also shows the high weight in the likelihood provided by length distribution vs. the indices (around a 99.5%)

Benchmark Decision: reject the double normal model, keep the original Ms and carry on analysis for both model candidates with logistic and spline selectivity.

Additional runs to test:

- A reduction of steepness (h) from 0.95 to 0.88 (prior value from literature for hake; Myers *et al.*, 2002);
- Remove the PtCPUE calibration index that was pushing the SSB trend upwards and presents differences with the other 5 indices;
- Reduce weight in the length distribution likelihood to help the model biomass to follow the index trends.

The reduction of h to 0.88 help t reduce the SSB trend in the spline model but not in the logistic one. Similar think happened removing PtCPUE and also reducing the length distribution weight.

Benchmark Decision: accept all the proposed changes and compare two options for Volpal selection with logistic and spline.

Model diagnosis for these two options were presented although no differences that suggest that a model is superior over the other. Furthermore, both models presented serious convergence issues.

***Benchmark Decision*:** The Group decided to support the logistic one based on risk aversion (lower biomass and higher F) as well as parsimony principle, i.e. less parameters to be estimated (2 for logistics vs. 5 for spline). This is important given the convergence problems observed in the models. This convergence issue requires further work to identify caused and reduce their impact.

Most of the work developed along these days was focused to improve the sensitivity of SSB and F to selectivity parameters under the described convergence problems. Other analysis, specifically those related to the biological implementation of a sex separated models could not be addressed and will require further work in the near future.

3.4 Final model

The final model includes the parameterization decided along the benchmark meeting with these main decisions: L_{inf} = 110; k = 0.14; h = 0.88; logistic selection; remove PtCPUE and reduced length distribution weight to a 10% compared with the base case. Phases in the estimation parameters order were also restructured to help convergence. Full details of model settings can be seen in the model files (starter, control and data).

Convergence is a main issue for this stock and the final model was chosen among those performed in the jitters and replicate the best one by:

>ss -phase 99 -maxfn 0; which will start the model in the final phase but not do any estimation allowing to have the hessian.

3.4.1 Final model: settings

A summary of main settings, diagnosis and results for this final model are presented here.

3.4.1.1 Biological processes

The growth pattern and natural mortality was set different for males and females. Maturity and length-weight relationship is common for males and females. The 4 biological process are constant in time.

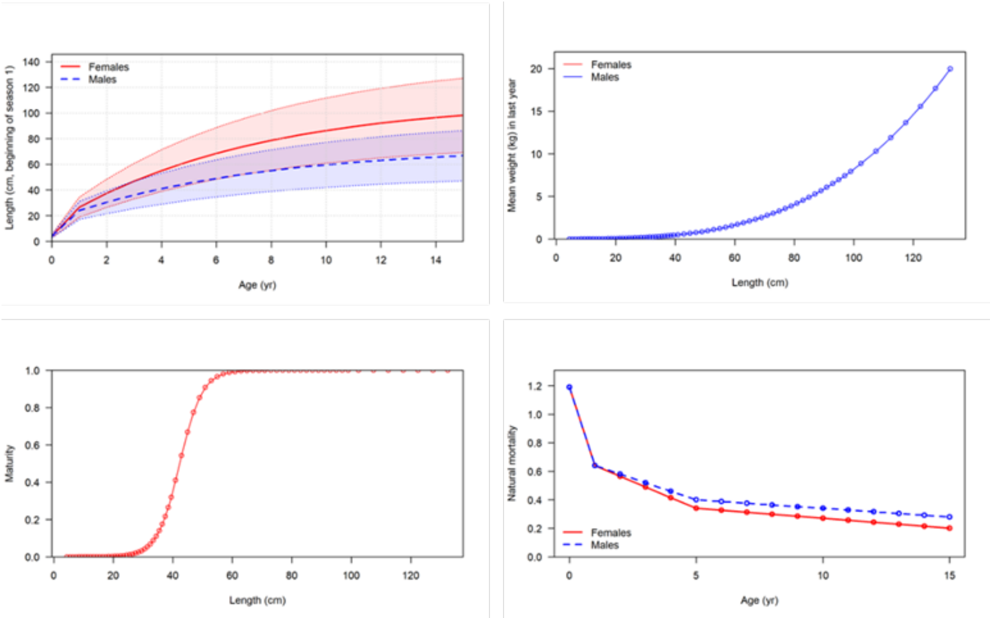


Figure 3.5. Biological settings for Southern hake SS model. Growth by sex (upper left); length-weight relationship (upper right); maturity-at-age (lower left) and natural mortality-at-age and sex (lower right).

3.4.1.2 Growth

L_{inf} and k were both fixed to males L_{inf} = 110 cm, females L_{inf} = 70 cm and a constant k = 0.14 for both, males and females after an L_{inf} sensitivity analysis (explore from female L_{inf} from 90 to 120 cm). In a working document presented during the workshop (WD 03) proposed to calculate L_{inf} based on a meta-analysis on different hake species and life invariants for Southern stock of hake. There was no time to explore alternative growth configurations based on life-history invariants.

A constant length weight relationship used in the final model, $W_{(g)} = \alpha \cdot TL^{\beta}_{(cm)}$, has parameters α=0.00377 and β=3.168 (WD 10)

As there was not time to analyse the conditioning of the biological part of the model during the benchmark it was decided to maintain the same values used initially and explore in the near future alternative options.

3.4.1.3 Maturity ogive

A female maturity ogive, constant for all years, was decided to use. Further work is required to implement yearly (or yearly grouped) maturity ogives.

3.4.1.4 Natural mortality

In the final run an age and sex-dependent natural mortality was used, with higher natural mortality rate at younger ages, and decreasing M until age 15. The vector of sex-separated values was based on the natural mortalities used in the assessment of the Adriatic and Sicilian European hake (FAO, 2019a, b).

Selectivity was set as double normal for all fleets and indices but the Volpal fleet, that is a mixture of gillnetters and longliners targeting larger fish. This fleet selectivity was configured as logistic. CPUE selectivities were mirrored to the corresponding fleet selectivity.

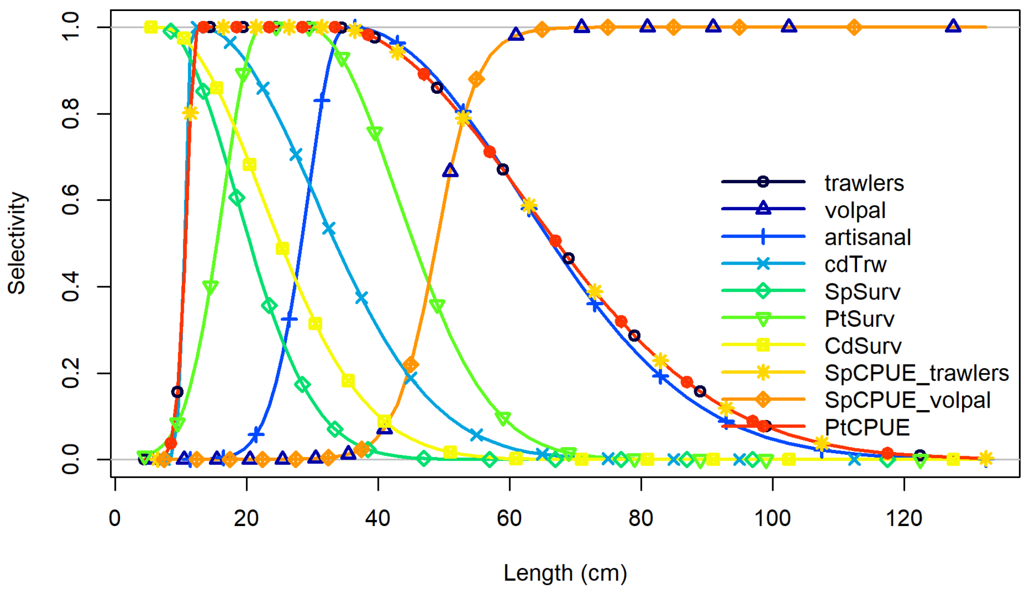


Figure 3.6. Selectivities estimated for all fleets and indices. All are double normal but volpal (and the mirrored one SpCPUE_volpal) which is logistic.

3.4.2 Final model: diagnostics

Different diagnosis were used along the benchmark (Carvalho *et al*., 2021; Minte-Vera *et al*., 2021) to take decisions to progress towards best model selection.

Differences between observed and modelled biomass indices. PtCPUE figures are presented although the index is not contributing to the model fit setting their lambda to 0.

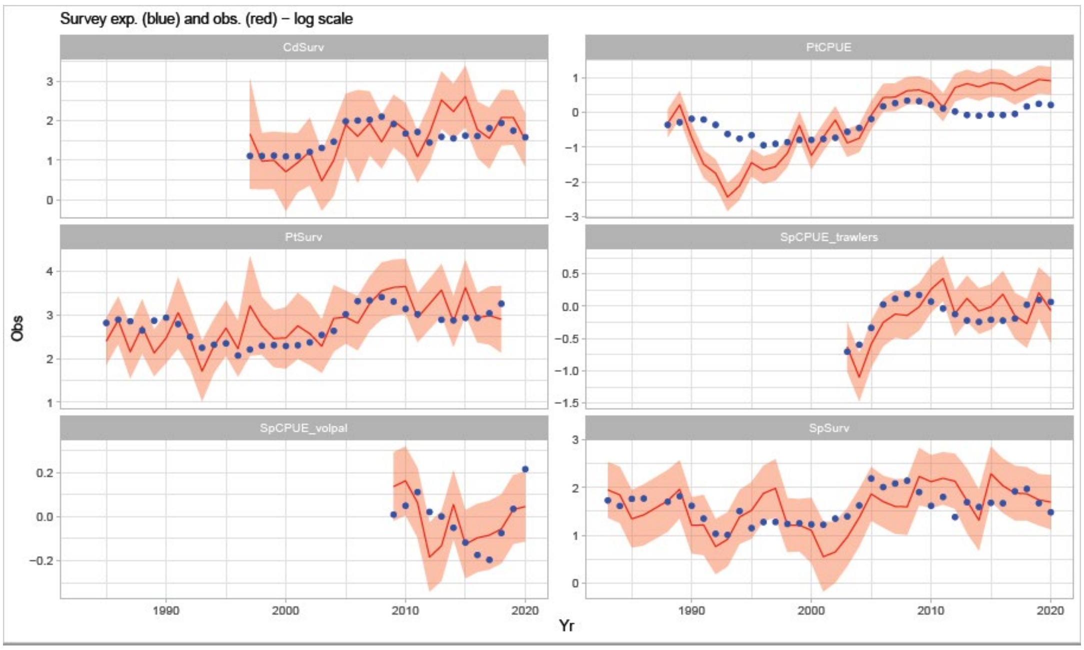


Figure 3.7.a. Biomass indices residuals. Notice that PtCPUE weight was set to zero. So the fit is presented but this index is not participating in the total model likelihood.

There are three surveys and two CPUEs covering recent periods of model time-series. The Survey Biomass indices started in 1983 (SpSurv) and afterwards different indices are contributing to the population biomass calibration. Standardized CPUEs covers the most recent period.

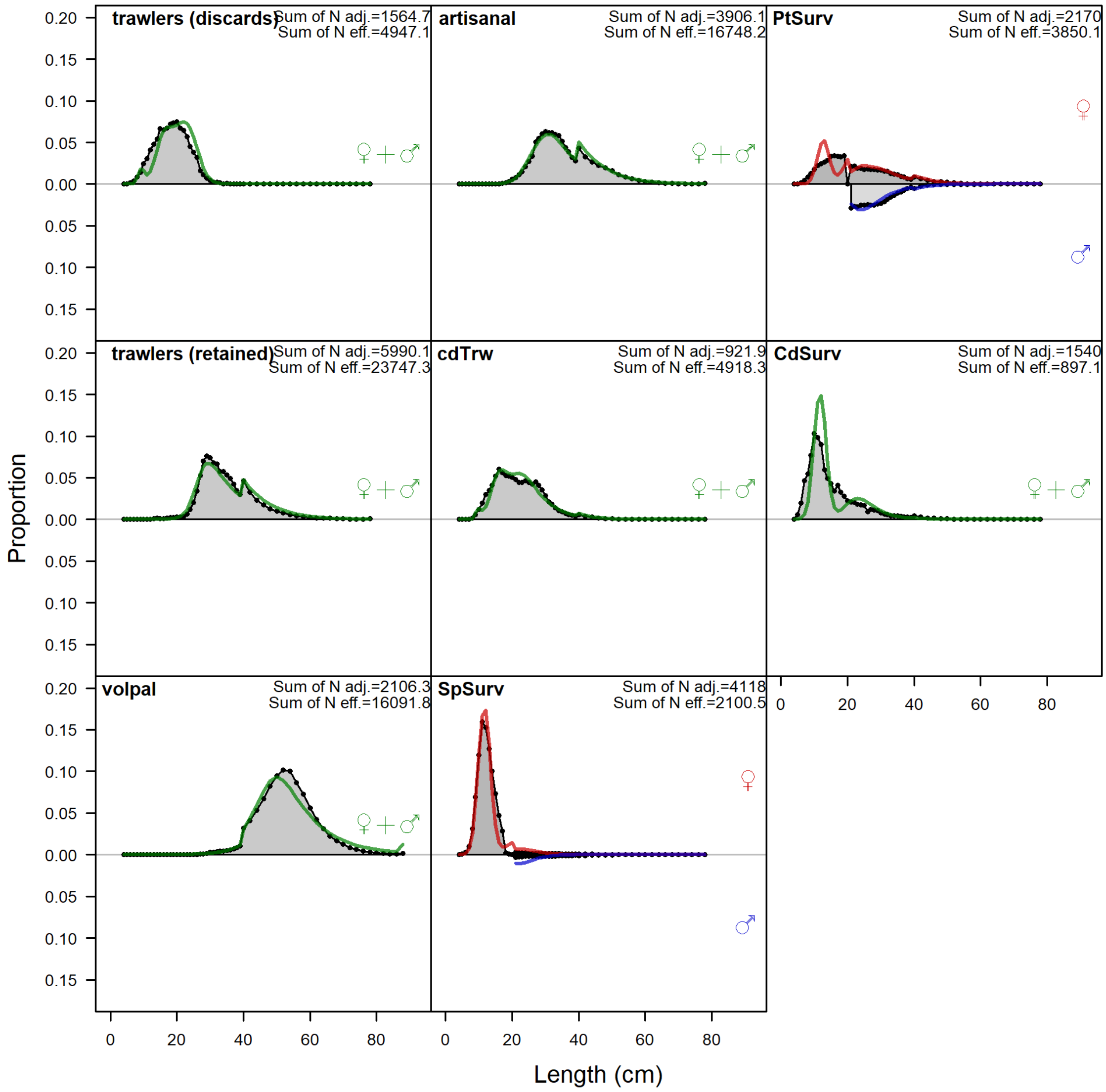


Figure 3.7.b: Residuals for all year grouped length distribution. PtSurv and SpSurv length distributions are fit separately to males (blue) and females (red)

In general index and length distribution fit relatively well the observations. The only thing to highlight is the age zero (<20 cm) fit for two surveys (PtSurv and CdSurv). Further work is required to identify and correct the causes of this fit issues.

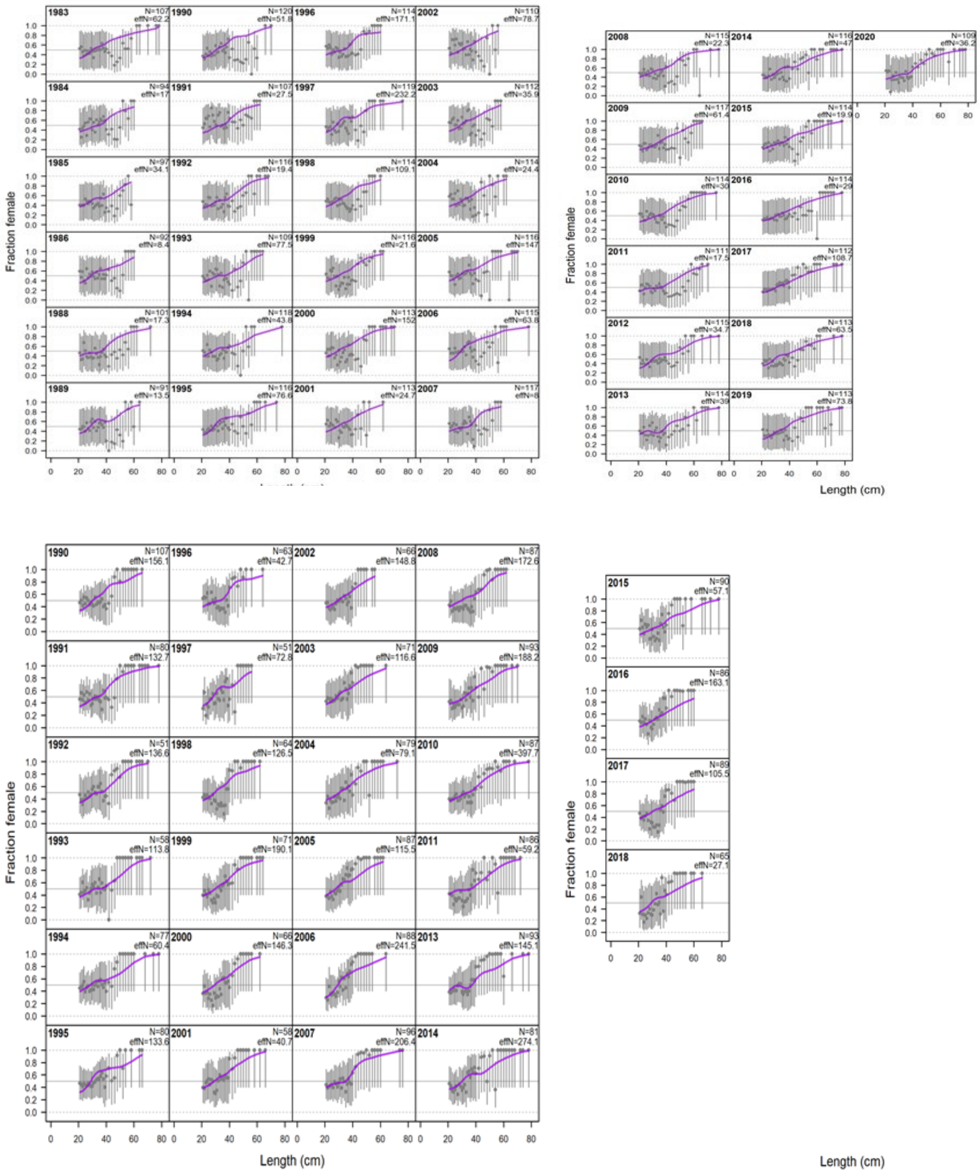


Figure 3.7.c. Observed sex ratio (grey) and modelled one (purple) for SpSurv (upper) and PtSurv (lower) for sizes larger than 20 cm.

Two surveys provide information to estimate sex ratios. SS does have an specific likelihood for sex ratios and this plot only provides visual information about how the differential growth and natural mortality shapes the sex ratio at length. This visual information shows that the model follows the increase of female proportion after 40 cm reaching a 100% females proportion after 80 cm.

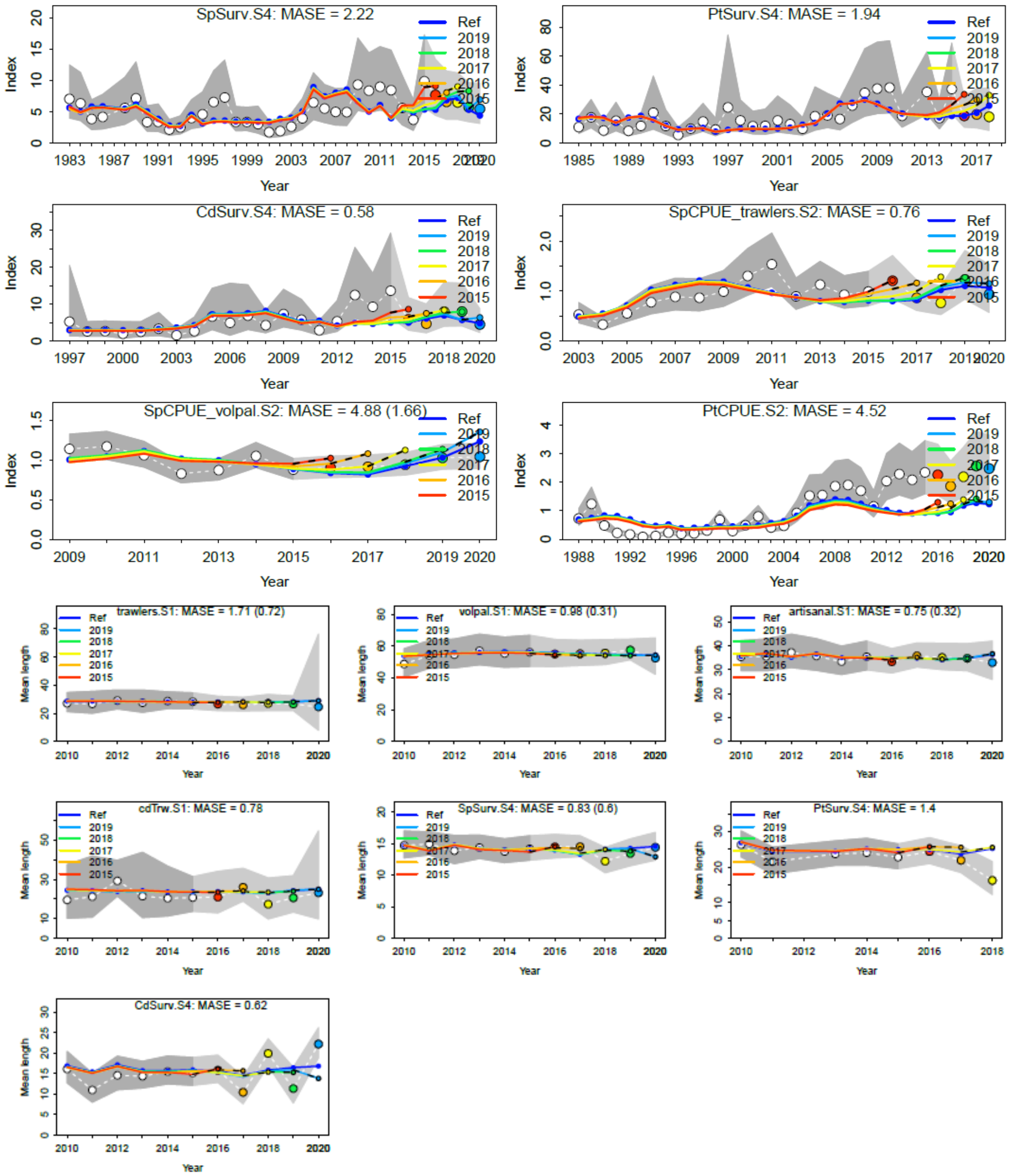


Figure 3.7.d. Mean absolute scaled error (MASE) for biomass indices (upper) and mean length (lower). PtCPUE is not included in the model.

MASE quantifies the model predictive power biomass indices and length distribution data. MASE scores < 1 indicate that the model has a superior prediction skill than the baseline forecast. 2 out of 5 indices (PtCPUE is not included in the model) has figures lower than 1, meanwhile 1 out of 7 length distribution mean size have values lower than 1.

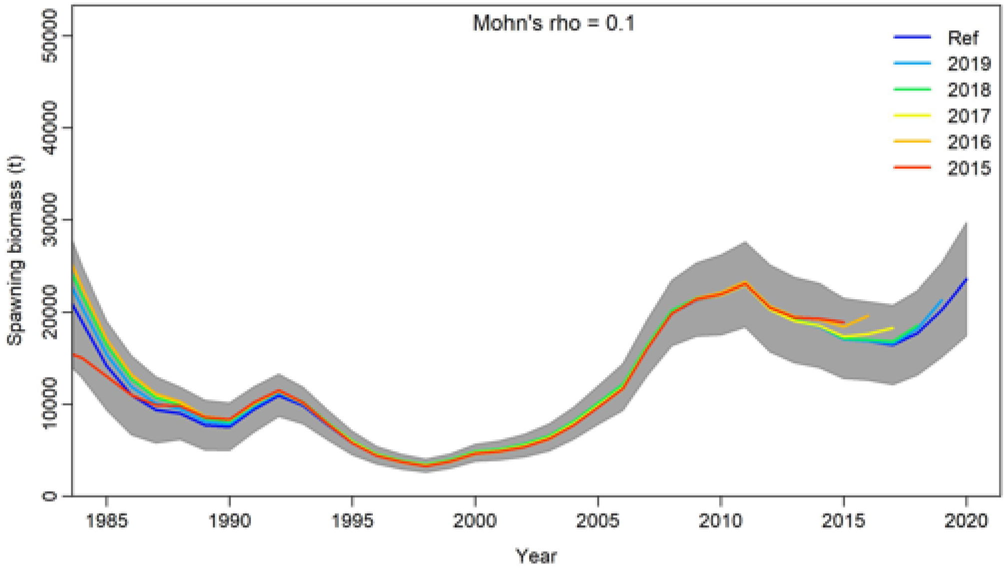


Figure 3.7.e: Retrospective pattern for SSB with 95 C.I. for the final run

Figure 3.7.e shows the retrospective pattern for SSB with a Mon's Rho figure of 0.096. A similar figure of -0.123 was achieve for the F retrospective pattern. This is a clear improvement regarding the rejected GADGET model that showed values around 0.5.

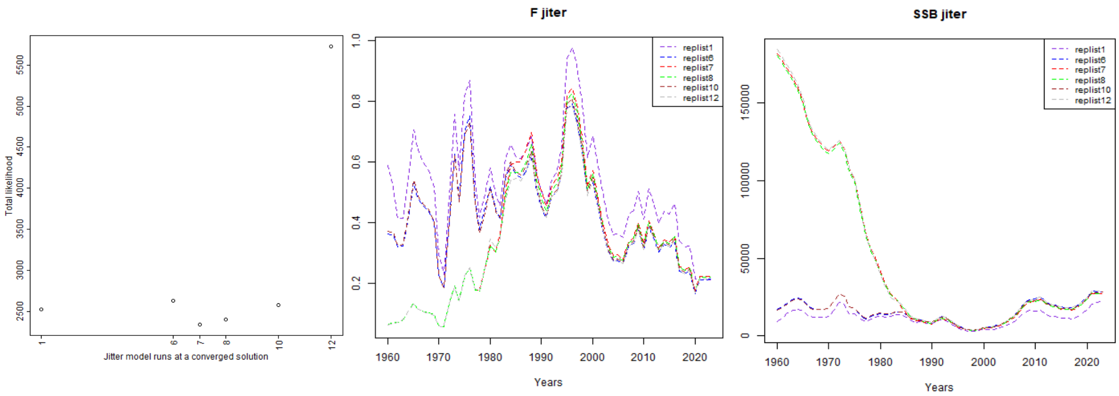


Figure 3.7.f. Jitter diagnostic for 6 out of 12 model that provides a positive definite hessian.

Figure 3.7.f provides a view of the main problem with this model. The figure presents the model results for 6 jitter runs that provides a positive definite hessian. Among these 5 presents values with a likelihood around 2500. All these provides similar values in terms of SSB and F in the latest 40 years, after 1985. SSB and F before 1985 are more sensitive to initial values. The model with lower likelihood (model 7 in the plot) was chosen as the final model.

The final model (as well as most of the model tested) are quite instable, with a quite flat likelihood surface that favours to achieve local minima instead of the global one. Different likelihood have strong impact on SSB and F trends. Just a few runs are able to inverse the hessian. Among these, those with lower likelihood are quite stable in terms of SSB and F trends.

There is not any individual diagnostic that provides a clear signal of good convergence but a combination of several. In this final model we can consider: (1) all the estimated parameters are inside the bounds; (2) the final likelihood is 2340 and the final gradient 0.0030; the final gradient did not get to the convergence set (0.0001) although given the big likelihood it can be considered an small value; (3) the Hessian is positive definite and (4) the jitter shows high difficulties to get to the same result. The chosen patch was to select the model with lower likelihood taking in consideration that models with similar likelihood provide similar results in terms of SSB and F trends. This is not an optimal solution, but given the problems can be a temporary one meanwhile the causes of this problems are not identified.

Diagnosis conclusion:

In general, all the diagnosis provides signals of a complex model that requires further work and improvements although can be considered an acceptable performance to provide catch advice. The more critical issue is the convergence. The jitter is developed to identify convergence problems by setting different starting values for the parameters and allowing ADMB to get to the best parameter combination with the lower likelihood (negative). A bad jitter performance shows that the likelihood surface is relatively flat and the models can get to different solution starting in different places.

Benchmark Decision: to accept the final model as a basis to provide catch advice. Although given the convergence problems yearly updates have to be made with care.

Benchmark Recommendation: explore broadly the convergence an alternative fit once the model is updated. Explore alternative configurations to better understand causes and solutions to this problem.

3.4.3 Final model: summary results

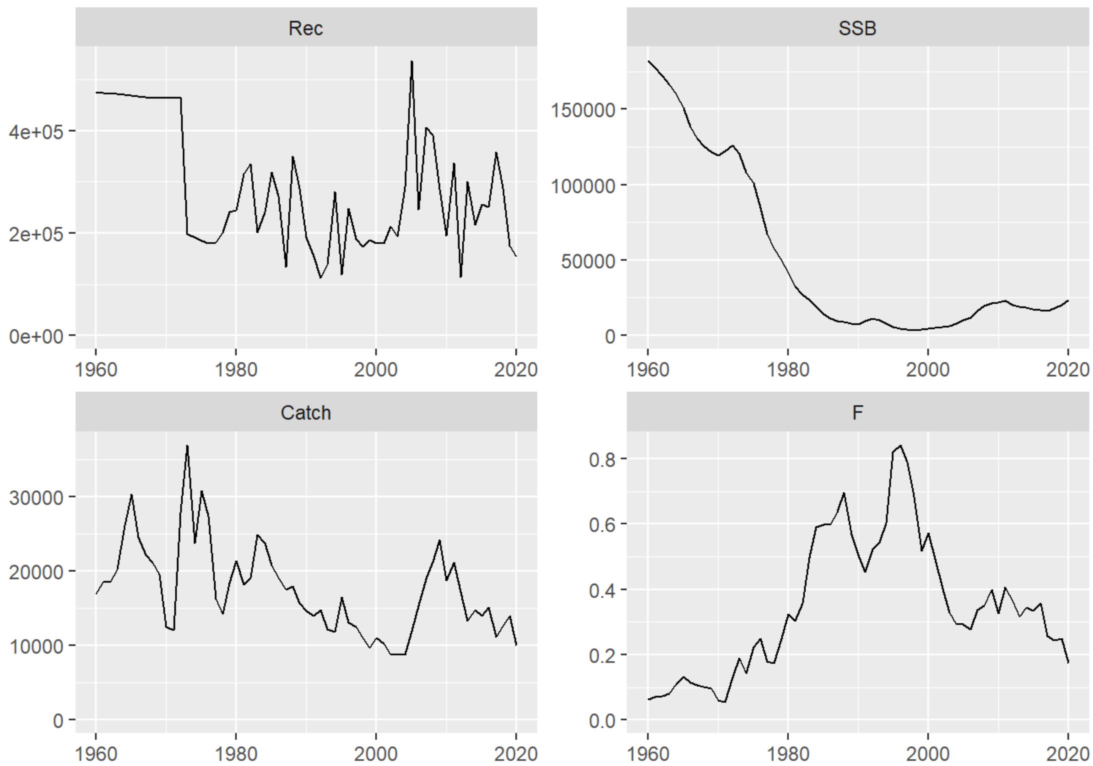


Figure 3.8. Summary model performance.

3.5 Reference points

Reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks (Published 1 March 2021).

Two complementary methods were used for the reference points estimation. First, the SS3 software that allows inferring MSY reference points (with associated uncertainty). And, next the *eqsr_fit* and *eqsim_run* functions (under the *msy* R package provided by ICES), for checking the compliance of MSY reference points with the ICES precautionary criterion (less than 5% probability of SSB < B_{lim} in the long term) and the calculation of other reference points that rely on risks calculation, such as F_{lim} and F_{p05}.

Currently adopted SS3 model for southern hake is sex-separated, with 4 seasons and 2 spawning events, where recruits are generated based on a Beverton and Holt stock–recruitment relationship which considers female only SSB. Additionally, it models several fleets. However, *eqsr_fit* and *eqsim_run* only deals with stock data with both sexes combined and one fleet running in yearly steps. Therefore, the SS3 output has been collapsed (to both sexes stock spawning at the beginning of the year, exploited by an unique fleet) and the maturity has been recalculated for getting female-only SSB.

3.5.1 Stock–recruit relationship

The form of the Beverton and Holt (BH) stock–recruit model is assumed and estimated by *eqsr_fit* using all the stock recruitment pairs since 1982 to 2019 (length data starts in 1982 and the latest recruitment estimate (2020) was considered too uncertain and excluded from the time-series), see Figure 3.9.

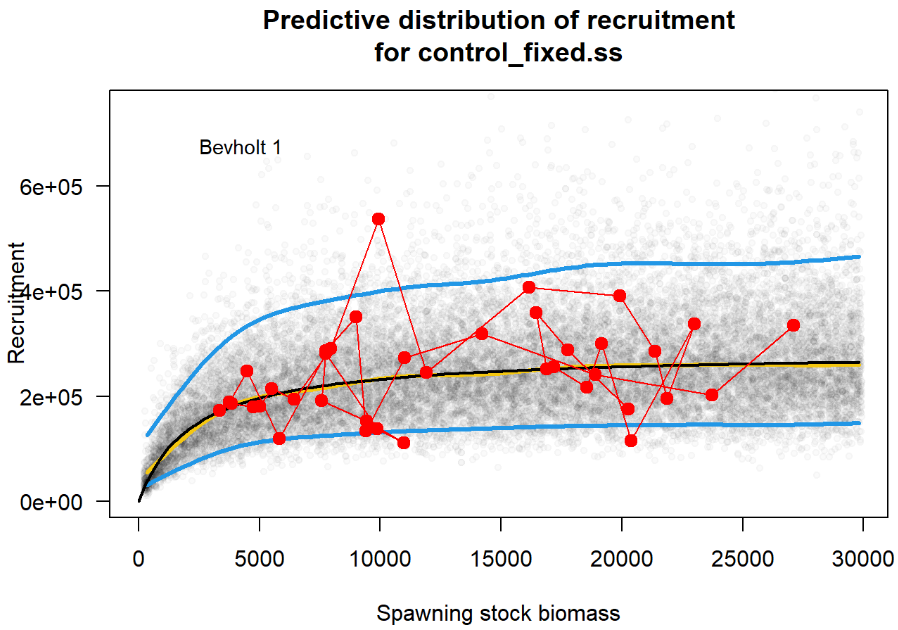


Figure 3.9. Southern hake stock recruitment model. SS3 estimates of the stock–recruitment pairs used for model fitting are depicted in red (1982–2019). Black lines show the average Beverton and Holt model. The grey dots represent simulated values, the yellow line represents the median and the blue lines the 5% and 95% percentiles for the simulated values.

For comparison proposes the compliance of MSY reference points with the ICES precautionary criterion was also checked using instead of the previous BH relationship the one estimated in SS3, so we force the SR function to have the same steepness and B_0, R_0, and calculate the recruitment variability (σ_R). In this report we focus on providing the results of the first approach (using an estimated BH relationship without fixed SS parameter values). However, it is important to mention that both approaches lead to the same conclusions about the compliance of SS MSY reference points with the ICES precautionary criterion.

3.5.2 Stock type and B_{lim}

The stock–recruit relationship was examined for the period 1982–2019, see Figure 3.10. The stock type was identified as type 2 (stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired.). B_{lim} is defined as the segmented regression change point, B_{lim}= 6011 t.

Figure 3.10. Scatterplot of SSB and recruitment pairs from 1982 to 2019 with year labels.

3.5.3 PA reference points

B_{pa}

B_{pa} is estimated as B_{lim} plus model uncertainty. The estimate of error around SSB in the year 2021 of the model was 0.139. Then, $B_{pa} = B_{lim} * \exp(1.645 * 0.139) = 7556$ t.

F_{lim}

F_{lim} is derived from B_{lim} and is determined as the F that on average would bring the stock to B_{lim}. This value is derived from long-term simulations (with *eqsim_run* with a segmented regression SR relationship, with the point of inflection at B_{lim}) as thus determines the F which, at equilibrium, yields a 50% probability of SSB > B_{lim}. This simulation is conducted without inclusion of a $B_{trigger}$ and without inclusion of assessment/advice errors. The value estimated was F_{lim} = 0.694 (details simulation in Figure 3.11).

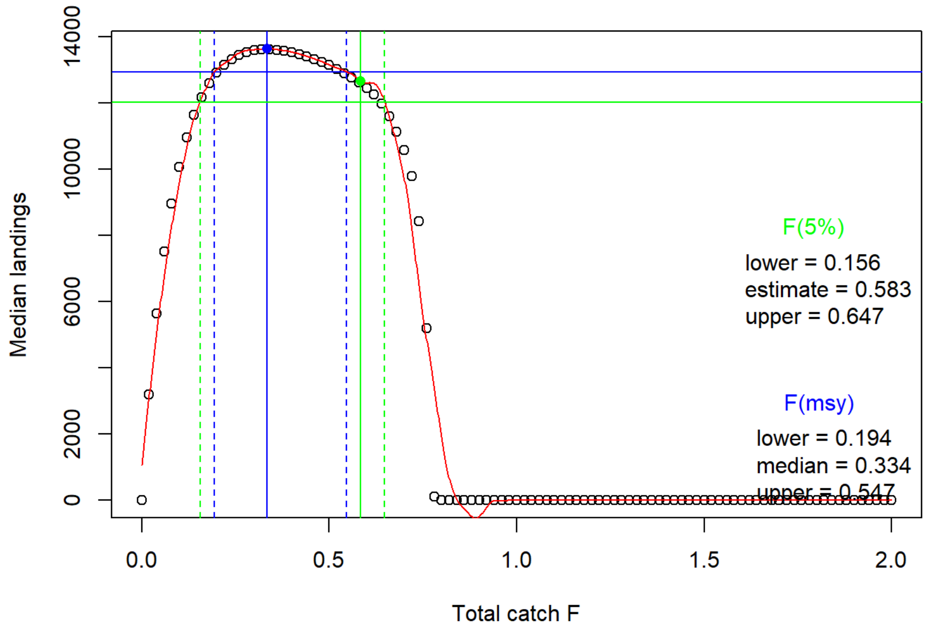


Figure 3.11. Southern hake. Median (across iterations) for the mean yield at stochastic equilibrium as a function of the fishing mortality applied. Blue vertical line corresponds to F_{msy} (with dashed line representing the F_{msy} range limits). Green vertical lines represent the fishing mortality at which P(SSB<B_{lim})>5%. Simulations run without assessment error and not implementing ICES MSY advice rule.

Set $B_{trigger}$

$B_{trigger}$ should be selected to safeguard against an undesirable or unexpected low SSB when fishing at F_{msy}. In the ICES MSY approach, $B_{trigger}$ is set at B_{pa} if there are lack of data on fishing at F_{msy}. For checking if the stock has been fished at F_{msy} for 5 or more years we focus on the period 1892 onwards, since before this year unrealistic high SSBs and low fishing mortalities are estimated by the model, estimates before 1982 have high uncertainty due to the data unavailability (length distributions, surveys, CPUE's start on 1982). Hence, looking at the 1982–2020 period, the stock has never been exploited at F_{msy} then $B_{trigger}$ is set at B_{pa}.

F_{p05}

The final long-term simulations (with *eqsim_run* based on BH stock–recruit function) implements the ICES advice rule which should be evaluated to check that the F_{msy} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having less than 5% annual probability of SSB < B_{lim} in the long term. The evaluation includes assessment/advice error and stochasticity in population biology and fishery selectivity and $B_{trigger}$ = 7556. The ICES default settings were used for cvF = 0.212; phiF = 0.423; cvSSB = 0 and phiSSB = 0. Then, the candidate F_{msy} value from SS3 (0.221) and the F_{msy} ranges (0.151, 0.311) are still found to be precautionary, which is the case as F_{p05} is estimated at 0.558 (Figure 3.12 and Figure 3.13). Table 3.1 summarized the results reported throughout this section. Additionally, Figure 3.14 reports the MSY estimates from SS3 assessment.

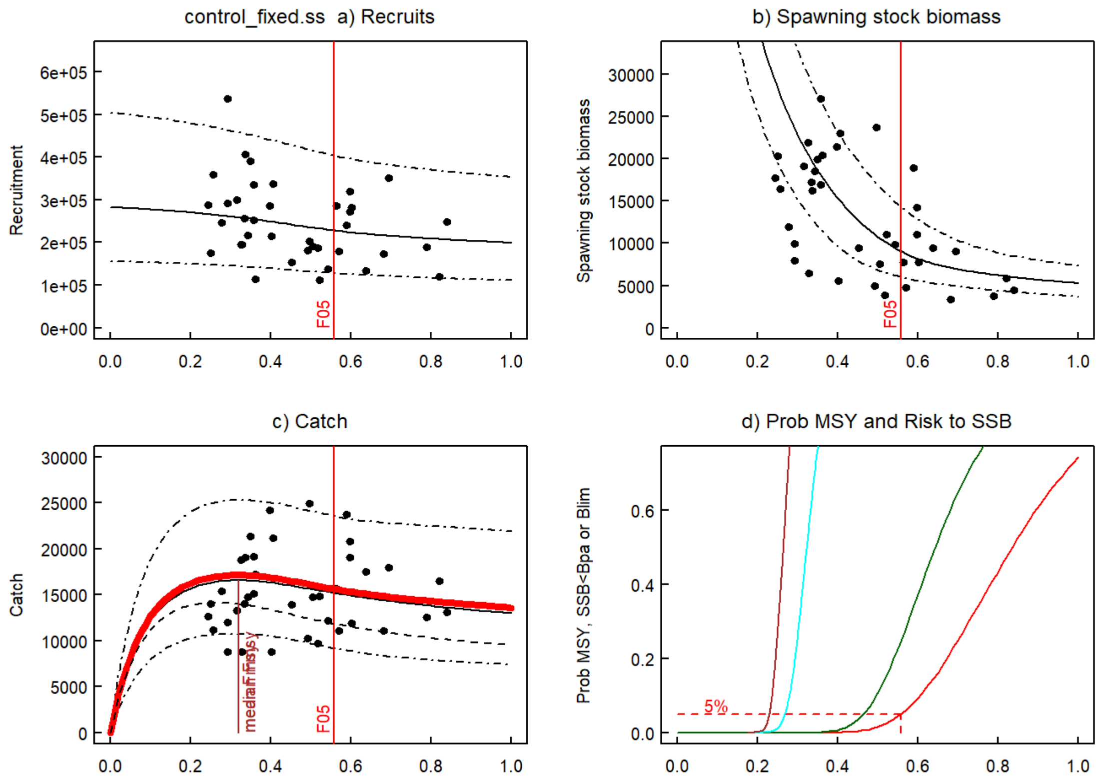


Figure 3.12. Southern hake. Simulated recruitment, SSB, yield and P(SSB<B_{lim}) as a function of the fishing mortality in the long-term simulations with eqsim_run under ICES AR. (a), (b) and (c): solid line represents the median value across the 1000 iterations, dashed lines represent 5% and 95% percentiles of the distribution, historical estimates are depicted by the black dots.

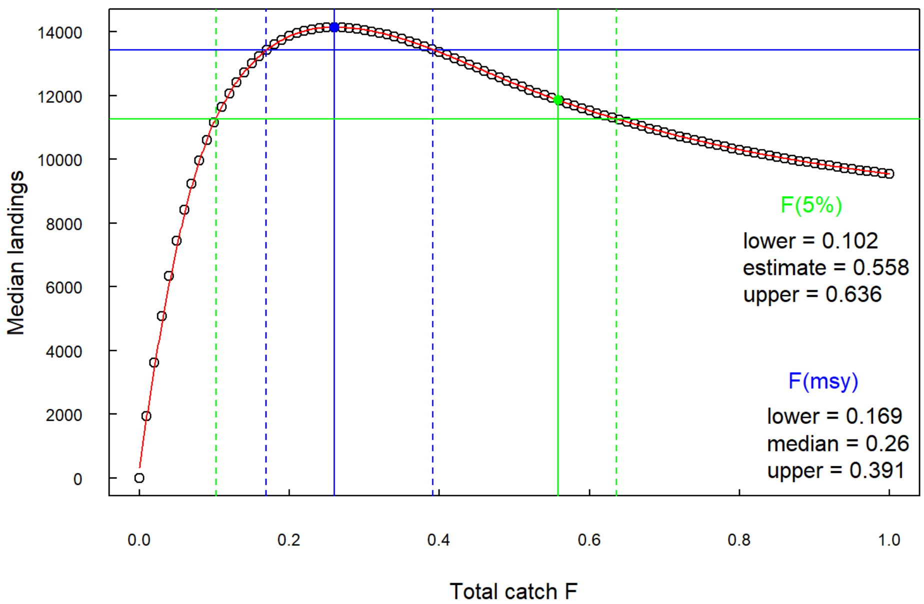


Figure 3.13. Southern hake. F_{p05}=F_{pa} (the F that provides a 95% probability for SSB to be above B_{lim}) estimation in the long-term simulations with eqsim_run under ICES AR.

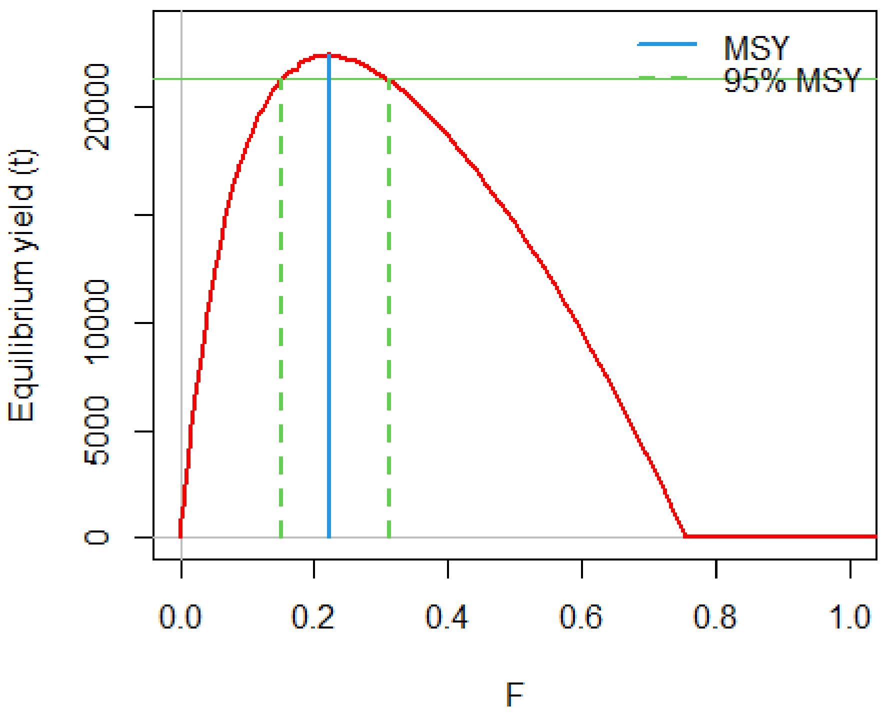


Figure 3.14. Southern hake. MSY estimates from SS3 assessment.

Table 3.1. Southern hake reference points after the 2022 benchmark.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	7556	B_{pa}
	F_{msy}	0.221	SS3 simulations.
Precautionary approach	B_{lim}	6011	Segmented regression change point.
	B_{pa}	7556	exp(1.654 ×σ) × B_{lim}, σ = 0.139.
	F_{lim}	0.694	The F that provides a 50% probability for SSB to be above B_{lim}.
	F_{pa}	0.558	F_{p05} with ICES MSY AR: The F that provides a 95% probability for SSB to be above B_{lim}.
Management plan	F_{MGT}	Not defined	
	SSB_{MGT}	Not defined	
	MAP MSY $B_{trigger}$	7556	MSY $B_{trigger}$
	MAP B_{lim}	6011	B_{lim}
	MAP F_{msy}	0.221	F_{msy}
	MAP range F_{lower}	0.151	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
	MAP range F_{upper}	0.311	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.

3.6 Short-term forecast settings

The following are default forecast options although a change in the selected years can be considered by WGBIE whether the group considers there is a good reason (e.g. changes in trends) to do it.

- Biology (Mean weights-at-age, maturity-at-age): average last 3 year.
- Discard proportions-at-age: as estimated by the retention model
- Exploitation pattern: average last 3 years
- F status-quo average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year.
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship.
- Recruitment in the last data year(s): if the working group believes these are not accurately estimated it can be replaced with the recruitment predicted from Stock Synthesis stock–recruit relationship.

The WGBIE working group will review these annually and adapt as necessary. Especial care must be taken this year since the Benchmark did not have time to explore their implementation in SS.

3.7 Final considerations

The model is quite instable. Just a few runs able to invers hessian. Among these, those with lower likelihood are quite stable in terms of SSB and F trends. Future models, once the yearly data are updated can suffer from same problems and it is suggested to explore in depth alternative runs starting at different initial values to be sure that the model converges al the best possible fit.

Further work is also required to better understand the causes and possible solutions to an easy convergence.

Model results before 1982, the period with less information (no info on biomass indices, neither length distribution) and lower quality of catch data are more sensitive to model settings and more difficult to get convergence. Model figures for this period must be considered with extra care.

Biology was one of the main challenges of this benchmark since the sex separated model requires different parameterizations for the biological processes. However, given the problems of sensitivity and convergence most of the benchmark work was devoted to this and only quite minor biological problems was addressed. Further work is required to review the biological process tighter with Northern hake.

Reference points analysis found some difficulties. ICES procedure to simulate the long-term equilibrium under precautionary considerations could not be implemented in the SS framework. The WK decided to transform SS outputs on age structured R objects to reproduce the risk analysis to check whether F_{MSY} and F ranges are affected by precautionary considerations. Once that was probed that this is not the case F_{MSY} and ranges was estimated in the SS framework which also will be used to make the projections.

Projections will be performed in the SS framework to be consistent with the model dynamics. However, the WK would not had time to check whether the selected projection setting can be implemented without problems. The WK suggest that the WGBIE checked and reformulate (if needed) these settings.

4 Celtic Seas, Bay of Biscay black-bellied anglerfish

Lophius budegassa in Subarea 7 and divisions 8.a–b and 8.d; ank.27.78abd

4.1 Development of the model

An initial model was developed at WKTADSA (January 2021); this was refined over the period leading up to the WKANGHAKE data workshop (November 2021) where several further suggestions were made. Development of the model continued up to the WKANGHAKE benchmark meeting with considerable help and suggestions from a few SS experts. The main developments since the WKANGHAKE data workshop are summarized below:

- Survey sample sizes (number of hauls) were provided.
- The use of biomass indices vs. abundance indices was tested and there was no perceptible difference.
- Sex-specific survey length data were provided and a sex-disaggregated model was developed.
- The two survey indices show conflicting trends in recent years. The raw survey data were checked, and the estimation procedures were checked in detail but no mistakes were found. Neither index was deemed more reliable than the other so it was decided to retain both indices.
- Length composition data from the commercial landings were analysed to identify a useful grouping of commercial fleets (WD11). Four fleets were identified: French trawlers, Spanish trawlers, Other trawlers and gillnets. However, for black anglerfish the fleet-specific data were quite noisy and it proved difficult to fit selection curves. Moreover, the differences between the fleets were relatively small. Therefore, all trawl fleets were combined into a single fleet. The gillnet fleet is only minor for this stock, but it was kept separate because its contribution is slowly increasing and because it is a very different fishing technique from trawling.
- Landings data since 1950 were considered to be reasonably reliable, therefore these were included in the model.
- Sample sizes for commercial length composition are reported to in the annual working group reports as well as to InterCatch. Because there were considerable differences between the two sources of data, expert judgement was used to estimate a reasonable compromise.
- Selectivity (dome-shaped vs. flat-topped) was explored and discussed in much detail. More information on this in section describing alternative runs.
- Biological parameters were fixed to the values agreed at the data compilation workshop.

The base case model is outlined below, the structure of this section follows that of the SS input files. Any settings not described below can be assumed to be the default as indicated in the manual.

4.1.1 Base case

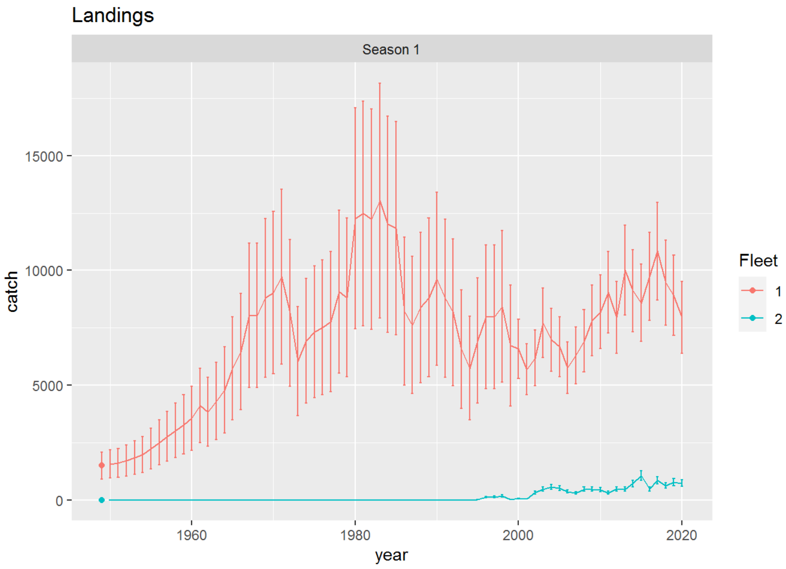
Starter file

- **SSversion**: 3.30
- **F_report_unts:** 5 (unweighted average F for range of ages)

- **F_age_range:** 3–10. The base case has logistic selectivity with full selection from age 3 onwards so the oldest age is not important; age 10 was chosen as it is not exceedingly rare.

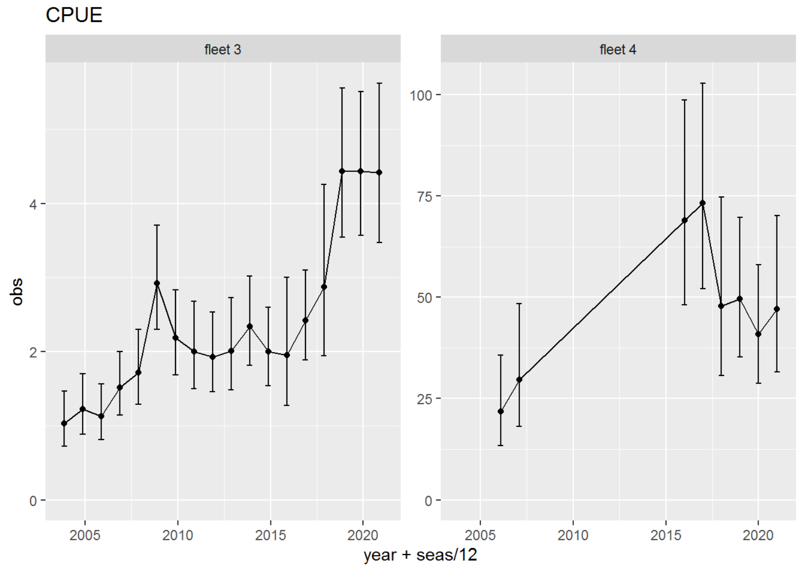
Data file

- **styr:** 1950. Reasonably reliable landings data start in this year
- **endyr:** 2020
- **nseas:** 1. Commercial data are aggregated by year; quarterly data are available but considered to be too noisy
- **Nsubseasons:** 4. A separate ALK is calculated for each sub-season; this allows appropriate fitting of the length cohorts in surveys that do not take place in the middle of the year.
- **spawn_month:** 1. The mean size of the recruits in Q4 surveys is around 12 cm and the growth rate of small fish is estimated around 10 cm/yr which suggests that spawning at the start of the year is a reasonable assumption.
- **Ngenders:** 2. Sexual dimorphism is known to occur; length composition by sex is available for both surveys.
- **Nages:** 15. This seems sufficient.
- **N_areas:** 1. Differences between areas are known to exist but a multi-area model was considered too complicated at this stage and remains to be explored.
- **Nfleets:** 4
    - FL1_TRAWL; commercial fleet; units: biomass.
    - FL2_Gillnets; commercial fleet; units: biomass
    - FR_IE_IBTS; survey; units: biomass. Combined French-Irish IBTS Q4 groundfish surveys
    - IE_MONKSURVEY; survey; units: biomass. Irish Q1 Anglerfish and Megrim Survey
- **Catch** (note: this is SS terminology but refers to landings only)
    - catch_se for both fleets is 0.2 from 1950 to 1999 and 0.1 from 2000 onwards.
    - Fleet 1 is assumed to have equilibrium catches before the star of the time-series.



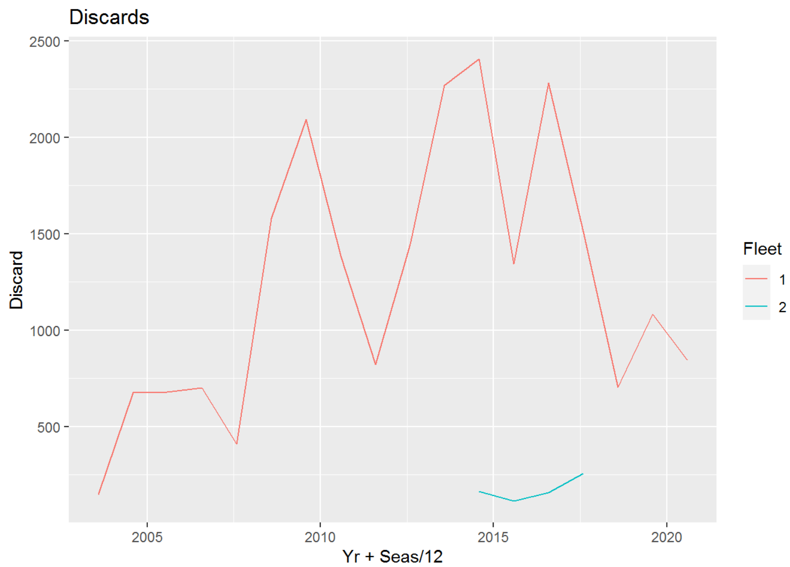
Time-series of annual landings (tonnes) with standard errors. Fleet 1 consists of all trawl gears and is by far the dominant fleet; Fleet 2 consists of gillnets; landings from this fleet have slowly increased over the last 20 years but still consist a small proportion of the total. Three separate trawl fleets were originally identified but the length compositions and discard data were considered to be too noisy to retain these as separate fleets.

- **CPUE**
  Both survey indices are provided as biomass and the error is provided on the lognormal scale (converted from normal scale using the equation in the SS manual)



Time-series of the FR_IE_IBTS (fleet 3) and the IE_MONKSURVEY (fleet 4)

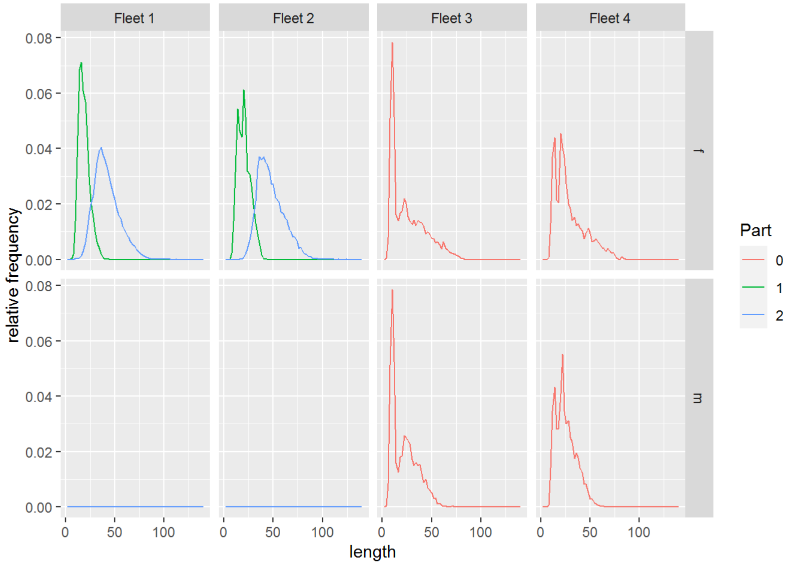
- **N_discard_fleets**: 2
  - FL1_TRAWL; units: biomass; error type: normal
  - FL2_Gillnets; units: biomass; error type: normal; years with very small discard estimates were removed to improve the model fit.



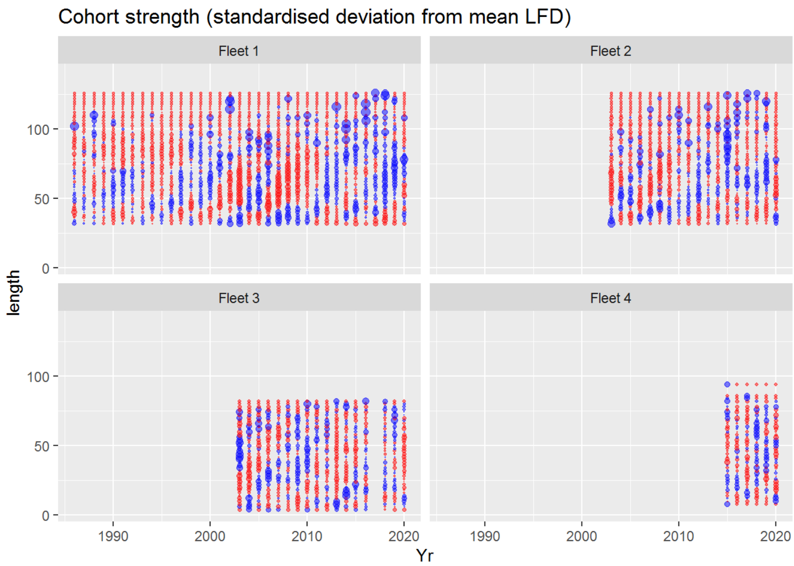
Time-series of discards (tonnes). Fleet 1 is FL1_TRAWL and fleet 2 is FL2_Gillnets

- **Length bins for the population and data**
  - 2 cm length bins from 2 to 130 cm; 5 cm bins from 130–140
- **Length composition data structure**
  - Length data are available for the 2 commercial fleets and 2 survey fleets. Length data for the early years of the IE_MONKSURVEY were not used.
  - Bin compression: 0.001; stronger compression does not allow the sex-ratio of the largest fish to be fitted because there are almost no males in those size bins which leads those bins to be compressed.

- Dirichlet option selected for all four fleets



Overall length composition (all years combined) for the commercial fleets (FL1_TRAWL and FL2_Gillnets) and the surveys (FR_IE_IBTS and IE_MONKSURVEY). Partition 0 is catch, 1 is discards and 2 is landings.



Standardized deviation from the mean length distribution. Blue circles indicate larger numbers-at-length than overall mean; red is lower than expected. The length data show strong cohort tracking up to at least 6 years for particularly strong and weak cohorts

Sample sizes by year and fleet. For the commercial fleets the sample sizes were based on those reported to in the annual working group reports as well as those reported to Inter-Catch. Because there were considerable differences between the two sources of data, expert judgement was used to estimate a reasonable compromise. For the surveys, the sample size is the number of hauls.

- **Age data:** No age data are available
- **Environmental data**: None
- **Generalised size comp data:** None
- **Tag-Recapture data:** None
- **Stock (Morph) comp data:** None
- **Selectivity priors:** None

Control file

- **EmpiricalWAA:** 0 (not available)
- **N_GP:** 1 (single growth pattern)
- **N_platoon**: 1 (single platoon)
- **recr_dist_method**: 4 – none, no parameters (growth pattern x settlement x area = 1).
- **recr_dist_pattern:** All recruitment assumed to occur in month 1 at age 0
- **N_Block_Designs:** 0
- **natM_type:** 3 (Age-specific M).
- **natM:** Lorenzen for young ages and flat for older ages where predation is not the main source of natural mortality. M for older ages based on the fishlife library, taking account of the life history of the stock. See WD06 for more details. There was no basis to assume different M for the two sexes; length-at-age for the young ages (where Lorenzen applies) is almost identical for males and females.

Age 0	Age 1	Age 2	Age 3	Age 4+
1.00	0.72	0.44	0.34	0.32

- **GrowthModel:** 1 (VonB)
- **Growth_Age_for_L1: 1**
- **Growth_Age_for_L2:** 999 (L2=L_{inf})
- **maturity_option:** 1 (length logistic)
- **First_Mature_Age:** 2 (ages below the first mature age will have maturity set to zero.)
- **fecundity_option:** 1 (linear eggs/kg on body weight)

- **MG_params:** All biology parameters are fixed and based on life history information compiled during the WKANGHAKE data compilation workshop
    - L_at_Amin_Fem_GP_1 12.5
    - L_at_Amax_Fem_GP_1 129
    - VonBert_K_Fem_GP_1 0.101
    - CV_young_Fem_GP_1 0.244 (estimated by the model, then fixed)
    - CV_old_Fem_GP_1 0.1 (assumed)
    - Wtlen_1_Fem_GP_1 0.0000177
    - Wtlen_2_Fem_GP_1 2.95
    - Mat50%_Fem_GP_1 65
    - Mat_slope_Fem_GP_1 -0.15
    - Eggs/kg_inter_Fem_GP_1 1
    - Eggs/kg_slope_Fem_GP_1 0
    - L_at_Amin_Mal_GP_1 12.5
    - L_at_Amax_Mal_GP_1 78
    - VonBert_K_Mal_GP_1 0.197
    - CV_young_Fem_GP_1 0.244 (estimated by the model, then fixed)
    - CV_old_Mal_GP_1 0.1 (assumed)
    - Wtlen_1_Mal_GP_1 0.0000177
    - Wtlen_2_Mal_GP_1 2.95
    - CohortGrowDev 1
    - FracFemale_GP_1 0.5
- **SR_function:** 3 (Beverton-holt)
- **SR_params:** all fixed except R0
    - SR_LN(R0) estimated in phase 1
    - SR_BH_steep 0.93
    - SR_sigmaR 0.5
    - SR_regime 0
    - SR_autocorr 0
- **do_recdev:** 1
- **MainRdevYrFirst:** 1986 (first data year)
- **MainRdevYrLast:** 2020 (there is information from the surveys and discards to inform Rdev)
- **Recfev_phase:** 2
- **last_early_yr_nobias_adj:** 1951 (suggested by r4ss)
- **first_yr_fullbias_adj:** 1990.7 (suggested by r4ss)
- **last_yr_fullbias_adj:** 2020.3 (suggested by r4ss)
- **first_recent_yr_nobias_adj:** 2021 (suggested by r4ss)
- **max_bias_adj:** 0.9297 (suggested by r4ss)
- **F_Method:** 4 Fleet-specific parameter/hybrid F (recommended).
- **F_4_Fleet_Params:**
    - Fleet 1: start F 0.30; phase 1
    - Fleet 2: start F 0.05; phase 2
- **Init_F**: there was some fishing before 1950; however, the model estimated initial F to be very low hitting the boundary of 1e-3 in most runs but in some runs initial F converged on a very high value. As it does not affect the rest of the model, the value was fixed at 0.01.
- **Q_options:**
    - Fleet 3 (IBTS): link 1 (simple Q); no extra se; no bias adj; float
    - Fleet 4 (MONK): link 1 (simple Q); no extra se; no bias adj; float
- **size_selex_types:**

  - FL1_Trawl: Pattern 1 (logistic); discards (with time-varying Retain_L_infl)
  - FL2_Gillnets: Pattern 1 (logistic); discards
  - FR_IE_IBTS: Pattern 24 (double-normal)
  - IE_MONK: Pattern 1 (logistic)
- **age_selex_types:** - None
- **size_selex_para:**
  - Main para estimated in phase 5, others in phase 3
  - Retention para estimated in phase 5 and 6; random walk on retention inflection parameter from 2005–2020 due to the gradual adoption of minimum market weight.
- **dirichlet_params:**
  - Estimates in phase 8 for all 4 fleets
- **size_selex_params_tv**: time varying retention size at inflection
  - dev_se fixed at 2.5
  - auocorr fixed at 0
- **Use_2D_AR1_selectivity:** 0
- **TG_custom:** 0
- **DoVar_adjust:** 1
- **maxlambdaphase:** 1
- **sd_offset:** 1
- **N_lambdas:** 0

Phases

The phases were set according to the following rule-of-thumb:

- Phase 1: R0 and Ms
- Phase 2: biology (+ time varying bio parameters or next phase)
- Phase 3: main recdev
- Phase 4: early recdev
- Phase 5: Main sel para and q (when estimated, not in this cases as we are using floats)
- Phase 6: Other sel para
- Phase 7: time varying para in sel
- Last phase: Dirichlet parameters

4.1.2 Model diagnostics

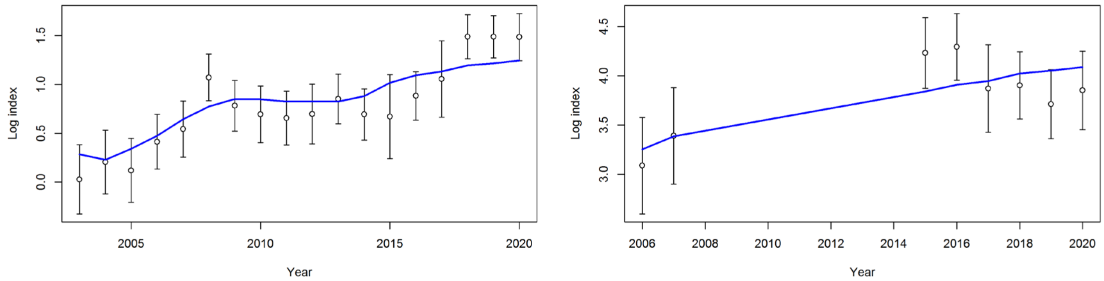
Full model diagnostics are available on the SharePoint folder “Software” (ank.27.7abd_finalSSmodel.zip). The approach to model diagnostics described below follows that described by Carvalho *et al*. (2021).

4.1.2.1 Convergence

- No parameters are estimated at or near bounds or with unusual variance.
- The final gradient is < 1e-4.
- The Hessian is positive definite.
- 50 jitter runs were performed using default settings for magnitude and all converged on the same likelihood as the base run.
- There was a strong correlation in the parameters controlling the ascending part of the double-normal selectivity curve for the IBTS survey (97%). However, the jitter runs always converged on the same solution so this was not considered to be problematic.

4.1.3 Goodness-of-fit

Fits and residuals were examined (see plots below). Runs tests were performed and RMSE was calculated.



IE_FR_IBTS IE_MONKSURVEY

Figure 4.1. The model fits the survey indices reasonably well but there is some conflict between the two indices.

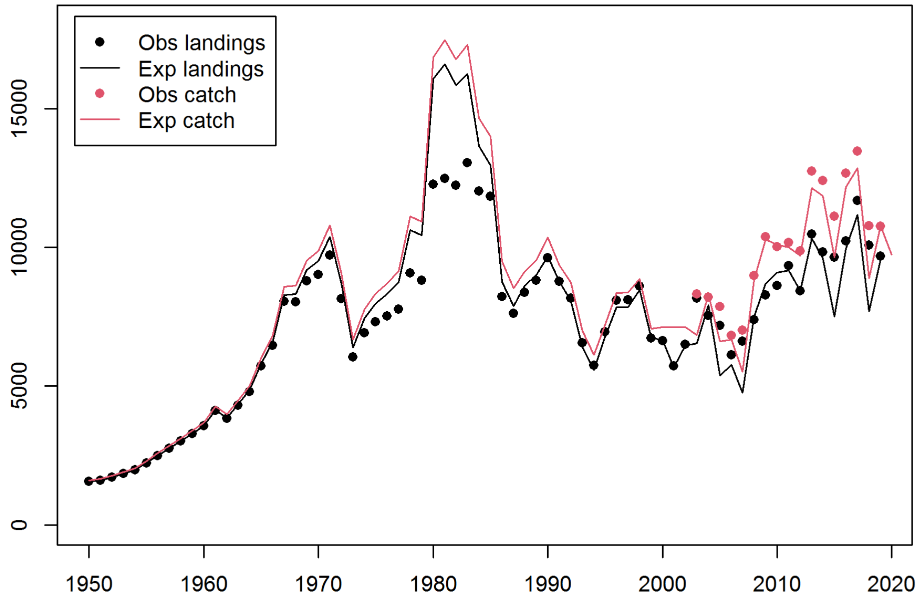


Figure 4.2. The fit to the landings just before the length data begin (1986) is poor. This may indicate that the model had insufficient flexibility in the recruitment deviations before that time and should be investigated at a future (inter) benchmark.

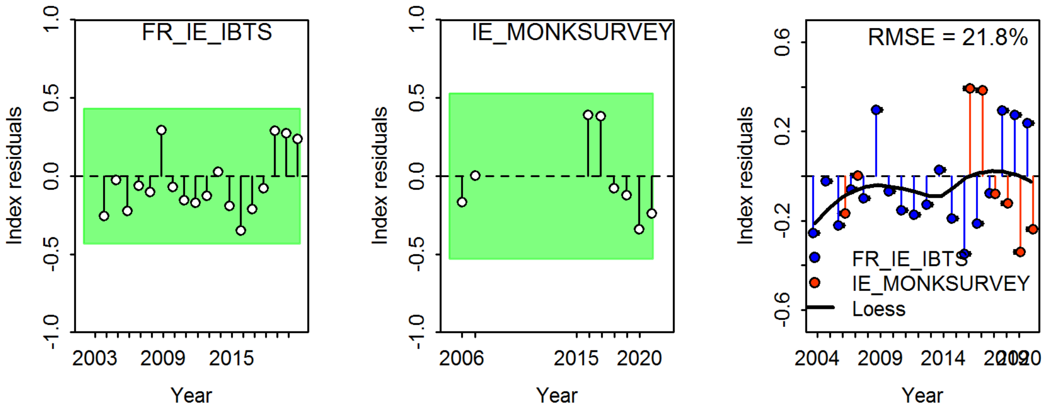


Figure 4.3. Both indices pass the runs test and have an acceptable RMSE.

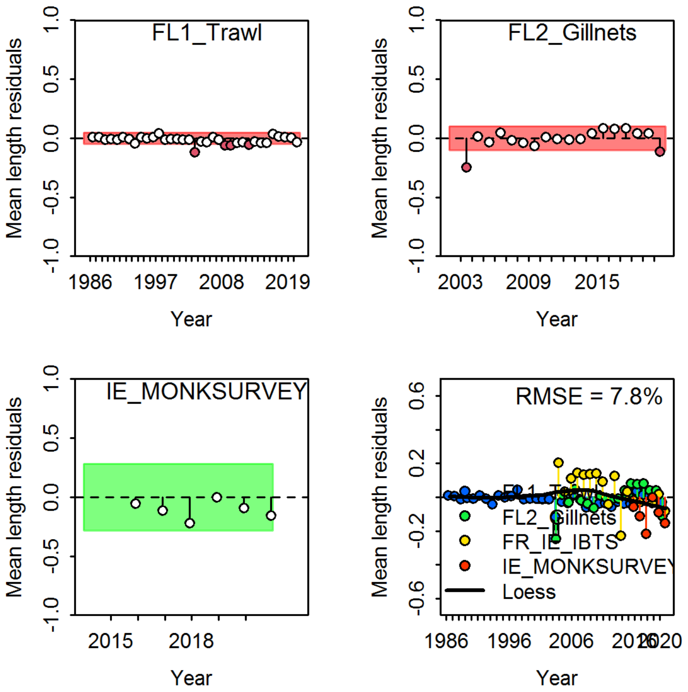


Figure 4.4. The mean length residuals of the Trawl fleet are generally very small, yet they fail the runs test (this is thought to be an artefact). The gillnet fleet has more small fish than expected in 2003 and 2020 which causes it to fail the runs test. The surveys pass the runs test for mean length and the RMSE is well below the threshold of 30%.

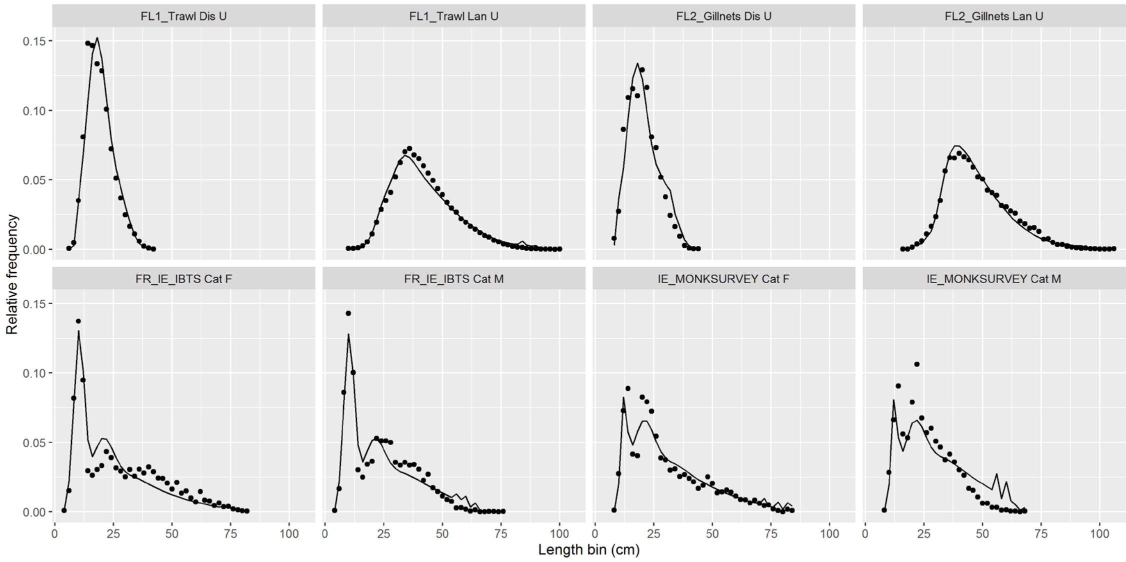


Figure 4.5. The overall fit to the length composition data (all years combined) is quite good for the discards; the landings of both fleets have a reasonable fit but logistic selection may be a bit too rigid. The IBTS survey has good fit for young fish but the third cohort seems to be underestimated for both sexes. The MONK survey has quite a good fit for females but not for large males, which are overestimated.

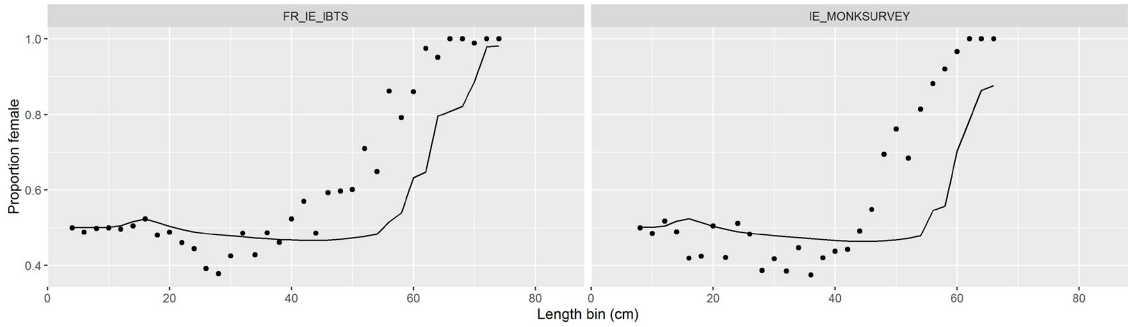


Figure 4.6. The overall fit to the sex-ratio (all years combined) is relatively poor, suggesting that either there is a difference in natural mortality between sexes or a larger difference in growth.

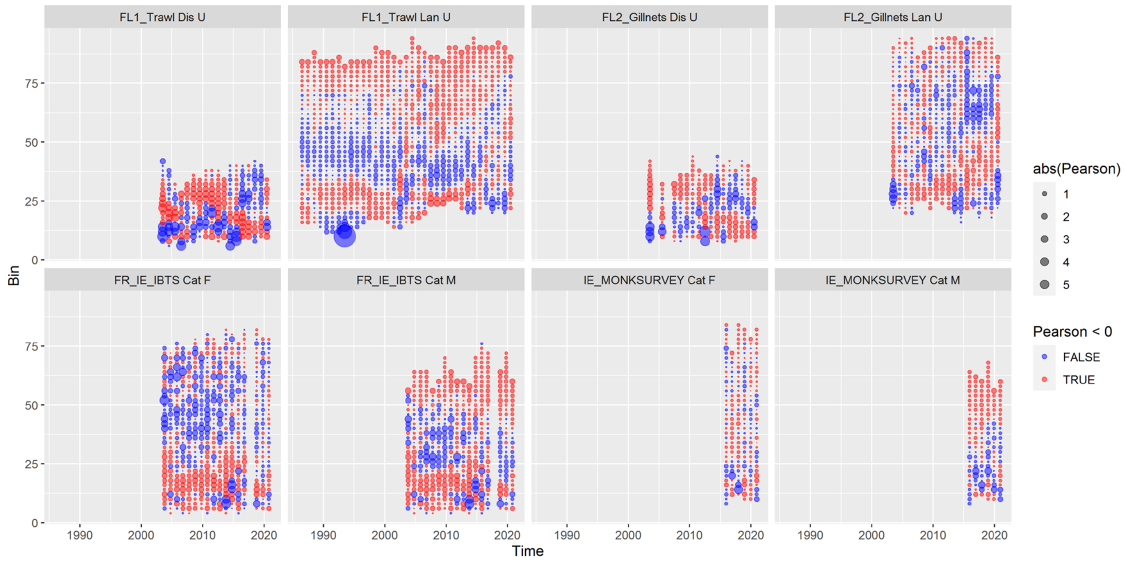


Figure 4.7 There are distinct patterns in the residuals. In particular, the main commercial fleet shows negative residuals for large fish, generally positive residuals for medium fish and negative for small fish; indicating a lack of fit that probably results from the logistic selection pattern although misspecification of M and/or growth may also play a role. Fleet 3 (IBTS survey) tends to have positive residuals for large females and negative residuals for large males. This may indicate that the difference in growth and/or M is not fully captured.

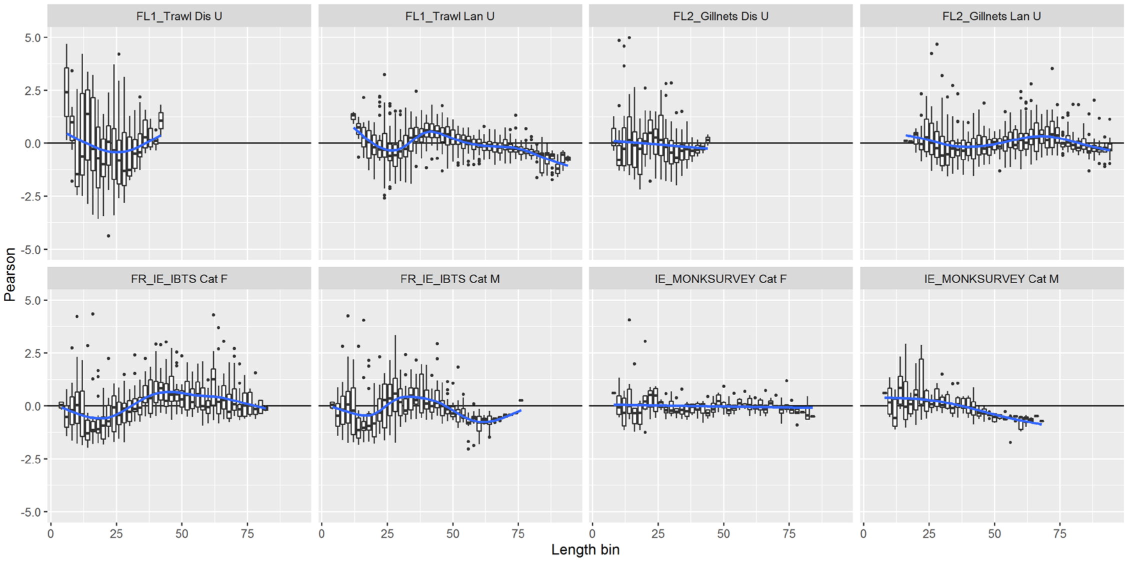


Figure 4.8. Trends in residuals by length; boxplots indicate the distribution of residuals in each year by length bin. In general, the discard data are noisy but they have no strong trends. The fit to the landings of fleet 1 (TRAWL) shows definite trends (see also bubble plots above). Fleet 3 (IBTS survey) has mainly negative residuals around 20 cm for both sexes as well as for large males. Fleet 4 (MONK survey) has mainly negative residuals for large females.

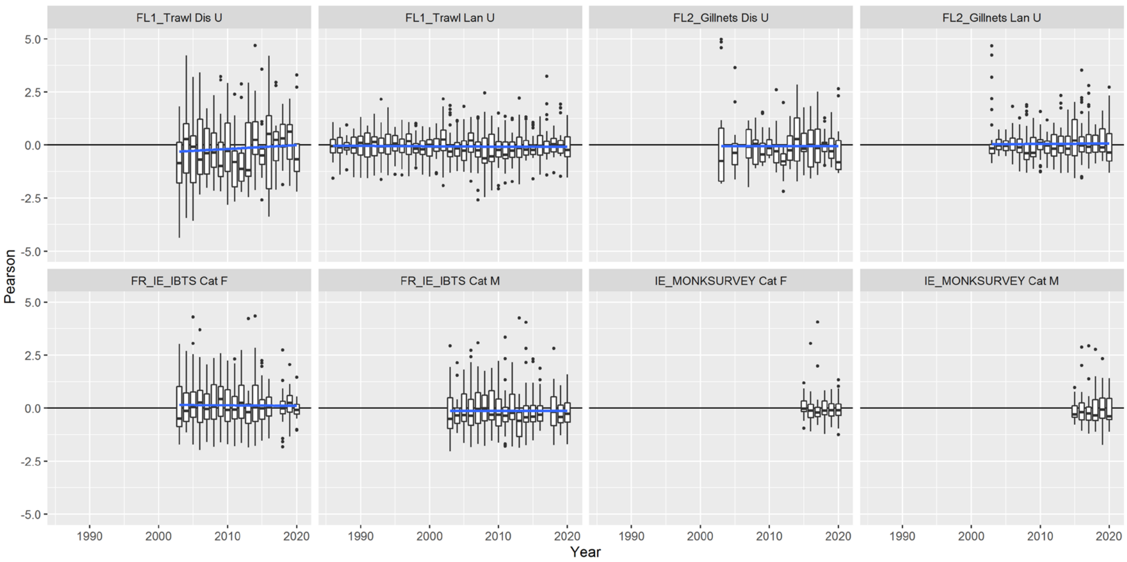


Figure 4.9. The residuals of the length compositions by year. No strong year-effects or trends are apparent.

4.1.3.1 Model consistency

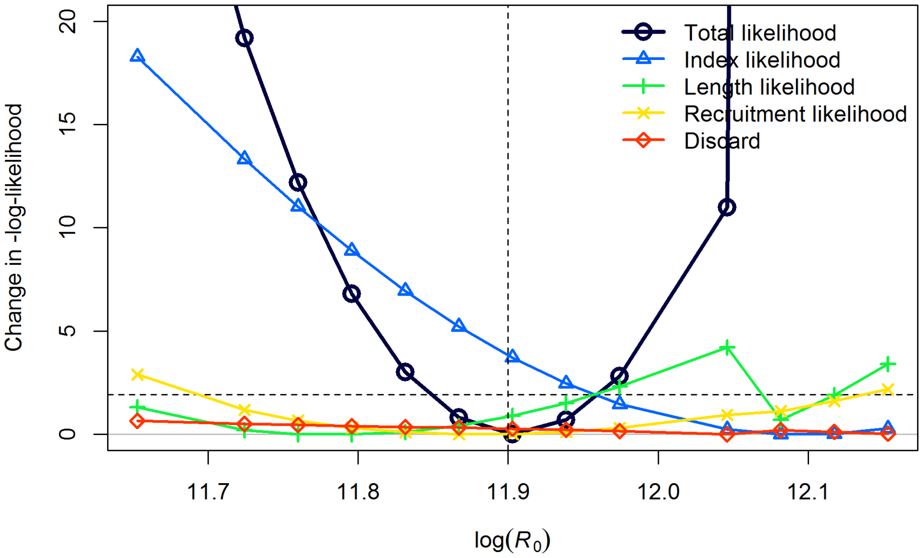


Figure 4.10. The R0 profile indicates that the indices (dominated by the IBTS index) and discards support a higher R0 while the length data (dominated by the FL1_Trawl fleet) supports a lower R0. This suggests that either M or selectivity are somewhat mis-specified.

Figure 4.11. Retrospective analysis shows almost no retrospective bias in SSB but F was revised down when 2018 data were introduced. This is related to the very large increase in the IBTS index in that year. Recruitment has been revised upwards a number of times.

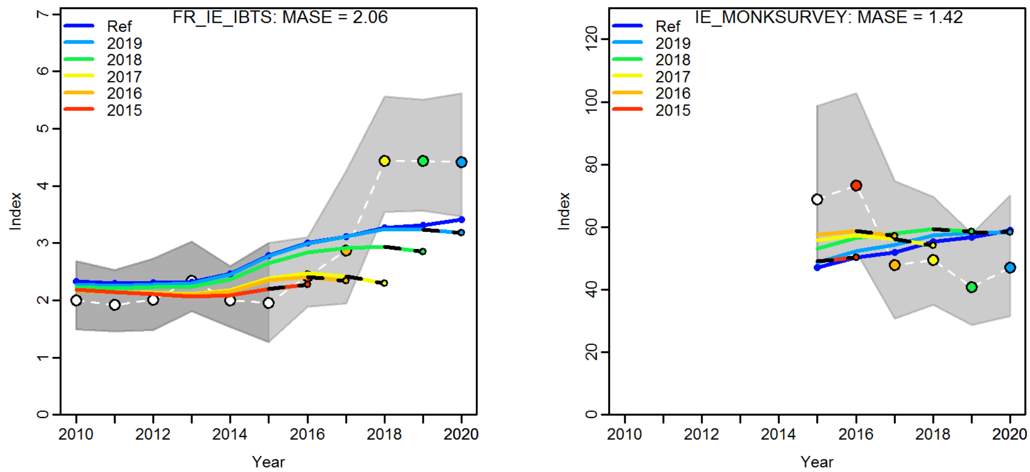


Figure 4.12. Hindcast cross validation of the survey indices. Neither index has good predictive power (MASE<1). This is partially due to the conflict between the two indices. In the case of the IBTS survey, the index is largely driven by recruitment and therefore unpredictable. The IAMS survey has a very short time-series which may also reduce its predictive power.

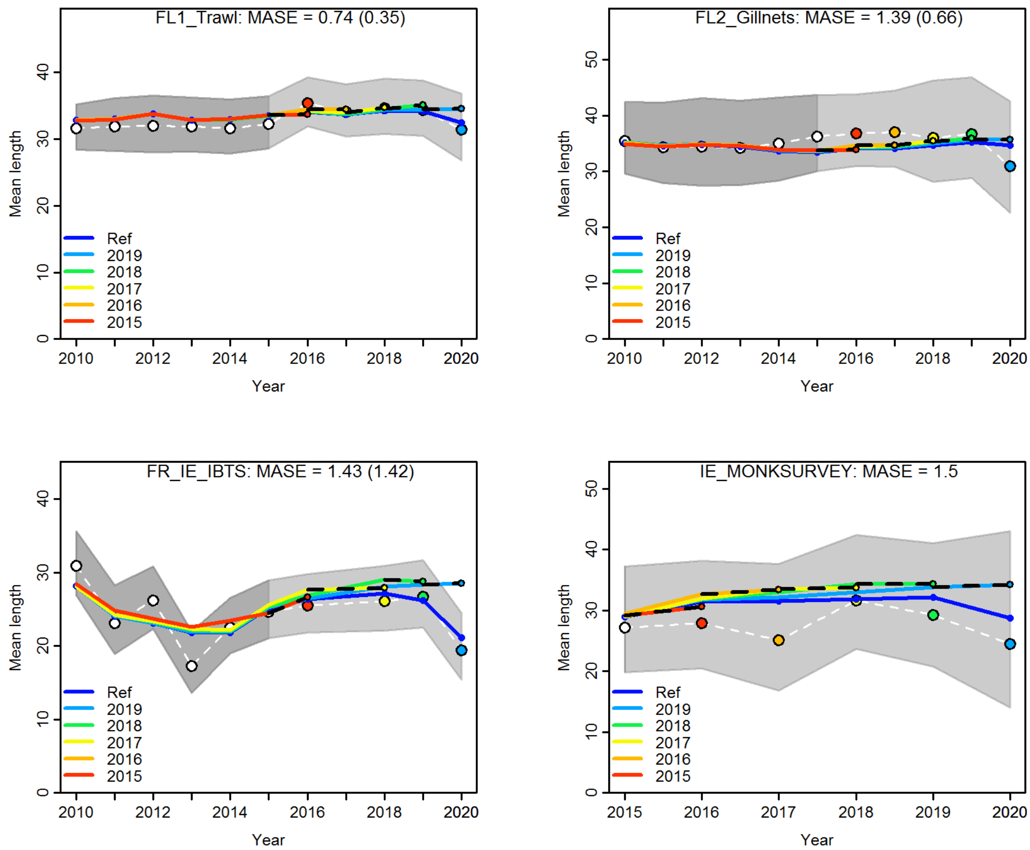


Figure 4.13. Hindcast cross validation of the mean length. The two commercial fleets and IBTS survey have low MASE scores (adjusted values in brackets; indicating good predictive power). The MONK survey may be too short to have much predictive power.

4.1.4 Stock development

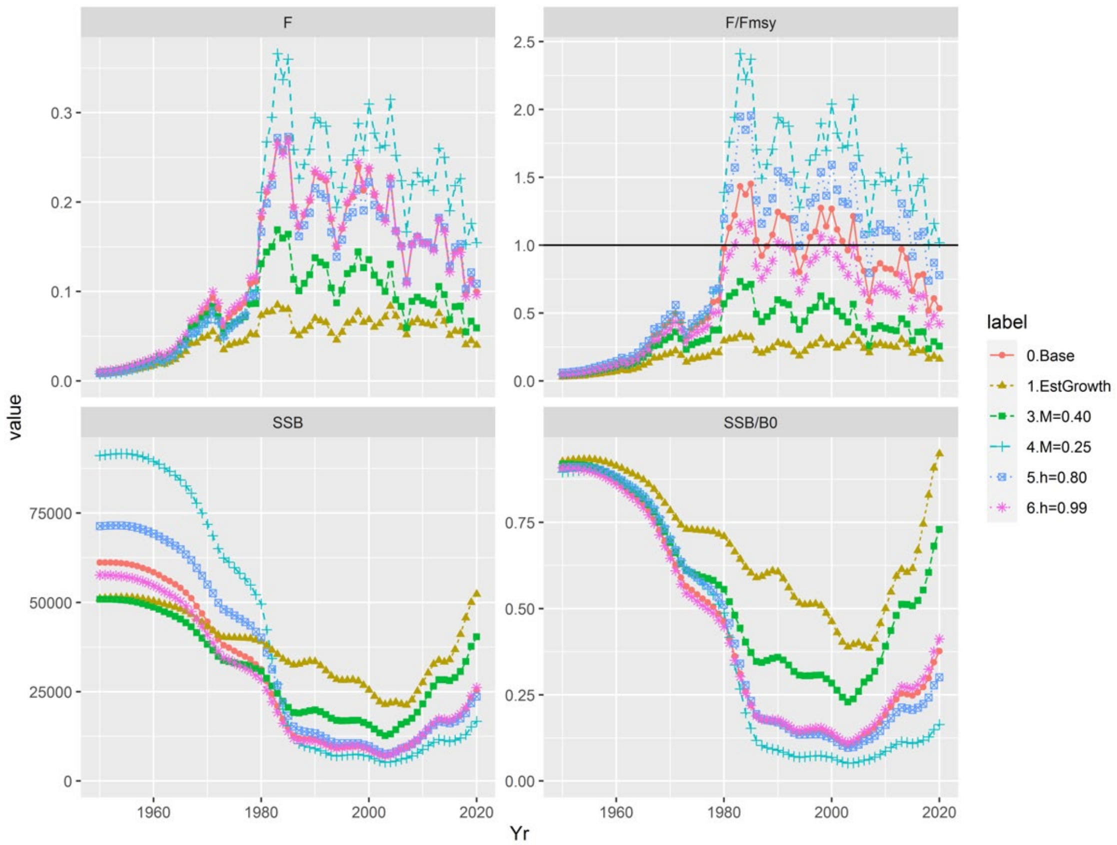
Figure 4.14. Stock development of the base case SS model (purple line). For comparison the trends in effort and LPUE from the main fleets are shown (scaled to F and SSB respectively): LpueEsp1 refers to the Spanish Vigo and A Coruña fleets; LpueEsp2 is the Spanish BACON fleets; LpueFra refers to the French demersal trawl fleets and LpueIrl refers to an Irish standardized LPUE index that was developed for WKANGLER 2018 but never used in an assessment model. Note that F/Fmsy is based on the Fmsy value estimated by SS (not that estimated by the ICES procedure through eqsim).

The stock development in the recent period is in line with the expectation that the stock was relatively highly exploited during the 1990s and early 2000s and that fishing pressure has reduced in recent years following substantial reductions in the capacity of the main fleets in the last 15–20 years, resulting in an increase in biomass over that period. The LPUE data shown in the plot was not used in the model but serves to provide independent information on the stock development.

4.1.5 Alternative runs

4.1.5.1 Biology

The biological parameters are based on the best available life history data and were agreed at the data compilation workshop. These parameters are all fixed in the base case, however the model is sensitive to some of these parameters.



			Num	MohnsRho		MASE indices		MASE length				Runs indices		RMSE	Runs length				RMSE
Run	TotLike	Grad	Para	SSB	F	IBTS	MONK	Trawl	Gill	IBTS	MONK	IBTS	MONK	joint	Trawl	Gill	IBTS	MONK	joint
Base case	-13534	1.E-07	167	-0.02	0.14	2.06	1.42	0.35	0.66	1.42	1.50	0.09	0.14	22%	0.01	0.03	0.34	0.00	8%
Estimate growth	1337	3.E-04	171	0.00	0.08	2.26	1.26	0.35	0.76	1.47	1.57	0.01	0.08	23%	0.45	0.00	0.65	0.00	9%
NatMort 0.25	-13521	2.E-04	167	0.05	0.10	2.21	1.18	0.33	0.68	1.66	1.35	0.01	0.14	23%	0.11	0.03	0.04	0.76	8%
NatMort 0.40	-13519	5.E-05	167	-0.07	0.22	2.73	1.42	0.38	0.63	1.27	1.55	0.09	0.14	23%	0.12	0.03	0.34	0.00	8%
Steepness 0.80	-13518	2.E-05	167	-0.08	0.24	2.68	1.24	0.36	0.65	1.15	1.45	0.09	0.14	23%	0.12	0.03	0.34	0.00	8%
Steepness 0.99	-13536	6.E-08	167	0.00	0.11	1.88	1.48	0.36	0.66	1.54	1.53	0.09	0.08	22%	0.01	0.03	0.34	0.00	8%

Figure 4.15. Stock development and diagnostics for runs with alternative biological assumptions.

- *Base is the base case model*
- *EstGrowth: k and L_{inf} are estimated for both males and females*
- *M=0.25 and M=0.40: natural mortality is scaled so M for fish age 4+ is 0.25 and 0.40 respectively*
- *h=0.80 and h=0.99 are runs where the BH steepness is set to 0.80 and 0.99 respectively*

4.1.5.2 Growth

The model can estimate growth parameters, however when L_{inf} and k are freely estimated for both species, L_{inf} is estimated to be very low (64 cm for females and 56 cm for males). The CV of large fish was increased to 0.25 to allow for occasional large fish (the largest size of fish in the landings that occurs in more than one year is 125 cm). Nevertheless, the model could only accommodate these occasional large fish by drastically reducing F (and consequently increasing SSB), resulting in a stock development that is unrealistic. The diagnostics (Mohn's Rho, MASE, runs tests and RMSE) for the run with estimated growth parameters overall no better than the base case and provide no basis to reject the base case in favour of a run with unrealistic stock development.

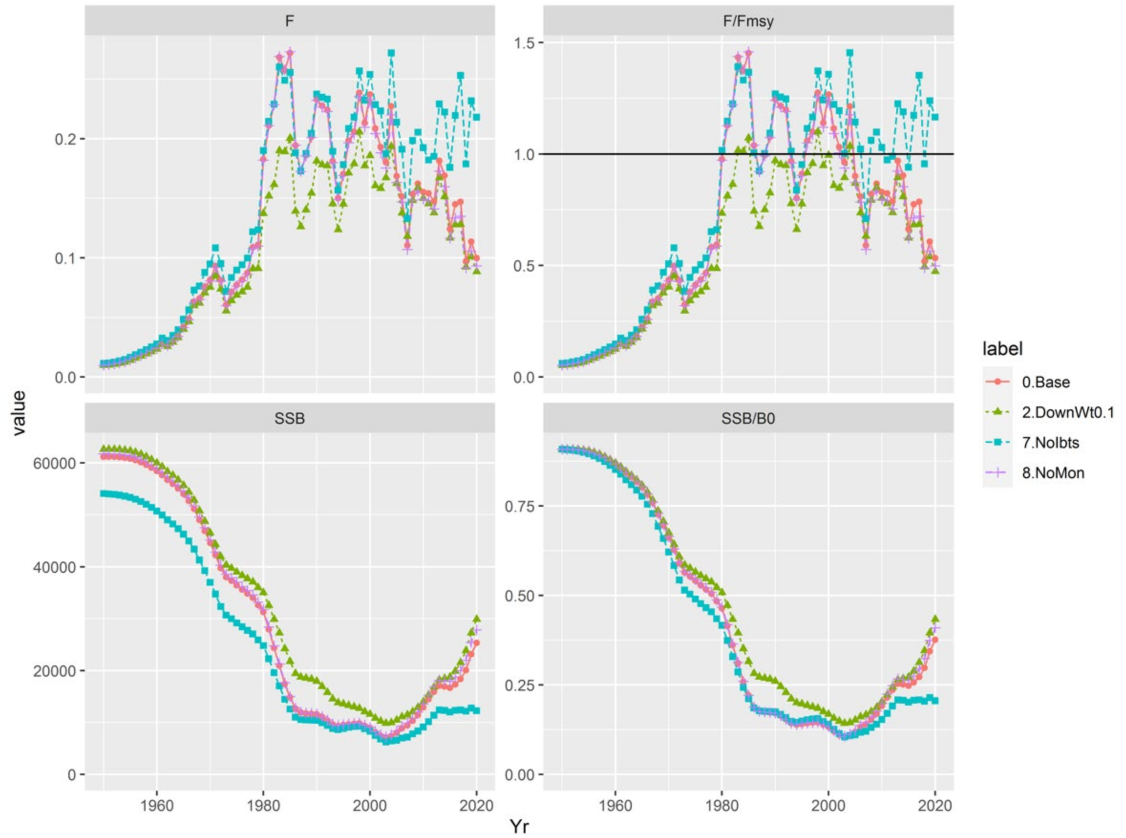
4.1.5.3 Natural mortality

Predictably, the scaling of the model is sensitive to the M assumption: increasing M results in a lower estimate of F and higher SSB, while decreasing M has the opposite effect. This applies both to the absolute estimates of F and SSB and to F/F_{msy} and SSB/B_0. The high-M run results in a slightly worse retrospective pattern for F but it does not have a major impact on the other diagnostics. Lower M does not improve the diagnostics either and therefore there is no reason to deviate from the base case, which has an M assumption that is based on the best available information (outlined in WD 06).

4.1.5.4 Steepness

Changing steepness has almost no impact on the absolute values of SSB and F but it does impact on the reference points. Changing steepness did not result in an improvement in the diagnostics and the effect on the reference points is relatively minor. Therefore, there is no reason to deviate from the steepness value assumed in the base case, which is based on the best available information (the FishLife R package).

4.1.5.5 Weighting/importance



			Num	MohnsRho		MASE indices		MASE length				Runs indices		RMSE	Runs length				RMSE
Run	TotLike	Grad	Para	SSB	F	IBTS	MONK	Trawl	Gill	IBTS	MONK	IBTS	MONK	joint	Trawl	Gill	IBTS	MONK	joint
Base case	-13534	1.E-07	167	-0.02	0.14	2.06	1.42	0.35	0.66	1.42	1.50	0.09	0.14	22%	0.01	0.03	0.34	0.00	8%
Downweight 0.1	1340	2.E-03	167	-0.05	0.20	2.18	1.41	0.39	0.69	1.44	1.66	0.01	0.08	23%	0.04	0.00	0.23	0.00	9%
No IBTS survey	3927	1.E-04	167	0.27	-0.14	3.13	1.14	0.49	0.55	NA	1.38	NA	0.27	33%	0.08	0.00	NA	0.00	6%
No MONK survey	-12627	4.E-05	167	-0.09	0.28	2.47	1.27	0.41	0.64	1.42	NA	0.09	NA	22%	0.01	0.03	0.34	NA	7%

Figure 4.16. Stock development and diagnostics for runs with alternative weighting assumptions.

- *Base is the base case model*
- *Downweight 0.1 is a run where all length composition data are down-weighted by a factor of 0.1*
- *No IBTS survey is a run without the IBTS survey index and length composition data*
- *No MONK survey is a run without the IBTS survey index and length composition data*

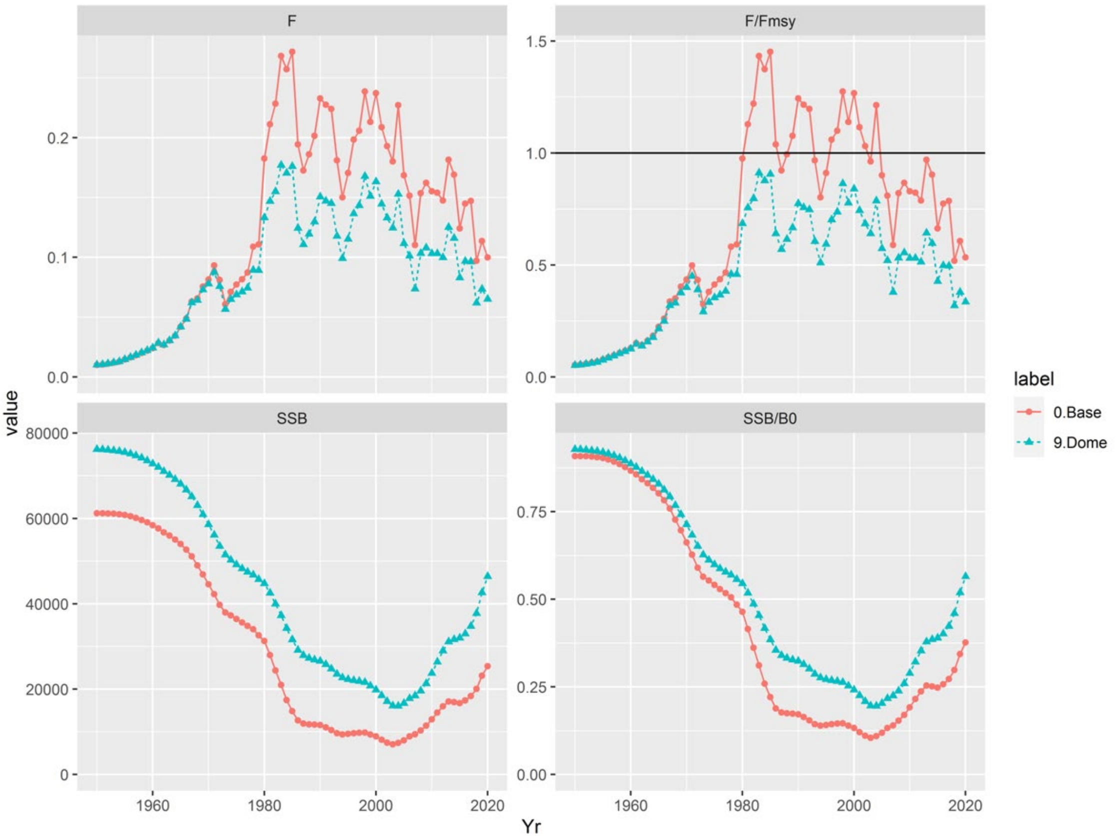
4.1.5.6 Down-weighting length composition

The length data result in the largest likelihood component. Down-weighting the sample sizes of the length composition data to 10% resulted in some changes in the period where length data were available but no survey data (1986–2003). The recent stock development was almost identical with the base case. The diagnostics did not provide a reason to deviate from the base case.

4.1.5.7 Single index runs

The two surveys provide some conflicting information in recent years. The IBTS indicates a continued increasing trend in SSB while the MONK survey indicates that SSB is levelling off. Omitting the IBTS survey improved the retrospective bias for F, while omitting the MONK survey resulted in a poor retrospective pattern for both F and SSB. There is no objective way to determine which survey provides the most accurate index, therefore there is no reason to deviate from the base case, which allows the model to find a "middle way" (which is close to the stock development of the run with only the IBTS survey.

4.1.5.8 Selection pattern of the commercial fleets



			Num	MohnsRho		MASE indices		MASE length				Runs indices		RMSE	Runs length				RMSE
Run	TotLike	Grad	Para	SSB	F	IBTS	MONK	Trawl	Gill	IBTS	MONK	IBTS	MONK	joint	Trawl	Gill	IBTS	MONK	joint
Base case	-13534	1.E-07	167	-0.02	0.14	2.06	1.42	0.35	0.66	1.42	1.50	0.09	0.14	22%	0.01	0.03	0.34	0.00	8%
Dome FL1	-13609	1.E-05	168	0.06	0.04	1.68	1.59	0.31	0.60	1.78	1.82	0.09	0.08	22%	0.25	0.03	0.34	0.00	8%

Figure 4.17. Stock development and diagnostics for runs with alternative weighting assumptions.

- *Base is the base case model*
- *Dome FL1 is a run with a double-normal selection pattern for the main commercial fleet*

Because no direct age data are available, the model has insufficient information to estimate a dome shape as it is strongly confounded with F. Logically, a gillnet fleet would be expected to have a dome-shaped selectivity; however, in this stock, the gillnet fleet appears to have slightly larger selectivity for large fish than the trawl fleet (presumably a spatial artefact or large fish may be strong enough swimmers to escape trawl gear better than smaller fish). Therefore, a double normal selection pattern was fitted to the trawl fleet (which is the dominant fleet). This resulted in a large cryptic biomass which was not considered to be realistic. Therefore, the base case model has a forced flat-topped selectivity for both commercial fleets. This causes some lack of fit but is considered the "least bad" option.

4.1.5.9 Remaining issues

WKANGHAKE considers the current model to be suitable for providing advice. However, there is room for future development:

- Some of the conflicts in the model may be result from regional changes in the stock over time and may be resolved by fitting a model with more than one area.
- The selectivity of the commercial fleets is quite rigid; more flexible options resulted in unrealistic scaling of F and SSB (generally creating large cryptic biomass). Logistic selection was considered the "least bad" option, however it does appear to cause some lack of fit.
- The length composition data dominates the likelihood components. Downscaling did not affect the perception of the stock but may me more appropriate.
- Only two commercial fleets were retained in the final model and one of these was responsible for the vast majority of the catch. One of the issues with having more fleets was the poor quality of the discard data. It may be possible to explore an option with a single discard fleet but multiple landings fleets.
- Growth of females for the first 6 or so years of life could be tracked quite well in the length data by following strong cohorts. However, it is not clear whether growth of females continues at the same rate after maturation (around age 6) because so few mature females are caught. Linked to this, natural mortality of spawning females may be considerable but there is currently no information to inform how high this may be. Spent/recovered females have been caught so the species is not entirely semelparous but the investment in reproduction is considerable and this is likely to have consequences for M at older ages.
- Growth of males could only reliably be tracked up to around age 3 (which is also the age at maturation of males). For the first 3 years the growth of the two sexes is almost identical but the sex ratio-at-length suggests that male growth slows down after this age and/or male natural mortality is higher after this age. More analysis of the sex-ratio information may help improve estimates of male growth and M.

4.2 Reference points

4.2.1 ICES approach to setting reference points

Reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks[6] (Published 1 March 2021). The ICES R package *msy* was used (EqSim approach).

An FLR stock object was created from SS outputs using the R library ss3om. This assessment only has one season but two sexes. EqSim works on a single season, single-sex stock object, therefore the sexes were combined. SSB was calculated from the stock numbers and weights-at-age and the *female* maturity ogive. Note that SS reports SSB in a 2-sex model as the female-only SSB but the reference points were calculated relative to the combined-sex SSB.

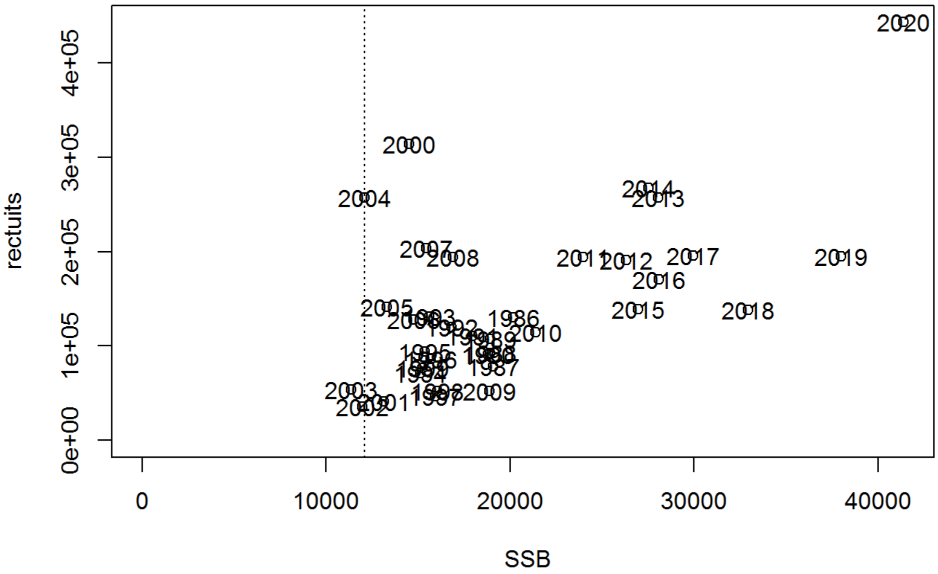
[6] ICES. 2021. ICES fisheries management reference points for category 1 and 2 stocks; Technical Guidelines. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021, Section 16.4.3.1. https://doi.org/10.17895/ices.advice.7891.

F and recruitment in the FLStock object were checked against the SS output (and matched closely).

4.2.1.1 Stock–recruit relationship

In order to be consistent with the SS assessment, the stock–recruit relationship estimated by SS was used for estimating reference points (except for PA reference points which are based on a segmented regression). The values of R_0, B_0 and h were translated to the traditional a and b parameters of the classic Beverton–Holt curve (see Mangel, 2010 for equations). However, in order to be consistent with the combined-sex SSB, the parameter B_0 (which is for females-only in SS output) was converted to a combined-sex B_0 by using the ratio of combined-sex biomass over female-only biomass in the first year of the assessment (which was close to unexploited).

4.2.1.2 Stock type and B_{lim}

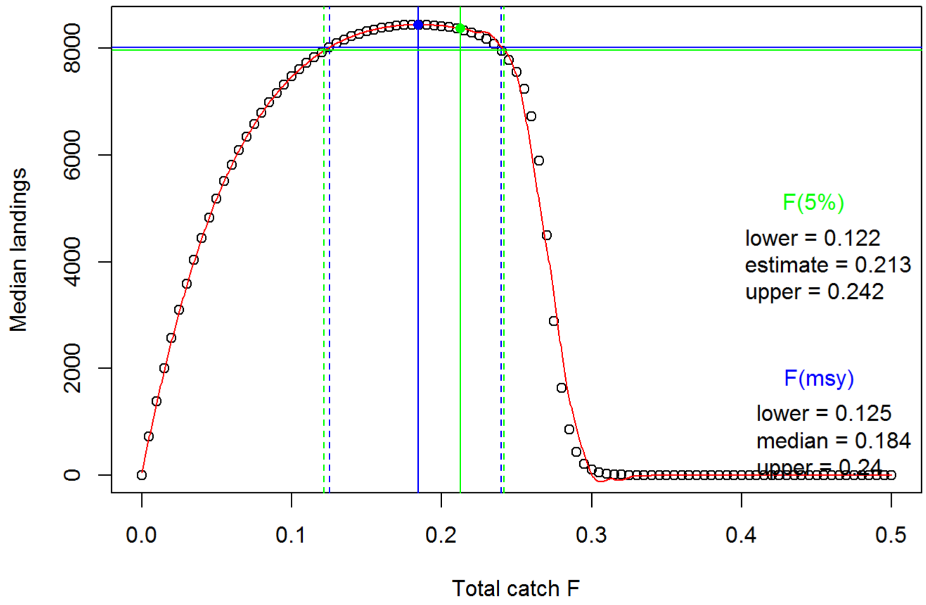


The stock–recruit relationship was examined for the period with length data only (1986 onwards). The stock type was identified as type 1 (spasmodic) or type 5 (no evidence of impaired recruitment). B_{lim} is defined as the lowest SSB with large recruitment (2004) for type 1 and as the lowest observed SSB (2003) for type 5. There was very little difference between the two options and the 2004 SSB was chosen as B_{lim} (12 073 t)

4.2.1.3 PA reference points

B_{pa} is estimated as B_{lim} plus model uncertainty. The estimate of error around SSB in the last year of the model was 0.09. This was considered a possible underestimate as it does not account for uncertainty due to possible misspecification in the model. Therefore the default value of 0.2 was used, resulting in $B_{pa} = B_{lim} * \exp(1.645 * 0.2) = 16\,776$

F_{lim} is estimated by simulating a stock with a segmented regression S–R relationship, with the point of inflection at B_{lim}, thus determining the F which, at equilibrium, yields a 50% probability of SSB > B_{lim}. This simulation is conducted without inclusion of a $B_{trigger}$ and without inclusion of assessment/advice errors.



The segmented regression simulation resulted in a large drop in yield for F values above 0.25. Therefore, F_{lim} was estimated at the relatively low value of 0.254. As this was inconsistent with F_{pa} (estimated later; using the BH SR and resulting in a much flatter yield curve) and because F_{lim} is not used for advice, it was decided leave the F_{lim} reference point undefined.

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

F_{MSY} is initially calculated based on an evaluation with the inclusion of stochasticity in a population and fishery as well as assessment/advice error but without the MSY $B_{trigger}$ advice rule. For this simulation the BH stock–recruit function with fixed B_0 (both sexes); R_0 and h parameters was used. The ICES default settings were used for cvF = 0.212; phiF = 0.423; cvSSB = 0 and phiSSB = 0. This resulted in an initial estimate of F_{MSY} = 0.162.

The final simulation implements the ICES advice rule which should be evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having less than 5% annual probability of SSB < B_{lim} in the long term. The evaluation includes assessment/advice error and stochasticity in population biology and fishery selectivity. $B_{trigger}$ is defined as B_{pa}= 16 776.

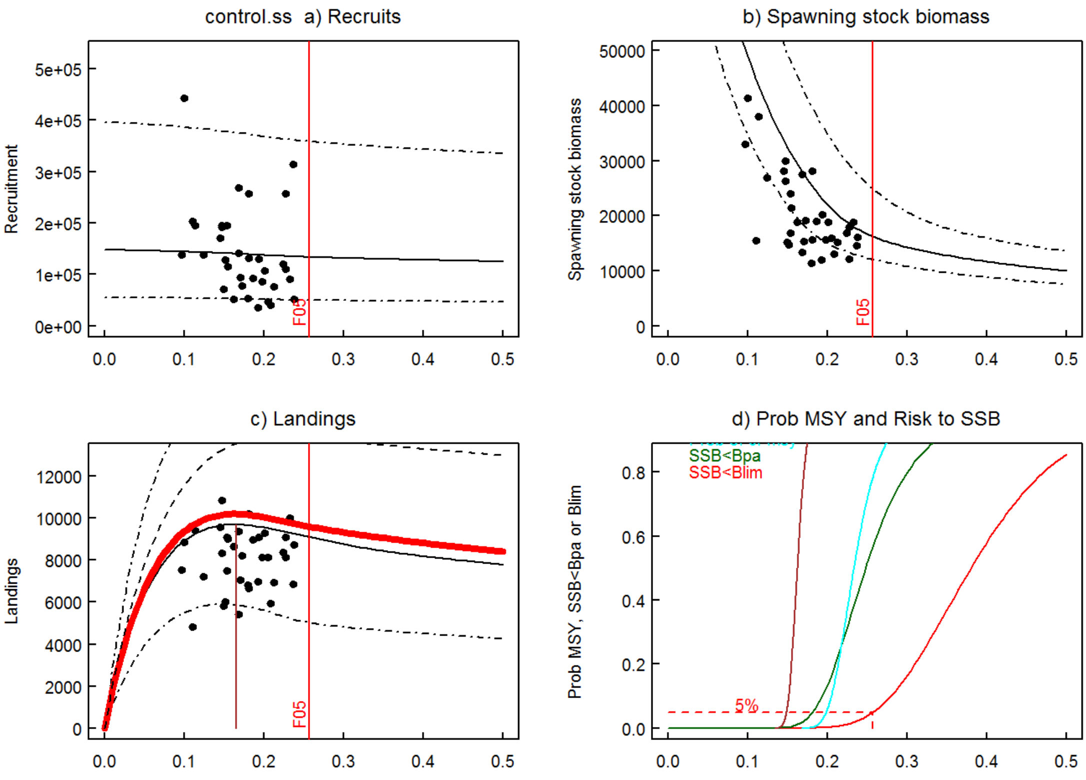


Figure 4.18. The final simulation (fixed Beverton–Holt SR and including advice rule). The x-axis shows F. Recruitment is almost independent of F due to the relatively high steepness assumption (top left). Equilibrium SSB is higher than observed SSB, suggesting that SSB (and yield) will continue to increase at current levels of F (top right). The yield curve (bottom-left) is quite flat-topped and fishing at Fmsy results in low risk of falling below B_{lim} (bottom right). Note that the choice of stock–recruit relationship is influential in these results (i.e. segmented regression indicates a strong reduction in yield at F>0.25)

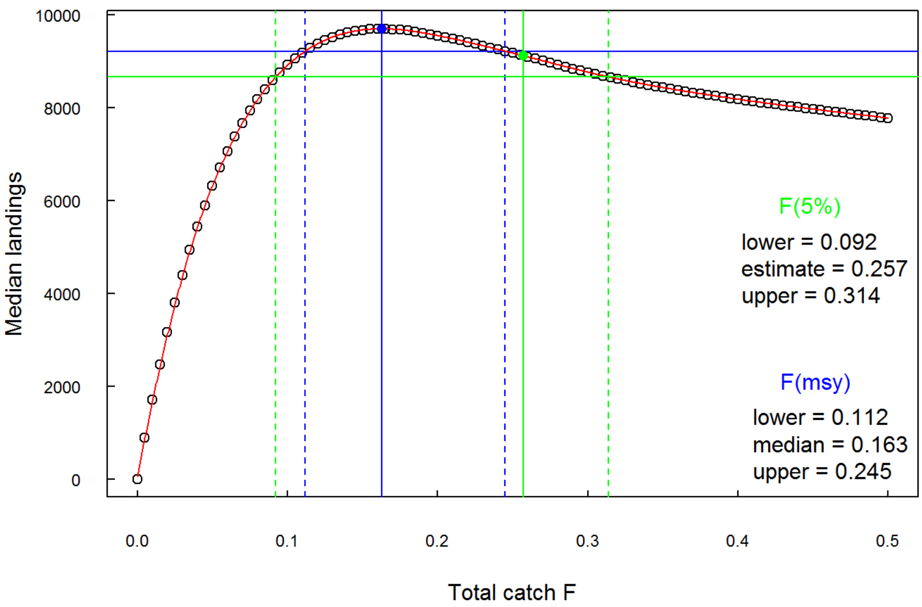


Figure 4.19. Fmsy is estimated at 0.163 in the final simulation with a range of 0.112–0.245. The upper range is below F0.5=F_{pa}=0.257.

The final reference points are as follows:

Reference point	Value	Rationale
B_{lim}	12073	SSB(2004); lowest SSB with high recruitment
B_{pa}	16776	B_{lim} with assessment error
MSY $B_{trigger}$	16776	B_{pa}
F_{lim}	Undefined (0.254)	F with 50% probability of SSB>B_{lim} (segreg without $B_{trigger}$), This is inconsistent with F_{pa} (which was estimated using a different stock–recruit relationship) and therefore F_{pa} will be undefined.
F_{pa}	0.257	F with 95% probability of SSB ≥ B_{lim} (BH with $B_{trigger}$)
F_{msy}	0.163	Stochastic simulations (BH with $B_{trigger}$)
$F_{msyLower}$	0.112	Stochastic simulations (BH with $B_{trigger}$)
$F_{msyUppe}$r	0.245	Stochastic simulations (BH with $B_{trigger}$)
B_{msy5pc}	17902	5% probability of SSB < B_{lim}

4.3 Forecast assumptions

- The following are default forecast options. The working group will review these annually and adapt as necessary:
- Mean weights-at-age, maturity-at-age: These are fixed, so the values from the last year can be used
- Discard proportions-at-age: average last 3 years
- Exploitation pattern: average last 3 years
- F status-quo average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year.
- F in the intermediate year: F status-quo
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship.
- Recruitment in the last data year(s): if the working group believes these are not accurately estimated it can be replaced with the recruitment predicted from Stock Synthesis stock–recruit relationship.

5 Celtic Seas, Bay of Biscay white anglerfish

Lophius piscatorius in Subarea 7 and divisions 8.a–b and 8.d; mon.27.78abd

5.1 Introduction

Here described is the development of the assessment model with the Stock Synthesis model for the northern white anglerfish L*ophius piscatorius* species. The Stock Synthesis assessment model (NOAA Fisheries Toolbox, 2011) is a highly flexible statistical model framework which allows the building of simple to complex models using a mix of data compositions available. The Stock Synthesis assessments were built using SS3 version SS-V3.30.18.00;_safe, the results were read with the r4ss R library version 1.43.0 and some of the diagnostics were analysed with ss3diags R library version 1.3.0 and the R version used 4.0.4.

The previous assessment model of white anglerfish was developed with a4a (ICES 2018) and due to the lack of data by age, then the transformation from length to age was done outside the model. So part of the uncertainty of the results was not consider in the outputs of the assessment. In addition, during the last assessment in 2021 the retrospective pattern of SSB for SSB (0.33) and F (−0.16) were outside the accepted range for long-lived species (ICES 2021).

An initial model was developed at WKTADSA (January 2021) with Stock Synthesis; and after the model was refined and presented in the data workshop for WKANGHAKE (November 2021) with some suggestions for the model development process in the WKANGHAKE benchmark.

The main developments were very similar to the black anglerfish model development since the WKANGHAKE data workshop and these are summarized below:

- Survey sample sizes (number of hauls) were provided.
- Sex-specific survey length data were provided and a sex-disaggregated model was developed.
- The SpGFS -WIBTS-Q3 survey was analysed during the WKTADSA and discussed during the WKANGHAKE data compilation workshop. It was discussed that although the index could not be considered representative of the all area in terms of the smallest fish, due to the lack of consistency compared with the other indices, the index would be included in the model considering the data of all the length distribution that the survey collects.
- Length composition data from the commercial landings were analysed to identify a useful grouping of commercial fleets (WD11). Four fleets were identified: French trawlers, Spanish trawlers, Other trawlers and gillnets.
- Landings data since 1950 were considered to be reasonably reliable, therefore these were included in the model.
- Sample sizes for commercial length composition are reported to in the annual working group reports as well as to InterCatch. Although there were considerable differences between the two sources of data, InterCatch data are used because they seem more reliable.
- Selectivity (dome-shaped vs. logistic) was explored and discussed in much detail. More information on this in section describing alternative runs.
- Biological parameters were fixed to the values agreed at the data workshop.

The base case model is outlined below, the structure of this section follows that of the SS input files. Any settings not described below can be assumed to be the default as indicated in the manual.

5.2 Development of the model

5.2.1 Base case input files

The model was developed based mainly on convergency, stability, plausibility and diagnostics that will be explained more in detail later. Here is described the settings of the model following the input files of SS. Any settings not described below can be assumed to be the default as indicated in the manual.

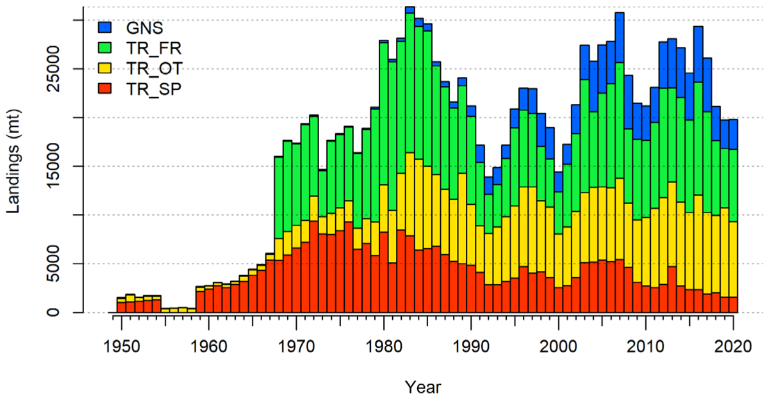
Starter file

- **SSversion**: 3.30
- **F_report_unts**: 5 (unweighted average F for range of ages)
- **F_age_range**: 3–15. The base case has logistic selectivity for the French Trawler FR_TR fleet with full selection from around age 3 onwards so the oldest age is not important; age 15 was chosen as it is not exceedingly rare.

Data file

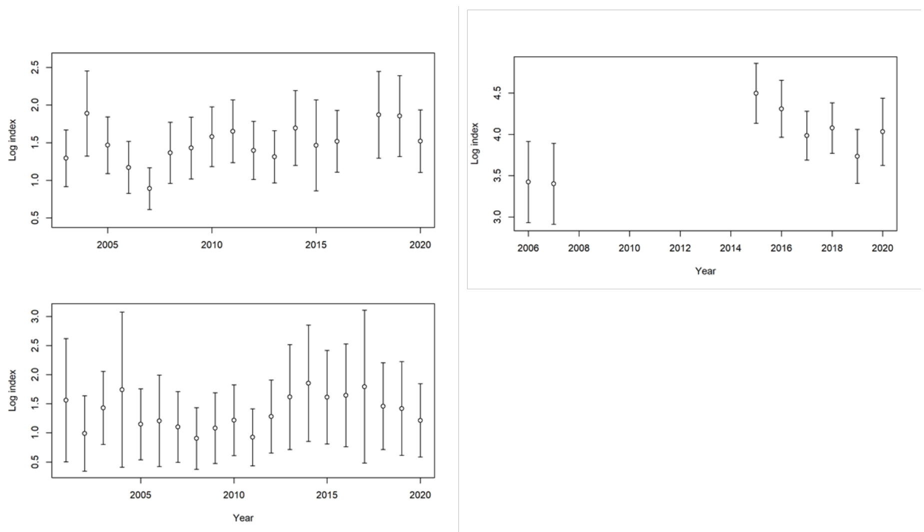
- **styr:** 1950. Reasonably reliable landings data start in this year
- **endyr:** 2020
- **nseas:** 1. quarterly data are available but mainly discards data seem to be collected by year and after divided into season, therefore, data does not show any seasonal pattern.
- **Nsubseasons:** 4. A separate ALK is calculated for each sub-season; this allows appropriate fitting of the length cohorts in surveys that do not take place in the middle of the year.
- **spawn_month:** 1. Following the same assumption as in the growth analysis done for white anglerfish in the WD04 which assumes 1 January as the birth date.
- **Ngenders:** 2. Sexual dimorphism is known to occur; length composition by sex is available for both surveys.
- **Nages:** 30. This seems sufficient, because the model shows a continuous pattern with age and length.
- **N_areas:** 1. Differences between areas are known to exist but a multi-area model was considered too complicated at this stage and remains to be explored.
- **Nfleets:** 4
  - GNS; Gillnets commercial fleet; units: biomass.
  - TR_FR; French trawlers commercial fleet; units: biomass.
  - TR_OTHER; Other trawlers commercial fleet; units: biomass.
  - TR_SP; Spanish trawlers commercial fleet; units: biomass.
  - FR_IE_IBTS; survey; units: numbers. Combined French-Irish IBTS Q4 groundfish surveys
  - IE_MONKSURVEY; survey; units: numbers. Irish Q1 Anglerfish and Megrim Survey
  - SpGFS; survey; units: numbers. Western IBTS Q4 Porcupine Survey.

- **Catch** (note: this is SS terminology but refers to landings only)
  - catch_se for both fleets is 0.2 from 1950 to 1999 and 0.1 from 2000 onwards.
  - The landings previous to 1950 are assumed to be 0 for all the commercial fleets, due to the very low catches at the beginning of the time-series.



Time-series of annual landings (tonnes). TR_FR is by far the dominant fleet the recent years together with TR_OTHERS ; GNS consists of gillnets; landings from this fleet have slowly increased over the last 20 years but still consist a small proportion of the total. TR_SP was the fishery with the highest catches at the beginning of the time-series but the catches are decreasing with time.

- **CPUE**
  The three survey indices are provided as biomass and the error is provided on the lognormal scale. (converted from normal scale using the equation in the SS manual)



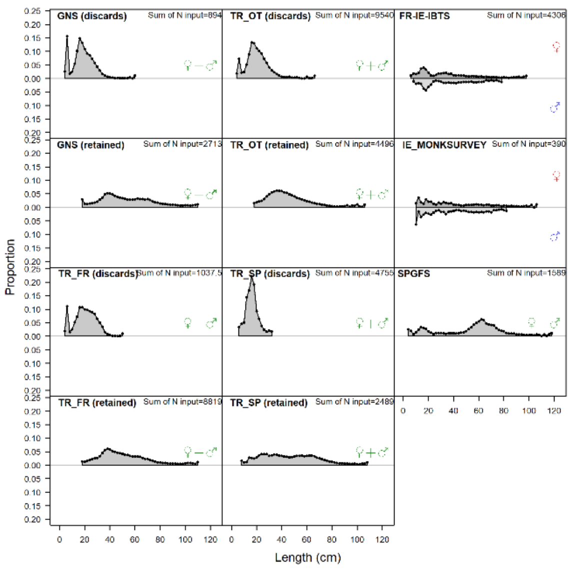
Time-series of the FR_IE_IBTS (fleet 5), the IE_MONKSURVEY (fleet 6), SPGFS (fleet 7).

- **N_discard_fleets**: 4
  - GNS; units: biomass; error type: normal
  - TR_FR; units: biomass; error type: normal
  - TR_OTHERS; units: biomass; error type: normal
  - TR_SP; units: biomass; error type: normal

  - Discards data are available from 2003 to 2020. We assume in the model that discards also happens in the past. A cv of 0.2 is assumed with a normal discard error type.
  - Discards data <100 t for GNS (2018,2019) and TR_FR (2006,2007), discards <350 t (2006,2007,2008) for TR_OT and discards<20 t TR_SP (2015,2017,2018,2019,2020)

were removed since the big jump within the data of each fleet was making difficult to the model to fit discards.

- **Length bins for the population and data**
  - 2 cm length bins from 2 to 130 cm; 10 cm bins from 130–180
- **Length composition data structure**
  - Length data are available for the 4 commercial fleets and 3 survey fleets. Length data for the early years of the IE_MONKSURVEY were not used.
  - Length composition of commercial fleets were available from 1986 for landings of each fleet and from 2003 for discards and aggregated for both sex in both cases.
  - The length data of the IBTS joint index and IE_MONKSURVEY are disaggregated by sex.
  - The time-series of SPGFS survey starts in 2001, of FR-IE-IBTS starts in 2003 and IE_MONKSURVEY in 2007 with no data between 2009 and 2015.
  - IE_MONKSURVEY usually is at the beginning of the year but we assumed that it happens at the end of the previous year, in order to be considered in the assessment of that year.
  - For the commercial fleets the sample sizes were based on number of trips to InterCatch. For the surveys, the sample size is the number of hauls.
  - Bin compression: 0.001; stronger compression does not allow the sex-ratio of the largest fish to be fitted because there are almost no males in those size bins which leads those bins to be compressed.
  - Dirichlet option selected for all four fleets



Overall length composition (all years combined) of landings (retained) and discards for the commercial fleets (GNS,TR_FR,TR_OTHERS,TR_SP) and the surveys (FR_IE_IBTS and IE_MONKSURVEY,SPGFS). The aggregated sample sizes by fleet are also shown in the figures For the commercial fleets the sample sizes were based on the number of trips reported to intercatch. For the surveys, the sample size is the number of hauls.

- **Age data:** No age data are available
- **Environmental data**: None
- **Generalised size comp data**: None
- **Tag-Recapture data:** None

- **Stock (Morph) comp data:** None
- **Selectivity priors:** None

Control file

- **EmpiricalWAA:** 0 (not available)
- **N_GP:** 1 (single growth pattern)
- **N_platoon**: 1 (single platoon)
- **recr_dist_method:** 4 – none, no parameters (growth pattern x settlement x area = 1).
- **recr_dist_pattern:** All recruitment assumed to occur in month 1 at age 0
- **N_Block_Designs:** 1
- **blocks_per_pattern: 1**
- **begin and end years of blocks:** 2007–2021
- **natM_type:** 3 (Age-specific M).
- **natM:** Lorenzen for young ages and flat for ages older than 3 where predation is not the main source of natural mortality. M for older ages based on the FishLife library, taking account of the life history of the stock. See WD06 for more details. There was no basis to assume different M for the two sexes; length-at-age for the young ages (where Lorenzen applies) is almost identical for males and females.

Age 0	Age 1	Age 2	Age 3	Age 4+
1.00	0.57	0.4	0.36	0.36

- **GrowthModel:** 1 (VonB)
- **Growth_Age_for_L1: 1**
- **Growth_Age_for_L2:** 999 ($L2=L_{inf}$)
- **maturity_option:** 1 (length logistic)
- **First_Mature_Age:** 2 (ages below the first mature age will have maturity set to zero.)
- **fecundity_option:** 1 (linear eggs/kg on body weight)
- **MG_params:** Most of the biology parameters are fixed and based on life history information compiled during the WKANGHAKE compilation workshop. The parameters that are estimated the initial value is given is listed below:
    - L_at_Amin_Fem_GP_1 19.2601 (initial value, estimated in phase 2)
    - L_at_Amax_Fem_GP_1 165
    - VonBert_K_Fem_GP_1 0.112
    - CV_young_Fem_GP_1 0.25 (estimated by the model, then fixed)
    - CV_old_Fem_GP_1 0.1 (assumed)
    - Wtlen_1_Fem_GP_1 3.03e-05
    - Wtlen_2_Fem_GP_1 2.82
    - Mat50%_Fem_GP_1 82
    - Mat_slope_Fem_GP_1 -0.1001
    - Eggs/kg_inter_Fem_GP_1 1
    - Eggs/kg_slope_Fem_GP_1 0
    - L_at_Amin_Mal_GP_1 27.5495 (initial value, estimated in phase 2)
    - L_at_Amax_Mal_GP_1 100
    - VonBert_K_Mal_GP_1 0.210458
    - CV_young_Fem_GP_1 0.25 (estimated by the model, then fixed)
    - CV_old_Mal_GP_1 0.1 (assumed)
    - Wtlen_1_Mal_GP_1 3.03e-05
    - Wtlen_2_Mal_GP_1 2.82
    - CohortGrowDev 1
    - FracFemale_GP_1 0.5
- **SR_function:** 3 (Beverton-holt)

- **SR_params:** all fixed except R0
  - SR_LN(R0) 11.6155 (initial value,estimated in phase 1)
  - SR_BH_steep 0.92
  - SR_sigmaR 0.6
  - SR_regime 0
  - SR_autocorr 0
- **do_recdev:** 1
- **MainRdevYrFirst:** 1986 (first data year)
- **MainRdevYrLast:** 2020 (there is information from the surveys and discards to inform Rdev)
- **Recdev_phase:** 3
- **To read 13 advanced options:** 1
- **recdev_early_start (0=none; neg value makes relative to recdev_start):** -6
- **recdev_early_phase:** 4
- **forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1):** 0
- **lambda for Fcast_recr_like occurring before endyr+1:** 1
- **last_early_yr_nobias_adj:** 1976.5 (suggested by r4ss)
- **first_yr_fullbias_adj:** 1986.3 (suggested by r4ss)
- **last_yr_fullbias_adj:** 2020 (suggested by r4ss)
- **first_recent_yr_nobias_adj:** 2020.4 (suggested by r4ss)
- **max_bias_adj:** 0.9591 (suggested by r4ss)
- **F_Method:** 4 Fleet-specific parameter/hybrid F (recommended).
- **F_4_Fleet_Params:**
  - GNS: start F 0.5; phase 1
  - TR_FR: start F 0.5; phase 1
  - TR_OTHER: start F 0.5; phase 1
  - TR_SP: start F 0.5; phase 1

- **Init_F**: there was some fishing before 1950; however, the model estimated initial F to be very low,and therefore it was assumed the catches to be equal to 0 previous to 1950.
- **Q_options:**
  - IBTS: link 1 (simple Q); extra se 1; no bias adj; float
  - MONK: link 1 (simple Q); no extra se; no bias adj; float
  - SPGFS: link 1 (simple Q); no extra se; no bias adj; float
- **Q_options:**
  - LnQ_base_FR-IE-IBTS(5): -10.0485
  - Q_extraSD_FR-IE-IBTS(5): 0.0769716 (initial values,estimated phase 4)
  - LnQ_base_IE_MONKSURVEY(6): -7.63264
  - LnQ_base_SPGFS(7): -9.99782
- **size_selex_types:**
  - GNS: Pattern 27 (spline 3 knots);
    - Retention curve
  - TR_FR: Pattern 24 (double normal with logistic shape)
    - the peak parameter initial value 25.4259, prior in 25.4259, with normal distribution with sd=1 and estimated in phase5.
    - Retention curve (with time-varying Retain_L_infl from 2003 to 2020, estimated in phase 7)
  - TR_OTHERS: Pattern 27 (spline 3 knots);
    - discards (with time-varying Retain_L_infl from 2003 to 2020, estimated in phase 7)
  - TR_SP: Pattern 27 (spline 3 knots);

        - Time block in the first value of the spline.
        - Retention curve.
    - FR_IE_IBTS: Pattern 24 (double normal);
    - MONK: Pattern 1 (logistic);
    - SPGFS: Pattern 24 (double normal with logistic shape)
- **age_selex_types:** - None
- **size_selex_para:**
    - Main para estimated in phase 5, others in phase 3
    - Retention para estimated in phase 5 and 6; random walk on retention inflection parameter from 2005–2020 due to the gradual adoption of minimum market weight.
- **dirichlet_params:**
    - Estimates in phase 8 for TR_OTHERS, TR_SP, FR-IE-IBTS, MONK. For the others the value were close to 5 and hitting the boundary so those parameters were removed.
- **size_selex_params_tv**:
    - time varying retention size at inflection for TR_FR and TR_OTHERS
        - dev_se fixed at 0.5
        - auocorr fixed at 0
    - time block in the value 1 of TR_SP: -2.53223 (initial value, estimated in phase 7)
- **Use_2D_AR1_selectivity:** 0
- **TG_custom:** 0
- **DoVar_adjust:** 1
- **maxlambdaphase:** 1
- **sd_offset:** 1
- **N_lambdas:** 0

Phases

The phases were set according to the following rule-of-thumb:

- Phase 1: R0 and Ms
- Phase 2: biology (+ time varying bio parameters or next phase)
- Phase 3: main recdev
- Phase 4: early recdev
- Phase 5: Main sel para and q (when estimated, not in this cases as we are using floats)
- Phase 6: Other sel para
- Phase 7: time varying para in sel
- Last phase: Dirichlet parameters

5.2.2 Biology: sources and explanations for the parameterization

5.2.2.1 Growth

The model keeps sexes separate due to differences in growth. Following the WD04 by Gerritsen. We assume von Bertalanffy growth follows:

- Kfem=0.112
- L_{inf}Fem=165
- L_{inf}Mal=100

We let the model estimate KMal, because in the WD04 explained that it was difficult to estimate with the data available.

The model assumes linear growh until age 1 and we let the model to estimate for both male and females internally so all the sources of data are used to estimate them.

We assume the cv of growth for young fish 0.25 and for adults 0.1. In previous versions the model estimated a value of 0.25, this could be because the spawning happens the all year. However, for adults we assume that is close to 0.1, because for adults it's difficult to estimate the cv.

5.2.2.2 Length-weight

The same values as in the a4a model: a = 3.03e-05 and b = 0.82 based on Gerritsen's analysis (ICES 2018)

5.2.2.3 Maturity

50% of maturity is assumed in 82 cm considering that the maturity size increases with latitude we took the middle point for the area WD05 by Gerritsen. The slope we assumed -0.1001, the same as in the previous assessment model estimated by Quincoces (2002).

5.2.2.4 Natural mortality

The natural mortality curve was estimated following the Lorenzen curve outside the model until age 3 and afterwards constant with a value of 0.36 based on FishLife (Thorson 2009), assuming that the natural mortality does not change after the fish is matured. The same mortality is assumed for male and females, so we assumed that although the growth is different for male and females there is no reason to have different natural mortality. Thus, $M_{age=0} = 1$, $M_{age=1} = 0.57$, $M_{age=2} = 0.4$, $M_{age>=3} = 0.36$.

5.2.2.5 Recruitment

Although the northern white anglerfish spawns year it peaks in the second season Quincoces *et al*. (2002). However, we assume that spawning only happens once at the beginning of the year following the WD04.

Beverton and Holt relationship is assumed for recruitment with a steepness 0.92 based on FisLife library (Thorson 2009) and sigmaR = 0.6.

The main recruitment deviates start in 1986, the same year as the beginning of the length composition data. The recruitment deviation biased was corrected following the suggestions of SS3.

5.2.3 Selectivity: sources and explanations for the parameterization

In previous versions of the model the logistic shape for all the commercial fleets, however, there were some strong residual pattern that were improved by assuming the splines with 3 knots. However, the residual pattern of TR_FR was not improved and the shape with the spline was close to be logistic, therefore, for simplicity and to avoid creating cryptic biomass the logistic shape was assumed. Also explained in the results section.

A prior for the peak parameter for the TR_FR fleet was assumed due to some convergency issues found during the jittering. The model showed two different convergency points with a local minimum and a global minimum but with very small difference in LL, 13 units of difference. In the local minimum the model converge towards a high selectivity for the small fish similar to what the first peak of the other commercial fleets. The global minimum suggests that the peak in selectivity for the TR_FR happens at larger size of fish. In the local minimum the landings of TR_FR were slightly underestimated while in the global minimum the discards. It was decided that it is inconsistent to think that the selectivity on the smallest fish is different for the TR_FR compared with the other fleets. Therefore, it was assumed that the convergency should be in the local minimum and therefore a prior was assumed with a narrow s.d. of 1 m, in order to avoid the model converge in the other option.

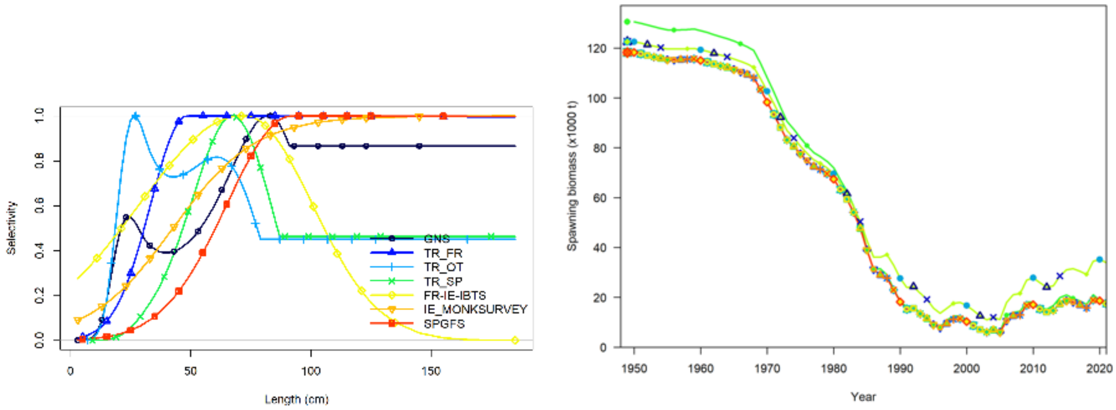


Figure 5.1. Shows the jittering of the model without assuming the prior. The trend going upward is the local minimum with TR_FR peak parameter. This figures can be compared with the base case results in Figure 5.3 and Figure 5.14.

5.2.4 Fishing mortality: sources and explanations for the parameterization

The model assumes there is not fishing in this species before 1950s because the catches are very low.

Fishing mortality is estimated with F method 4 (a hybrid between method 2 and 3), because it's the most appropriate method when F is high.

5.2.5 Re-weighting: sources and explanations for the parameterization

The length composition are reweighted based on the Dirichlet method. The advantage of this method is that the parameters are estimated within the model and therefore, the all uncertainty is considered when the parameters of reweighting the length composition are estimated (Thorson *et al*., 2017). In addition, it does not need to estimate the parameters in an iterative way.

5.3 Results

Below we show the parameter values by the model. The estimated parameter values do not show any convergency issue. The estimated reweighting parameters with the Dirichlet method for fleets GNS and TR_FR are very close to 1, therefore those parameters were removed from the model because in addition they were hitting the boundary.

Table 5.1. The estimated values by the model.

Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
L_at_Amin_Fem_GP_1	19.2601	2	10	30	19.2601	OK	0.220699	4.47E-06	No_prior	NA	NA	NA	OK
L_at_Amin_Mal_GP_1	27.5495	2	10	30	27.5495	OK	0.181562	1.05E-05	No_prior	NA	NA	NA	OK
VonBert_K_Mal_GP_1	0.210451	2	0.05	0.3	0.210458	OK	0.0057952	1.24E-05	No_prior	NA	NA	NA	OK
SR_LN(R0)	11.6151	1	1.5	30	11.6155	OK	0.0351193	7.34E-05	No_prior	NA	NA	NA	OK
F_fleet_1_YR_1950_s_1	0.0002642	1	0	2	0.5	act	0.0000593	0.000178 399	F	NA	NA	NA	CHECK
F_fleet_1_YR_1951_s_1	0.0004596	1	0	2	0.5	act	0.0001032	−4.48E-06	F	NA	NA	NA	CHECK
F_fleet_1_YR_1952_s_1	0.0002606	1	0	2	0.5	act	0.0000585	0.000288 451	F	NA	NA	NA	CHECK
F_fleet_1_YR_1953_s_1	0.0003094	1	0	2	0.5	act	0.0000695	−5.19E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1954_s_1	0.0002626	1	0	2	0.5	act	0.000059	3.49E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1955_s_1	0.0002435	1	0	2	0.5	act	0.0000547	−6.53E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1956_s_1	0.0002326	1	0	2	0.5	act	0.0000522	−6.46E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1957_s_1	0.0002048	1	0	2	0.5	act	0.000046	−5.34E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1958_s_1	0.0001937	1	0	2	0.5	act	0.0000435	2.11E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1959_s_1	0.0001928	1	0	2	0.5	act	0.0000433	−3.33E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1960_s_1	0.0001357	1	0	2	0.5	act	0.0000305	1.07E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1961_s_1	0.0001399	1	0	2	0.5	act	0.0000314	0.000118 404	F	NA	NA	NA	CHECK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_1_YR_1962_s_1	0.0001509	1	0	2	0.5	act	0.0000339	1.81E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1963_s_1	0.0001656	1	0	2	0.5	act	0.0000372	-1.54E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1964_s_1	0.0002212	1	0	2	0.5	act	0.0000497	3.51E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1965_s_1	0.0002153	1	0	2	0.5	act	0.0000484	1.52E-06	F	NA	NA	NA	CHECK
F_fleet_1_YR_1966_s_1	0.0002587	1	0	2	0.5	act	0.0000582	2.00E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1967_s_1	0.0003384	1	0	2	0.5	act	0.0000761	-7.72E-06	F	NA	NA	NA	CHECK
F_fleet_1_YR_1968_s_1	0.0003552	1	0	2	0.5	act	0.0000799	0.000198 923	F	NA	NA	NA	CHECK
F_fleet_1_YR_1969_s_1	0.0004035	1	0	2	0.5	act	0.0000909	1.08E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1970_s_1	0.0003668	1	0	2	0.5	act	0.0000828	-9.21E-06	F	NA	NA	NA	CHECK
F_fleet_1_YR_1971_s_1	0.0004264	1	0	2	0.5	act	0.0000964	0.000158 289	F	NA	NA	NA	CHECK
F_fleet_1_YR_1972_s_1	0.0005037	1	0	2	0.5	act	0.0001142	-2.39E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1973_s_1	0.0005232	1	0	2	0.5	act	0.0001188	5.73E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1974_s_1	0.0004238	1	0	2	0.5	act	0.0000963	-1.20E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1975_s_1	0.0004786	1	0	2	0.5	act	0.0001088	1.04E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1976_s_1	0.00054	1	0	2	0.5	act	0.000123	2.82E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1977_s_1	0.0004862	1	0	2	0.5	act	0.0001108	-1.53E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1978_s_1	0.0005913	1	0	2	0.5	act	0.0001349	-8.33E-05	F	NA	NA	NA	CHECK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_1_YR_1979_s_1	0.0008105	1	0	2	0.5	act	0.0001852	1.17E-05	F	NA	NA	NA	CHECK
F_fleet_1_YR_1980_s_1	0.001242	1	0	2	0.5	act	0.0002848	4.00E-08	F	NA	NA	NA	OK
F_fleet_1_YR_1981_s_1	0.0017736	1	0	2	0.5	act	0.0004091	5.71E-05	F	NA	NA	NA	OK
F_fleet_1_YR_1982_s_1	0.0021595	1	0	2	0.5	act	0.0005035	-6.93E-05	F	NA	NA	NA	OK
F_fleet_1_YR_1983_s_1	0.0048924	1	0	2	0.5	act	0.0011483	6.27E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1984_s_1	0.0062668	1	0	2	0.5	act	0.0014723	6.29E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1985_s_1	0.0057169	1	0	2	0.5	act	0.0013394	1.44E-05	F	NA	NA	NA	OK
F_fleet_1_YR_1986_s_1	0.0038508	1	0	2	0.5	act	0.0008999	5.73E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1987_s_1	0.005709	1	0	2	0.5	act	0.0013392	9.70E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1988_s_1	0.0071736	1	0	2	0.5	act	0.0016874	6.05E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1989_s_1	0.0093477	1	0	2	0.5	act	0.0021972	5.21E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1990_s_1	0.0133969	1	0	2	0.5	act	0.0031538	5.25E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1991_s_1	0.0267217	1	0	2	0.5	act	0.0063423	1.48E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1992_s_1	0.0318929	1	0	2	0.5	act	0.0076786	1.37E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1993_s_1	0.0329724	1	0	2	0.5	act	0.0079286	-2.82E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1994_s_1	0.0237592	1	0	2	0.5	act	0.0056305	-4.14E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1995_s_1	0.0288574	1	0	2	0.5	act	0.0067237	-2.59E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1996_s_1	0.0314102	1	0	2	0.5	act	0.0072492	-5.36E-07	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_1_YR_1997_s_1	0.0371355	1	0	2	0.5	act	0.00855	4.97E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1998_s_1	0.0567951	1	0	2	0.5	act	0.0130684	-3.27E-06	F	NA	NA	NA	OK
F_fleet_1_YR_1999_s_1	0.0635069	1	0	2	0.5	act	0.0147698	1.38E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2000_s_1	0.0431513	1	0	2	0.5	act	0.0059419	6.51E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2001_s_1	0.0430606	1	0	2	0.5	act	0.0059184	6.73E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2002_s_1	0.0546236	1	0	2	0.5	act	0.0072114	5.24E-07	F	NA	NA	NA	OK
F_fleet_1_YR_2003_s_1	0.053244	1	0	2	0.5	act	0.0058579	-1.56E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2004_s_1	0.0683523	1	0	2	0.5	act	0.0085662	-4.43E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2005_s_1	0.0570629	1	0	2	0.5	act	0.0062746	1.22E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2006_s_1	0.0450262	1	0	2	0.5	act	0.0056659	1.54E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2007_s_1	0.0525766	1	0	2	0.5	act	0.0066384	-4.35E-07	F	NA	NA	NA	OK
F_fleet_1_YR_2008_s_1	0.0608727	1	0	2	0.5	act	0.0071327	7.14E-07	F	NA	NA	NA	OK
F_fleet_1_YR_2009_s_1	0.0444531	1	0	2	0.5	act	0.0051265	4.27E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2010_s_1	0.0407818	1	0	2	0.5	act	0.0047132	3.48E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2011_s_1	0.0371864	1	0	2	0.5	act	0.0042631	5.62E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2012_s_1	0.044565	1	0	2	0.5	act	0.0052978	-2.56E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2013_s_1	0.0464855	1	0	2	0.5	act	0.0060474	-2.71E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2014_s_1	0.0484698	1	0	2	0.5	act	0.0059425	-2.48E-07	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_1_YR_2015_s_1	0.0454803	1	0	2	0.5	act	0.0061852	1.78E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2016_s_1	0.0519719	1	0	2	0.5	act	0.0074683	5.81E-06	F	NA	NA	NA	OK
F_fleet_1_YR_2017_s_1	0.0498133	1	0	2	0.5	act	0.0075992	5.56E-07	F	NA	NA	NA	OK
F_fleet_1_YR_2018_s_1	0.0333108	1	0	2	0.5	act	0.0053931	1.52E-05	F	NA	NA	NA	OK
F_fleet_1_YR_2019_s_1	0.0291186	1	0	2	0.5	act	0.0050747	1.09E-05	F	NA	NA	NA	OK
F_fleet_1_YR_2020_s_1	0.0311469	1	0	2	0.5	act	0.0058392	-3.51E-05	F	NA	NA	NA	OK
F_fleet_2_YR_1951_s_1	0.0000009	1	0	2	0.5	act	0.0000002	0.00167757	F	NA	NA	NA	CHECK
F_fleet_2_YR_1958_s_1	0.0000027	1	0	2	0.5	act	0.0000006	0.0013189	F	NA	NA	NA	CHECK
F_fleet_2_YR_1960_s_1	0.0000018	1	0	2	0.5	act	0.0000004	-0.000280534	F	NA	NA	NA	CHECK
F_fleet_2_YR_1961_s_1	0.0000028	1	0	2	0.5	act	0.0000006	-0.00118922	F	NA	NA	NA	CHECK
F_fleet_2_YR_1962_s_1	0.0000028	1	0	2	0.5	act	0.0000006	-1.46E-05	F	NA	NA	NA	CHECK
F_fleet_2_YR_1964_s_1	0.0000028	1	0	2	0.5	act	0.0000006	-0.000710045	F	NA	NA	NA	CHECK
F_fleet_2_YR_1966_s_1	0.0000028	1	0	2	0.5	act	0.0000006	-0.000101516	F	NA	NA	NA	CHECK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_2_YR_1967_s_1	0.0000029	1	0	2	0.5	act	0.0000006	0.000273393	F	NA	NA	NA	CHECK
F_fleet_2_YR_1968_s_1	0.025871	1	0	2	0.5	act	0.0058449	-3.96E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1969_s_1	0.0299762	1	0	2	0.5	act	0.006799	1.06E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1970_s_1	0.0282624	1	0	2	0.5	act	0.0064177	4.74E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1971_s_1	0.0345189	1	0	2	0.5	act	0.0078821	-3.61E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1972_s_1	0.030182	1	0	2	0.5	act	0.0068935	-8.53E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1973_s_1	0.0178188	1	0	2	0.5	act	0.0040498	-1.44E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1974_s_1	0.0288003	1	0	2	0.5	act	0.0065961	8.04E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1975_s_1	0.0297854	1	0	2	0.5	act	0.0068385	-5.27E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1976_s_1	0.0305642	1	0	2	0.5	act	0.0070353	-2.89E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1977_s_1	0.0315551	1	0	2	0.5	act	0.0072816	-7.52E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1978_s_1	0.0381492	1	0	2	0.5	act	0.0088576	-5.49E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1979_s_1	0.0492911	1	0	2	0.5	act	0.0115603	-2.69E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1980_s_1	0.0645566	1	0	2	0.5	act	0.0153517	-9.27E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1981_s_1	0.0736783	1	0	2	0.5	act	0.0176733	-2.44E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1982_s_1	0.0734681	1	0	2	0.5	act	0.0177167	-6.59E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1983_s_1	0.0827341	1	0	2	0.5	act	0.0195558	-1.75E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1984_s_1	0.0795863	1	0	2	0.5	act	0.0183255	-1.64E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_2_YR_1985_s_1	0.0869867	1	0	2	0.5	act	0.0198816	-1.42E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1986_s_1	0.0781066	1	0	2	0.5	act	0.0178598	-1.49E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1987_s_1	0.0835089	1	0	2	0.5	act	0.0191144	-1.03E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1988_s_1	0.0765837	1	0	2	0.5	act	0.0174333	2.32E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1989_s_1	0.0795667	1	0	2	0.5	act	0.0180728	5.17E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1990_s_1	0.0906724	1	0	2	0.5	act	0.0205784	1.51E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1991_s_1	0.0769538	1	0	2	0.5	act	0.0178825	-7.77E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1992_s_1	0.0555732	1	0	2	0.5	act	0.0131904	2.62E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1993_s_1	0.0576282	1	0	2	0.5	act	0.0134515	-9.00E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1994_s_1	0.0694234	1	0	2	0.5	act	0.0158141	-2.69E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1995_s_1	0.0848278	1	0	2	0.5	act	0.0189074	-4.86E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1996_s_1	0.0810721	1	0	2	0.5	act	0.0179518	-8.61E-08	F	NA	NA	NA	OK
F_fleet_2_YR_1997_s_1	0.0842746	1	0	2	0.5	act	0.0187617	-4.20E-06	F	NA	NA	NA	OK
F_fleet_2_YR_1998_s_1	0.0720228	1	0	2	0.5	act	0.0162223	7.94E-07	F	NA	NA	NA	OK
F_fleet_2_YR_1999_s_1	0.0749785	1	0	2	0.5	act	0.0170872	-9.93E-07	F	NA	NA	NA	OK
F_fleet_2_YR_2000_s_1	0.0649087	1	0	2	0.5	act	0.0084575	-1.05E-07	F	NA	NA	NA	OK
F_fleet_2_YR_2001_s_1	0.100047	1	0	2	0.5	act	0.0129989	1.85E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2002_s_1	0.094921	1	0	2	0.5	act	0.0115912	-4.62E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_2_YR_2003_s_1	0.117317	1	0	2	0.5	act	0.0136914	-8.56E-09	F	NA	NA	NA	OK
F_fleet_2_YR_2004_s_1	0.0739255	1	0	2	0.5	act	0.0068525	-1.06E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2005_s_1	0.0795735	1	0	2	0.5	act	0.0082968	-1.08E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2006_s_1	0.0814272	1	0	2	0.5	act	0.0096879	-2.45E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2007_s_1	0.0943339	1	0	2	0.5	act	0.011185	-1.35E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2008_s_1	0.0674371	1	0	2	0.5	act	0.0066521	1.31E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2009_s_1	0.076879	1	0	2	0.5	act	0.0086778	-1.34E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2010_s_1	0.0684544	1	0	2	0.5	act	0.0076304	6.17E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2011_s_1	0.0676174	1	0	2	0.5	act	0.0071173	-1.04E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2012_s_1	0.0807286	1	0	2	0.5	act	0.0087678	5.94E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2013_s_1	0.0698965	1	0	2	0.5	act	0.0071747	2.76E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2014_s_1	0.0806213	1	0	2	0.5	act	0.0092774	8.04E-08	F	NA	NA	NA	OK
F_fleet_2_YR_2015_s_1	0.0685052	1	0	2	0.5	act	0.0074942	1.82E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2016_s_1	0.0801931	1	0	2	0.5	act	0.0099745	4.70E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2017_s_1	0.0732656	1	0	2	0.5	act	0.0098515	3.49E-06	F	NA	NA	NA	OK
F_fleet_2_YR_2018_s_1	0.0579254	1	0	2	0.5	act	0.0081892	1.16E-05	F	NA	NA	NA	OK
F_fleet_2_YR_2019_s_1	0.0481915	1	0	2	0.5	act	0.0073865	-1.13E-05	F	NA	NA	NA	OK
F_fleet_2_YR_2020_s_1	0.0589321	1	0	2	0.5	act	0.0102998	4.18E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_3_YR_1950_s_1	0.0026016	1	0	2	0.5	act	0.0005961	-1.65E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1951_s_1	0.0043752	1	0	2	0.5	act	0.0010029	-4.30E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1952_s_1	0.0023805	1	0	2	0.5	act	0.0005455	-1.71E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1953_s_1	0.0027387	1	0	2	0.5	act	0.0006276	2.02E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1954_s_1	0.0022981	1	0	2	0.5	act	0.0005266	-1.06E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1955_s_1	0.0024363	1	0	2	0.5	act	0.0005583	-4.25E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1956_s_1	0.0026979	1	0	2	0.5	act	0.0006183	1.56E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1957_s_1	0.0028866	1	0	2	0.5	act	0.0006616	-4.29E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1958_s_1	0.0025185	1	0	2	0.5	act	0.0005772	-1.01E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1959_s_1	0.0026496	1	0	2	0.5	act	0.0006072	2.61E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1960_s_1	0.0021617	1	0	2	0.5	act	0.0004954	6.08E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1961_s_1	0.0020485	1	0	2	0.5	act	0.0004695	-4.08E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1962_s_1	0.0021013	1	0	2	0.5	act	0.0004816	-1.47E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1963_s_1	0.0019952	1	0	2	0.5	act	0.0004573	6.89E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1964_s_1	0.0036007	1	0	2	0.5	act	0.0008256	-3.31E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1965_s_1	0.0037325	1	0	2	0.5	act	0.000856	2.55E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1966_s_1	0.0034601	1	0	2	0.5	act	0.0007935	6.39E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1967_s_1	0.003978	1	0	2	0.5	act	0.0009125	-1.41E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_3_YR_1968_s_1	0.0150109	1	0	2	0.5	act	0.0034556	-6.07E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1969_s_1	0.0171336	1	0	2	0.5	act	0.0039512	5.90E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1970_s_1	0.0169283	1	0	2	0.5	act	0.0039086	-7.09E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1971_s_1	0.0172415	1	0	2	0.5	act	0.0039862	-7.88E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1972_s_1	0.0201119	1	0	2	0.5	act	0.0046607	1.76E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1973_s_1	0.0144246	1	0	2	0.5	act	0.0033403	-7.98E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1974_s_1	0.0173344	1	0	2	0.5	act	0.00402	4.32E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1975_s_1	0.0193205	1	0	2	0.5	act	0.004488	-1.21E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1976_s_1	0.018356	1	0	2	0.5	act	0.0042674	-6.31E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1977_s_1	0.0185878	1	0	2	0.5	act	0.004326	-4.02E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1978_s_1	0.0219745	1	0	2	0.5	act	0.0051254	-1.23E-05	F	NA	NA	NA	OK
F_fleet_3_YR_1979_s_1	0.0305243	1	0	2	0.5	act	0.0071554	-1.71E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1980_s_1	0.044453	1	0	2	0.5	act	0.0105081	-2.68E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1981_s_1	0.0545338	1	0	2	0.5	act	0.0130108	-5.21E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1982_s_1	0.0679993	1	0	2	0.5	act	0.0165541	-1.08E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1983_s_1	0.101729	1	0	2	0.5	act	0.0244573	4.79E-07	F	NA	NA	NA	OK
F_fleet_3_YR_1984_s_1	0.105094	1	0	2	0.5	act	0.0244195	-1.60E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1985_s_1	0.101608	1	0	2	0.5	act	0.0235083	-1.09E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_3_YR_1986_s_1	0.104976	1	0	2	0.5	act	0.0243136	−1.39E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1987_s_1	0.111408	1	0	2	0.5	act	0.0257839	−6.10E-07	F	NA	NA	NA	OK
F_fleet_3_YR_1988_s_1	0.104567	1	0	2	0.5	act	0.0237803	−4.67E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1989_s_1	0.161192	1	0	2	0.5	act	0.0358408	−3.81E-07	F	NA	NA	NA	OK
F_fleet_3_YR_1990_s_1	0.124796	1	0	2	0.5	act	0.0284599	−1.03E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1991_s_1	0.120546	1	0	2	0.5	act	0.0282661	−1.50E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1992_s_1	0.154506	1	0	2	0.5	act	0.0363374	−4.03E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1993_s_1	0.151546	1	0	2	0.5	act	0.0343926	−2.37E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1994_s_1	0.137095	1	0	2	0.5	act	0.0308237	−2.73E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1995_s_1	0.135076	1	0	2	0.5	act	0.0300804	−4.49E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1996_s_1	0.14891	1	0	2	0.5	act	0.0328506	−3.91E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1997_s_1	0.186746	1	0	2	0.5	act	0.0412336	−5.99E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1998_s_1	0.186325	1	0	2	0.5	act	0.0412374	−4.29E-06	F	NA	NA	NA	OK
F_fleet_3_YR_1999_s_1	0.220273	1	0	2	0.5	act	0.0488438	−2.53E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2000_s_1	0.155102	1	0	2	0.5	act	0.02031	−5.20E-08	F	NA	NA	NA	OK
F_fleet_3_YR_2001_s_1	0.170355	1	0	2	0.5	act	0.0227333	1.64E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2002_s_1	0.135245	1	0	2	0.5	act	0.0170927	−1.17E-05	F	NA	NA	NA	OK
F_fleet_3_YR_2003_s_1	0.117163	1	0	2	0.5	act	0.0142617	−6.21E-07	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_3_YR_2004_s_1	0.122841	1	0	2	0.5	act	0.0149548	1.40E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2005_s_1	0.104103	1	0	2	0.5	act	0.0124948	−1.10E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2006_s_1	0.0995073	1	0	2	0.5	act	0.0123596	−8.97E-07	F	NA	NA	NA	OK
F_fleet_3_YR_2007_s_1	0.121144	1	0	2	0.5	act	0.0151623	−7.98E-07	F	NA	NA	NA	OK
F_fleet_3_YR_2008_s_1	0.11362	1	0	2	0.5	act	0.0145021	−4.88E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2009_s_1	0.11363	1	0	2	0.5	act	0.0140623	−2.52E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2010_s_1	0.106242	1	0	2	0.5	act	0.0114284	2.87E-07	F	NA	NA	NA	OK
F_fleet_3_YR_2011_s_1	0.105968	1	0	2	0.5	act	0.0121686	−2.18E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2012_s_1	0.11446	1	0	2	0.5	act	0.0145268	−4.01E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2013_s_1	0.116389	1	0	2	0.5	act	0.0138091	5.40E-08	F	NA	NA	NA	OK
F_fleet_3_YR_2014_s_1	0.124818	1	0	2	0.5	act	0.0148839	−8.09E-07	F	NA	NA	NA	OK
F_fleet_3_YR_2015_s_1	0.107836	1	0	2	0.5	act	0.0127014	−1.13E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2016_s_1	0.123747	1	0	2	0.5	act	0.0176463	−1.30E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2017_s_1	0.111665	1	0	2	0.5	act	0.0171411	−1.02E-05	F	NA	NA	NA	OK
F_fleet_3_YR_2018_s_1	0.119579	1	0	2	0.5	act	0.0193899	8.80E-06	F	NA	NA	NA	OK
F_fleet_3_YR_2019_s_1	0.14343	1	0	2	0.5	act	0.0240907	−2.29E-05	F	NA	NA	NA	OK
F_fleet_3_YR_2020_s_1	0.119582	1	0	2	0.5	act	0.0217864	1.62E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1950_s_1	0.0047457	1	0	2	0.5	act	0.0010777	−1.56E-05	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_4_YR_1951_s_1	0.0049099	1	0	2	0.5	act	0.0011152	−9.32E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1952_s_1	0.0052775	1	0	2	0.5	act	0.0011989	−2.25E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1953_s_1	0.0056862	1	0	2	0.5	act	0.001292	−2.87E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1954_s_1	0.0060999	1	0	2	0.5	act	0.0013862	1.36E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1958_s_1	0.000003	1	0	2	0.5	act	0.0000007	0.000382249	F	NA	NA	NA	CHECK
F_fleet_4_YR_1959_s_1	0.0101446	1	0	2	0.5	act	0.0023077	−8.55E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1960_s_1	0.011064	1	0	2	0.5	act	0.0025179	−5.51E-09	F	NA	NA	NA	OK
F_fleet_4_YR_1961_s_1	0.0128675	1	0	2	0.5	act	0.0029304	−3.00E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1962_s_1	0.0120363	1	0	2	0.5	act	0.0027409	1.31E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1963_s_1	0.0135627	1	0	2	0.5	act	0.0030902	1.45E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1964_s_1	0.0151878	1	0	2	0.5	act	0.0034626	3.13E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1965_s_1	0.0182158	1	0	2	0.5	act	0.0041574	−1.34E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1966_s_1	0.0207399	1	0	2	0.5	act	0.0047382	−1.08E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1967_s_1	0.0260144	1	0	2	0.5	act	0.0059546	9.67E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1968_s_1	0.0266133	1	0	2	0.5	act	0.0060982	1.79E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1969_s_1	0.0304448	1	0	2	0.5	act	0.0069958	−7.99E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1970_s_1	0.0357079	1	0	2	0.5	act	0.0082335	−1.65E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1971_s_1	0.040568	1	0	2	0.5	act	0.0093855	−4.59E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
F_fleet_4_YR_1972_s_1	0.0552008	1	0	2	0.5	act	0.0128575	4.42E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1973_s_1	0.0487735	1	0	2	0.5	act	0.0113546	1.04E-05	F	NA	NA	NA	OK
F_fleet_4_YR_1974_s_1	0.0494636	1	0	2	0.5	act	0.0115286	2.13E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1975_s_1	0.0529342	1	0	2	0.5	act	0.0123691	3.89E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1976_s_1	0.0595936	1	0	2	0.5	act	0.0139823	−5.10E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1977_s_1	0.0421784	1	0	2	0.5	act	0.0098477	−2.42E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1978_s_1	0.0466532	1	0	2	0.5	act	0.0109239	6.54E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1979_s_1	0.039268	1	0	2	0.5	act	0.0091842	8.36E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1980_s_1	0.0577305	1	0	2	0.5	act	0.0136463	−4.43E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1981_s_1	0.0386612	1	0	2	0.5	act	0.009111	−6.02E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1982_s_1	0.0719096	1	0	2	0.5	act	0.0172876	4.59E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1983_s_1	0.0743265	1	0	2	0.5	act	0.017758	2.64E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1984_s_1	0.0625292	1	0	2	0.5	act	0.0147523	4.30E-07	F	NA	NA	NA	OK
F_fleet_4_YR_1985_s_1	0.0651035	1	0	2	0.5	act	0.0152491	−8.25E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1986_s_1	0.0720343	1	0	2	0.5	act	0.0166297	4.29E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1987_s_1	0.0728954	1	0	2	0.5	act	0.0169354	1.24E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1988_s_1	0.0706785	1	0	2	0.5	act	0.0165722	3.08E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1989_s_1	0.0721714	1	0	2	0.5	act	0.0168971	2.46E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_4_YR_1990_s_1	0.0750503	1	0	2	0.5	act	0.0174472	−2.56E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1991_s_1	0.0748393	1	0	2	0.5	act	0.0175785	−3.10E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1992_s_1	0.0611123	1	0	2	0.5	act	0.0146739	2.01E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1993_s_1	0.0643869	1	0	2	0.5	act	0.0154794	4.42E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1994_s_1	0.0635247	1	0	2	0.5	act	0.0150042	1.35E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1995_s_1	0.0600067	1	0	2	0.5	act	0.0139462	−7.54E-07	F	NA	NA	NA	OK
F_fleet_4_YR_1996_s_1	0.0745909	1	0	2	0.5	act	0.0171022	−4.13E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1997_s_1	0.0678327	1	0	2	0.5	act	0.0155541	2.42E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1998_s_1	0.0810803	1	0	2	0.5	act	0.0186714	−7.34E-06	F	NA	NA	NA	OK
F_fleet_4_YR_1999_s_1	0.0844827	1	0	2	0.5	act	0.0197339	5.93E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2000_s_1	0.0634166	1	0	2	0.5	act	0.0088046	1.06E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2001_s_1	0.0698685	1	0	2	0.5	act	0.0096028	5.88E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2002_s_1	0.0718086	1	0	2	0.5	act	0.0094987	1.73E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2003_s_1	0.0875396	1	0	2	0.5	act	0.0111943	2.77E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2004_s_1	0.0757401	1	0	2	0.5	act	0.0095413	3.41E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2005_s_1	0.0690768	1	0	2	0.5	act	0.0088149	−1.68E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2006_s_1	0.0620222	1	0	2	0.5	act	0.0079271	1.14E-07	F	NA	NA	NA	OK
F_fleet_4_YR_2007_s_1	0.0648582	1	0	2	0.5	act	0.0079978	4.30E-06	F	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
F_fleet_4_YR_2008_s_1	0.0642075	1	0	2	0.5	act	0.0081791	−4.38E-07	F	NA	NA	NA	OK
F_fleet_4_YR_2009_s_1	0.0486625	1	0	2	0.5	act	0.0063914	4.53E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2010_s_1	0.0395868	1	0	2	0.5	act	0.0051841	2.66E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2011_s_1	0.0311935	1	0	2	0.5	act	0.0040055	−1.69E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2012_s_1	0.0315141	1	0	2	0.5	act	0.0040329	2.14E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2013_s_1	0.0523576	1	0	2	0.5	act	0.006856	1.29E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2014_s_1	0.0320557	1	0	2	0.5	act	0.0043529	8.89E-06	F	NA	NA	NA	OK
F_fleet_4_YR_2015_s_1	0.0277595	1	0	2	0.5	act	0.0038593	−1.71E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2016_s_1	0.0256282	1	0	2	0.5	act	0.0036582	7.59E-07	F	NA	NA	NA	OK
F_fleet_4_YR_2017_s_1	0.0210202	1	0	2	0.5	act	0.0031626	−4.31E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2018_s_1	0.0242875	1	0	2	0.5	act	0.0039125	−3.77E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2019_s_1	0.0208286	1	0	2	0.5	act	0.0036262	3.09E-05	F	NA	NA	NA	OK
F_fleet_4_YR_2020_s_1	0.021307	1	0	2	0.5	act	0.0040185	−1.42E-05	F	NA	NA	NA	OK
Q_extraSD_FR-IE-IBTS(5)	0.077017	4	0	1	0.0769716	OK	0.0494973	−1.89E-07	No_prior	NA	NA	NA	OK
Siz-eSpline_GradLo_GNS(1)	0.559209	6	−0.001	1	0.559211	OK	0.0272732	−1.81E-06	Sym_Beta	0	0.001	0.0000139	OK
Siz-eSpline_GradHi_GNS(1)	−0.0429519	6	−1	0.001	−0.0429519	OK	0.0075575	7.60E-06	Sym_Beta	0	0.001	0.0017819	OK

Value	Phase	Min	Max	Init	Status	Parm_StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
SizeSpline_Val_1_GNS(1)	−3.86814	5	−9	7	−3.86817	OK	0.138628	1.00E-07	Sym_Beta	0	0.001	0.0001376	OK
SizeSpline_Val_3_GNS(1)	−0.738137	5	−9	7	−0.73816	OK	0.0742173	−1.24E-05	Sym_Beta	0	0.001	0.000001	OK
Retain_L_infl_GNS(1)	32.6009	5	5	100	32.6009	OK	0.305272	1.20E-05	No_prior	NA	NA	NA	OK
Retain_L_width_GNS(1)	3.30552	6	0.1	20	3.30552	OK	0.136615	5.78E-06	No_prior	NA	NA	NA	OK
Size_DblN_peak_TR_FR(2)	25.4259	5	10	60	25.4259	OK	0.546543	6.61E-06	Normal	25.4259	1	0	OK
Size_DblN_ascend_se_TR_FR(2)	4.33731	6	−15	8	4.3373	OK	0.091311	−8.34E-06	No_prior	NA	NA	NA	OK
Retain_L_infl_TR_FR(2)	27.5199	5	5	100	27.5202	OK	0.34151	1.65E-05	No_prior	NA	NA	NA	OK
Retain_L_width_TR_FR(2)	2.45457	6	0.1	20	2.45459	OK	0.079804	5.82E-07	No_prior	NA	NA	NA	OK
SizeSpline_GradLo_TR_OT(3)	0.530156	6	−0.001	1	0.530158	OK	0.0120886	4.11E-05	Sym_Beta	0	0.001	0.0000034	OK
SizeSpline_GradHi_TR_OT(3)	−0.0854589	6	−1	0.001	−0.0854553	OK	0.0084754	1.20E-05	Sym_Beta	0	0.001	0.0011519	OK
SizeSpline_Val_1_TR_OT(3)	−3.92684	5	−9	7	−3.92685	OK	0.0834337	0.000114608	Sym_Beta	0	0.001	0.0001437	OK
SizeSpline_Val_3_TR_OT(3)	−1.83256	5	−9	7	−1.83254	OK	0.0664219	−5.97E-05	Sym_Beta	0	0.001	0.0000109	OK
Retain_L_infl_TR_OT(3)	27.1758	5	5	100	27.176	OK	0.589001	−1.66E-05	No_prior	NA	NA	NA	OK
Retain_L_width_TR_OT(3)	3.58554	6	0.1	20	3.58554	OK	0.0830535	−8.33E-06	No_prior	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After- bound	
Siz-eSpline_GradLo_TR_SP(4)	0.522912	6	−0.001	1	0.522914	OK	0.022787	−1.02E-05	Sym_Beta	0	0.001	0.0000018	OK
Siz-eSpline_GradHi_TR_SP(4)	−0.0836438	6	−1	0.001	−0.0836346	OK	0.0095125	−1.71E-06	Sym_Beta	0	0.001	0.0011711	OK
Siz-eSpline_Val_1_TR_SP(4)	−4.57878	5	−9	7	−4.57885	OK	0.238773	−3.11E-05	Sym_Beta	0	0.001	0.0002233	OK
Siz-eSpline_Val_3_TR_SP(4)	−0.391424	5	−9	7	−0.391314	OK	0.0821294	-4.70E-05	Sym_Beta	0	0.001	0.0000058	OK
Retain_L_infl_TR_SP(4)	19.0972	5	5	100	19.0971	OK	0.413716	2.36E-05	No_prior	NA	NA	NA	OK
Retain_L_width_TR_SP(4)	2.09051	6	0.1	20	2.09051	OK	0.0625552	3.50E-06	No_prior	NA	NA	NA	OK
Size_DblN_peak_FR-IE-IBTS(5)	62.7802	5	25	75	62.7795	OK	2.73377	1.18E-05	No_prior	NA	NA	NA	OK
Size_DblN_ascend_se_FR-IE-IBTS(5)	8.09365	5	−9	9	8.09361	OK	0.128663	−1.90E-05	No_prior	NA	NA	NA	OK
Size_DblN_de-scend_se_FR-IE-IBTS(5)	7.2432	6	−5	30	7.2432	OK	0.254601	2.88E-05	No_prior	NA	NA	NA	OK
Size_inflec-tion_IE_MONKSURVEY(6)	28.944	5	10	130	28.9435	OK	4.83099	9.69E-07	No_prior	NA	NA	NA	OK
Size_95%width_IE_MONKSURVEY(6)	39.7938	6	−15	60	39.7919	OK	9.8337	−1.45E-06	No_prior	NA	NA	NA	OK
Size_DblN_peak_SPGFS(7)	86.278	5	5	130	86.2778	OK	2.17802	4.80E-06	No_prior	NA	NA	NA	OK
Size_DblN_as-cend_se_SPGFS(7)	7.2402	5	−1	9	7.24019	OK	0.0647642	−4.15E-06	No_prior	NA	NA	NA	OK

Value	Phase	Min	Max	Init	Status	Parm_ StDev	Gradient	Pr_type	Prior	Pr_SD	Pr_Like	After-bound	
ln(DM_theta)_1 (TR_OT)	0.85913	8	−5	5	0.859132	OK	0.0909707	7.05E-06	Normal	0	1.813	0.112277	OK
ln(DM_theta)_2 (TR_SP)	1.12865	8	−5	5	1.1286	OK	0.138652	2.22E-06	Normal	0	1.813	0.193772	OK
ln(DM_theta)_3 (IBTS)	2.37913	8	−5	5	2.37915	OK	0.421826	1.02E-06	Normal	0	1.813	0.861018	OK
ln(DM_theta)_4 (MONK)	4.69247	8	−5	5	4.69248	OK	0.754811	5.83E-07	Normal	0	1.813	3.34948	OK
ln(DM_theta)_5 (SPGFS)	1.32113	8	−5	5	1.32114	OK	0.193313	−5.05E-06	Normal	0	1.813	0.2655	OK
Siz-eSpline_Val_1_TR_SP(4)_ BLK1add_2007	−2.53221	7	−9	7	−2.53223	OK	0.193743	−3.11E-05	Sym_Beta	0	0.001	0.0000373	OK

5.3.1 Growth

The growth pattern of males and females.

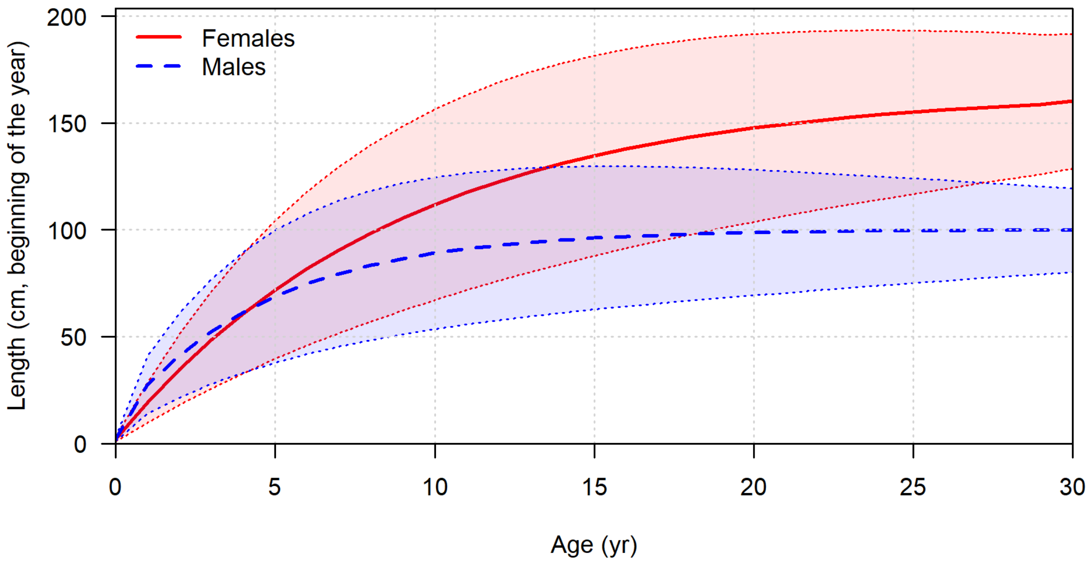


Figure 5.2. The length-at-age for males and females.

5.3.2 Selectivity and length compositions fits

Figure 5.2 shows that all the commercial fleet show bimodal shape in selectivity, although the SP_TR show that pattern only before 2007 and for the TR_FR shows the logistic shape because that's the assumed pattern. However, with the splines the model also estimates bimodal shape for TR_FR although it shows similar to the logistic pattern and the residuals are not improved. The reason to fix the FR_TR parameter at 25.43 was based on the jittering analysis explained in the diagnostic section.

The time block for TR_SP as well as the random walks in the retention curve for TR_FR and TR_OT are due to the changes in the fish discards towards bigger fish.

The model also suggest that the fleets are better at catching small fish than the survey. Probably this is explained with the small time window at which the surveys happen compared with the commercial fleets that fish during the year.

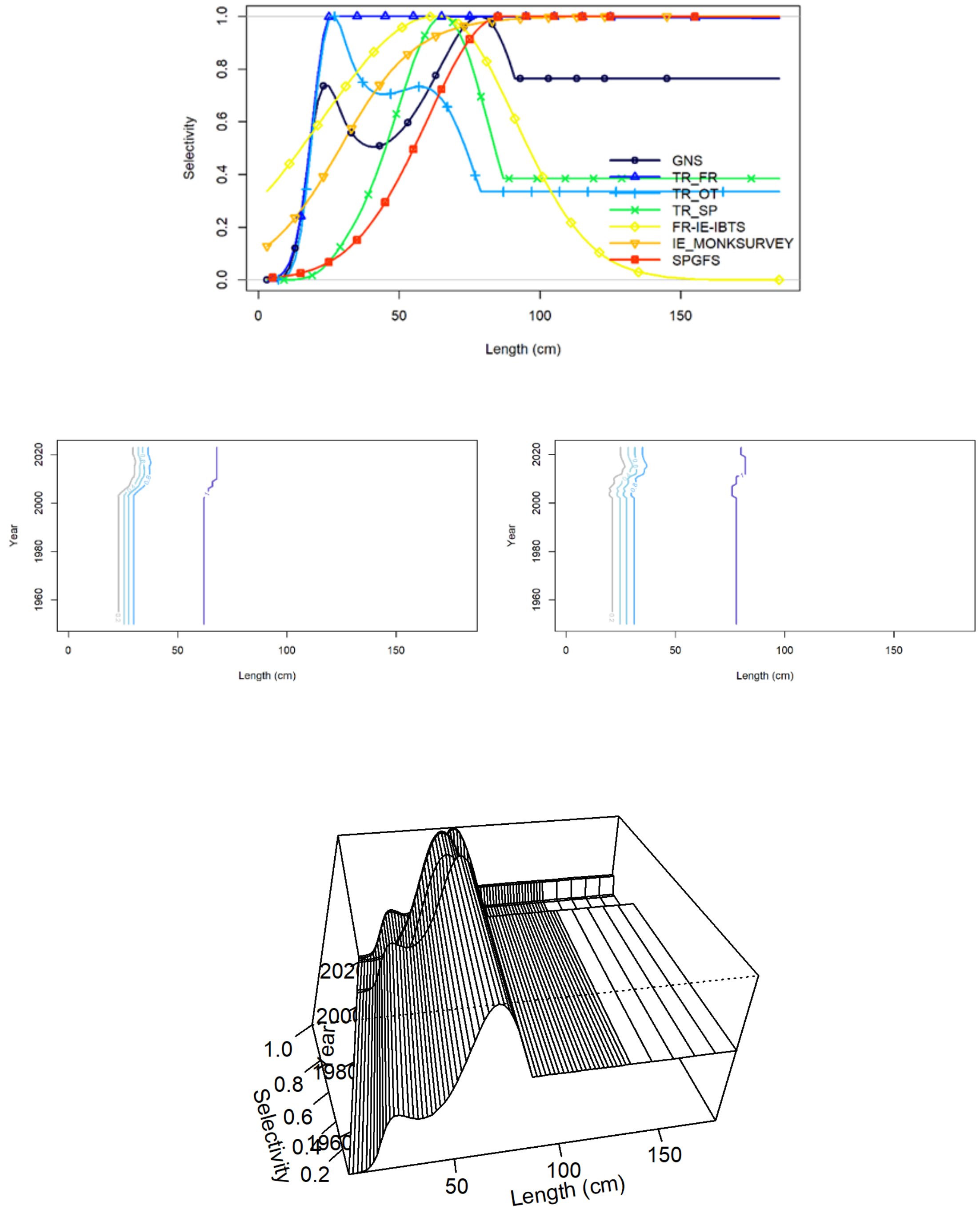


Figure 5.3. In the top the estimated selectivity for each fleet, middle figures show the random walk in the retention curve for TR_FR (left) and TR_OT (right) and the bottom figure the selectivity pattern of TR_SP with time block in 2007.

The lower selectivity at around 45 cm and the bimodal shape in selectivity probably could be explained with lower fish availability at that size range which could be due to the different vertical distribution of fish with size as well as the different spatial distribution with size (Figure 5.3).

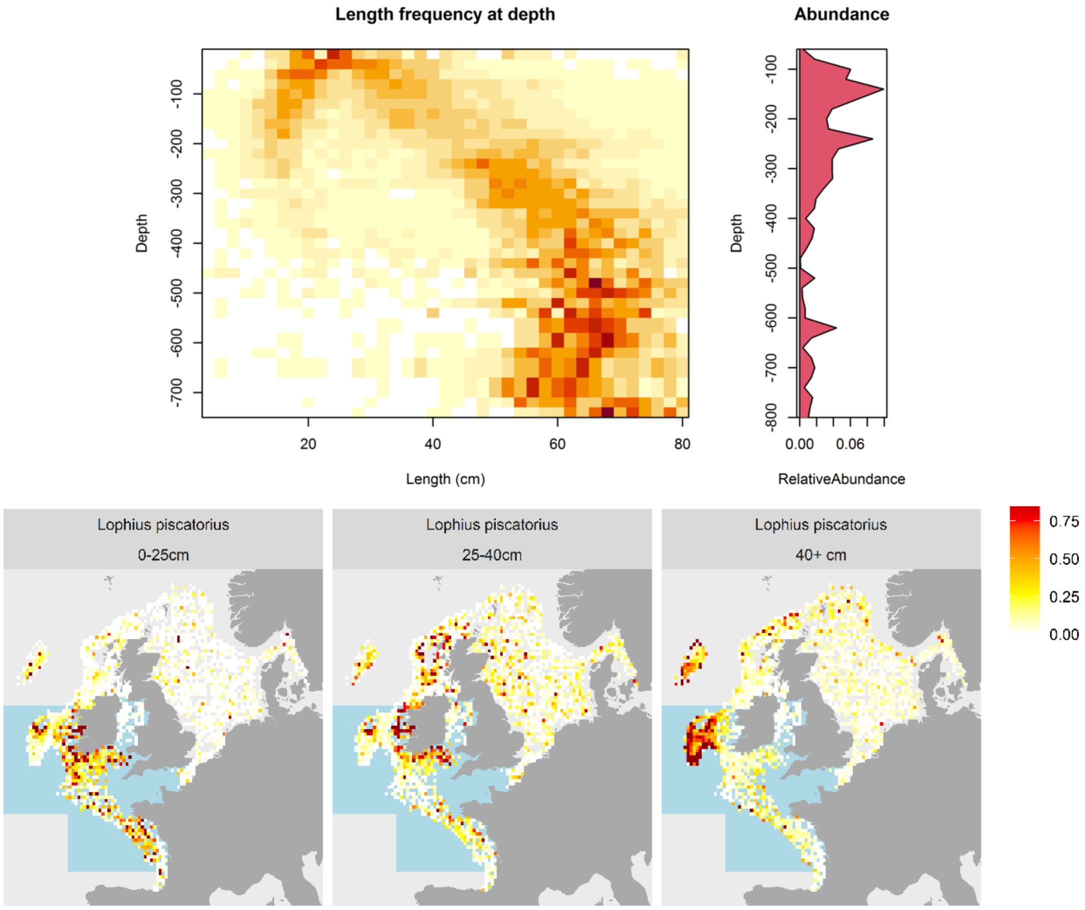


Figure 5.4. The relative abundance of white anglerfish at depth (top figure) and space (bottom figure).

The jittering in a previous model without the prior in the TR_FR peak parameter showed that the model could converge in a local minimum or in the global minimum. The difference in the likelihood was very low 13 units, however the trend in SSB was different. The difference was due to differences on the estimated peak parameter of the TR_FR. Then following the signal of selectivity on small fish of the other fleets, it was decided that the peak parameter of TR_FR fleet should have a prior at 25.5 with s.d. of 1 and normal distribution. So then the stability of the model as well as the plausibility of the results and from the 30 runs of the jittering only one did not give the same results as the others.

The model fits the length composition data compared to the fits in general. Although, the model show some bias the male's length distribution and also the SPGFS surveys length distribution. The bimodal shape of SPGFS is very difficult to fit even with a spline. The survey sometimes catches small fish and others no, so we though that the small fish observed by this survey were nor representative of the all area. Therefore, the selectivity of this fleet was defined as logistic with the peak in the large fish.

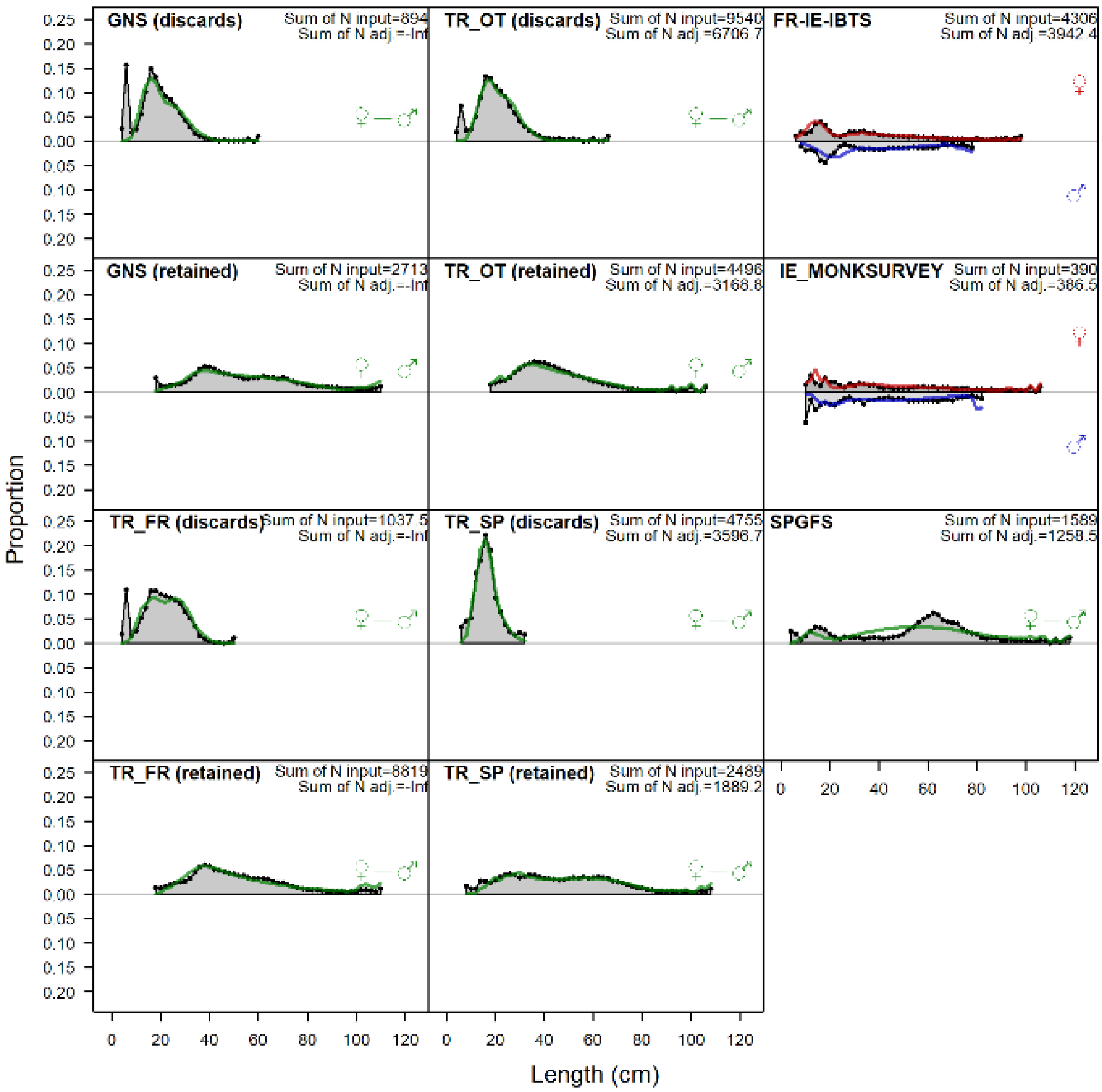


Figure 5.5. The figure below shows the aggregated length composition by fleets and surveys.

5.3.3 Indices

The model fits quite well the indices; however, the model does not fit very well the increase observed in the joint index in 2019 and 2018 due to the contradictory trends in the other two surveys.

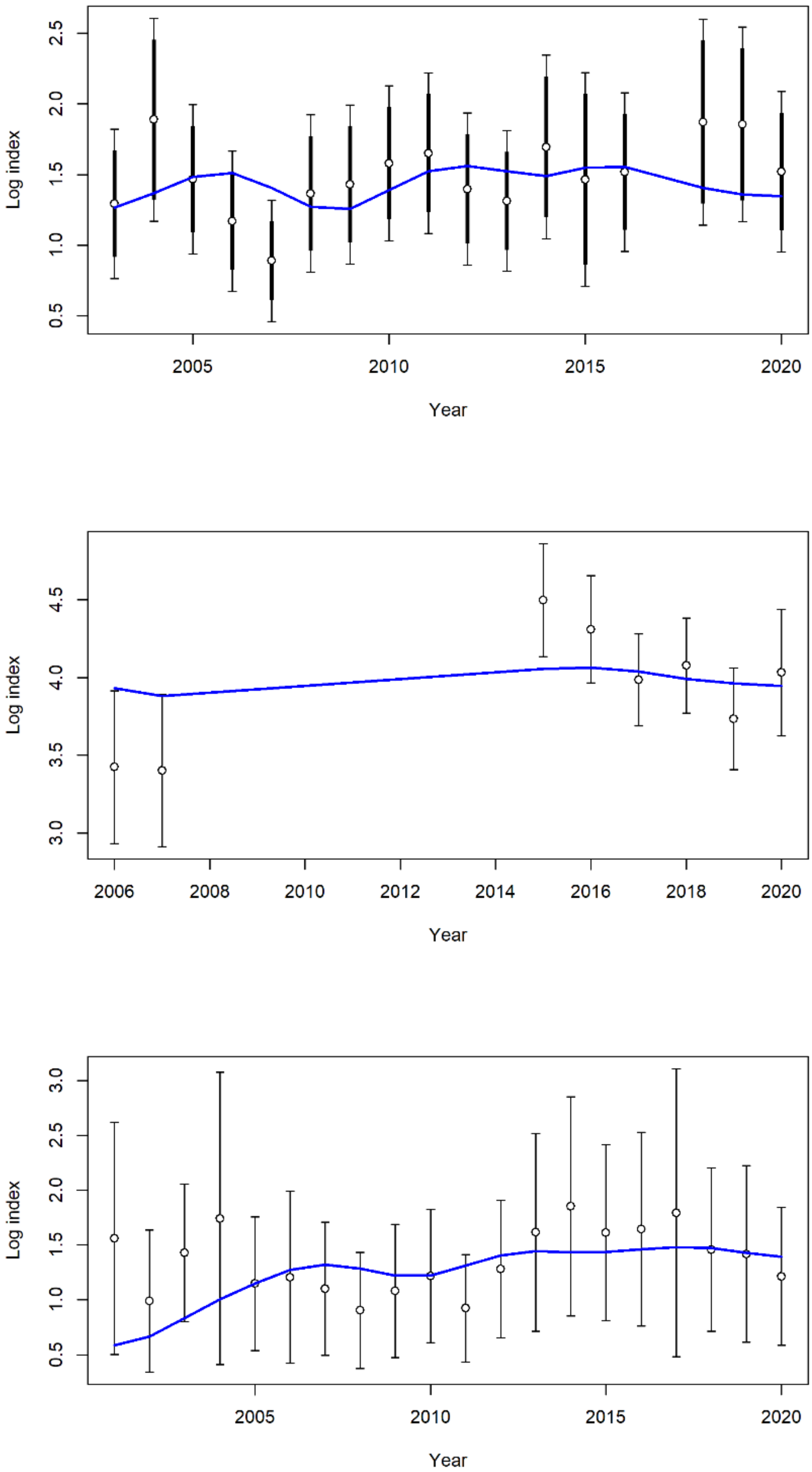


Figure 5.6. The indices and the fits of the model of the IBTS joint index (top), monksurvey (middle) and the SPGFS survey (bottom).

5.3.4 Stock recruitment

The figure shows the estimated Beverton and Holt stock recruitment relationship with a small decrease in recruitment at biomass below 30 000 t. The recruitment deviates estimates are corrected with the suggested parameterization by SS3.

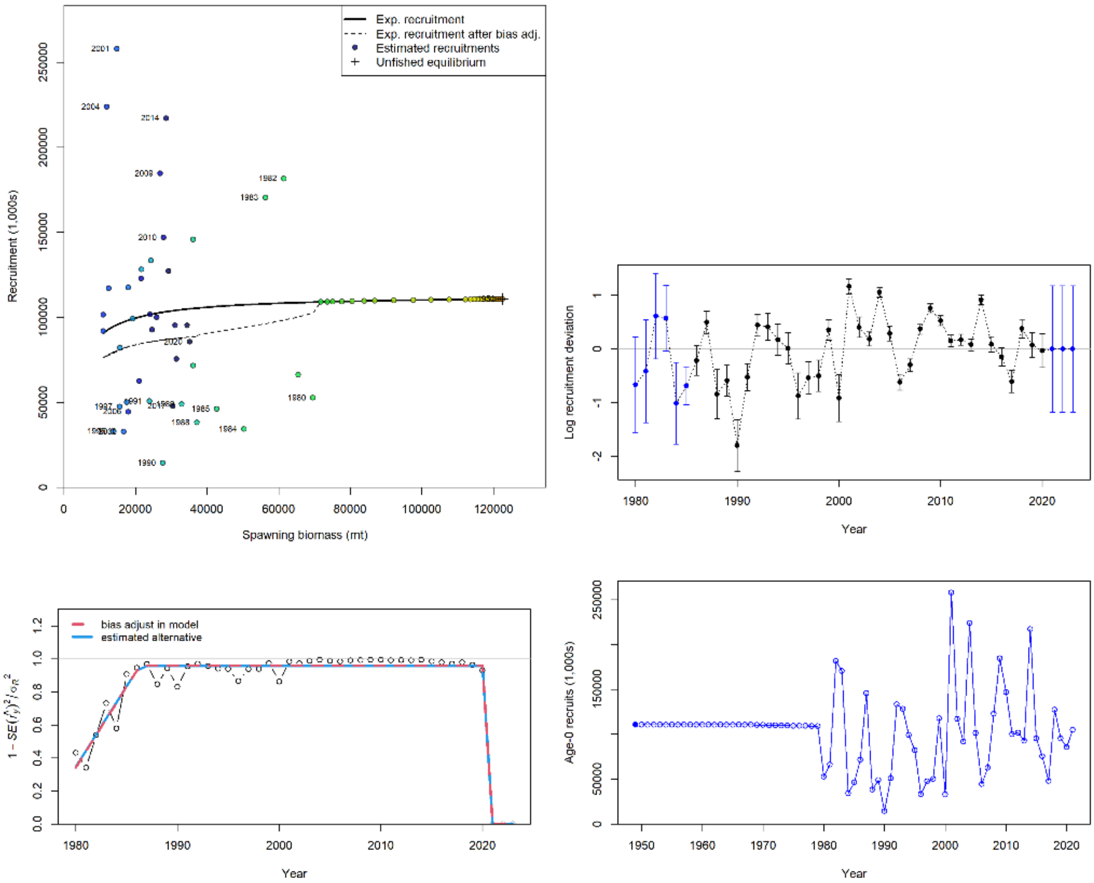


Figure 5.7. The estimated stock recruitment relationship, the deviates, the introduced correction for the estimation of the recruitment deviates and the estimated recruitments by year.

5.3.5 Catches

The model fits well the landings of all the commercial fleets although the landings of the TR_FR are underestimated. The estimated discards by fleets are quite close to the observed values although in the case of the TR_SP, the model is not able to estimate them. However the observed discards for the TR_SP are very low, most of them below 200 mt.

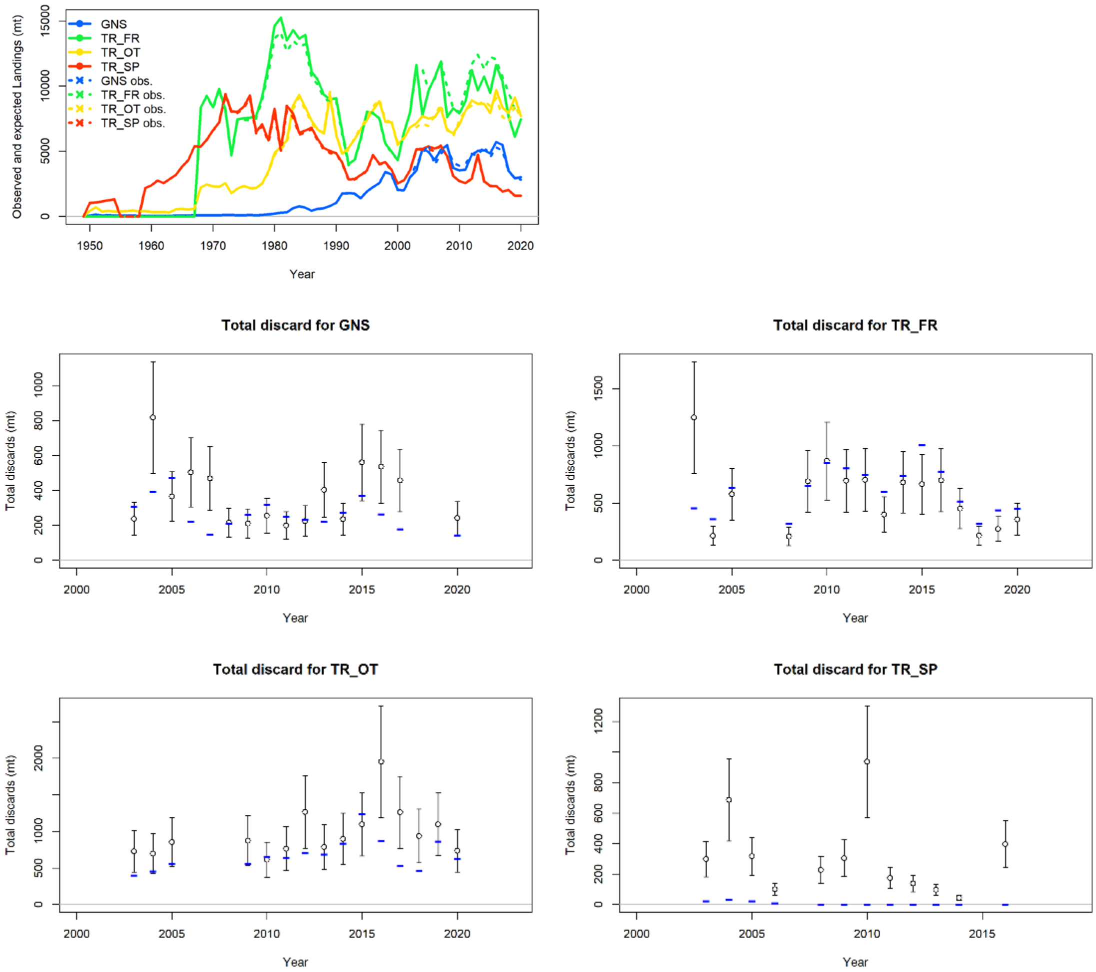


Figure 5.8. The predicted and observed landings and discards by fleet.

5.3.5.1 Time-series SSB and fishing mortality

The model estimated a big decrease in biomass until 2000 and after increases until similar to 1986 where the length composition data starts. The fishing mortality was very low at the beginning of the time-series and increased to 0.3 in 2003 and decreases until 2021 with an F of 0.15 in 2021.

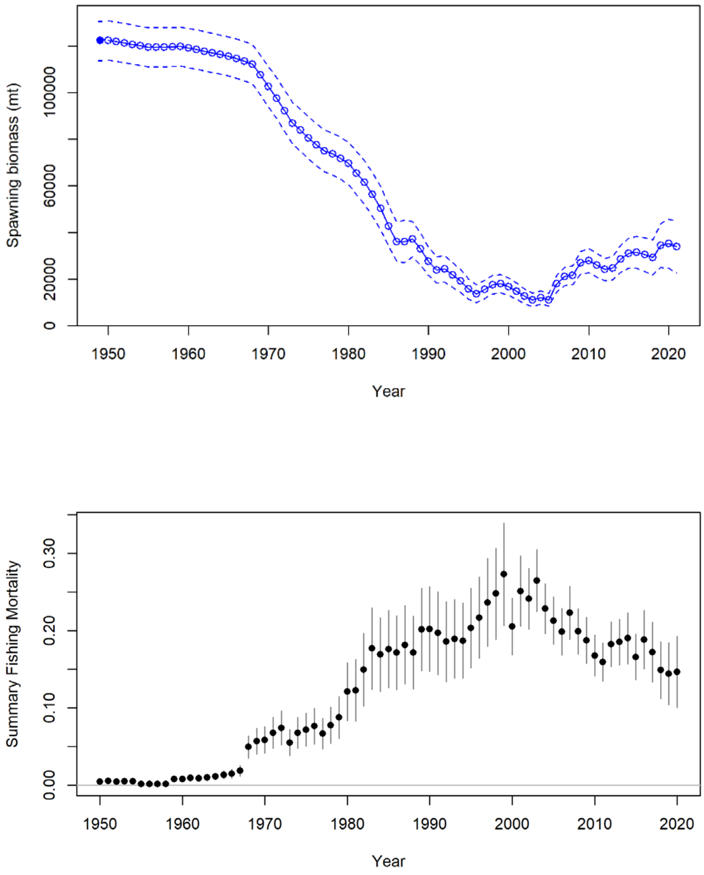


Figure 5.9. The estimated time-series of SSB and Fishing mortality (age 3–15) and uncertainty.

Table 5.2. Summary of the diagnostics.

Conver.	Total_LL	N_Params	Runs_test_IBTS	Runs_test_MONK	Runs_test_SPGFS	MASE_IBTS	MASE_MONK	MASE_SPGFS	Retro_SSB_Rho	Forecast_SSB_Rho	RetroF_Rho	ForecastF_Rho
0.00168352	−9113.11	391	Passed	Passed	Failed	1.57	0.705	1.04	−0.0025	0.012918	0.00173	0.0302

5.4 Model diagnostics

The diagnostic of the model was done based on the plausibility of the results, expert's knowledge, runs test (to analyse the fits of the model), hindcasting (for the predictive skills of the model), the jittering and retrospective and forecast analysis (for stability) (Carvallo *et al.*, 2019). The model passes the runs test of the IBTS survey and the Monksurvey but not the SpGFS survey and it passes also the length composition runs test for all the fleets but not for the IBTS joint index. The model shows predictive skills of the monksurvey index (MASE<1) and for the SPgfS the MASE value was very close to 1 (1.04). The retrospective and forecast of SSB had a very low value of Mohn's rho of 0 and 0.01 for forecast and the same for F fishing mortality (between age 3 and 15) with a Mohn's rho of 0 in the retrospective pattern and 0.03 in the forecast.

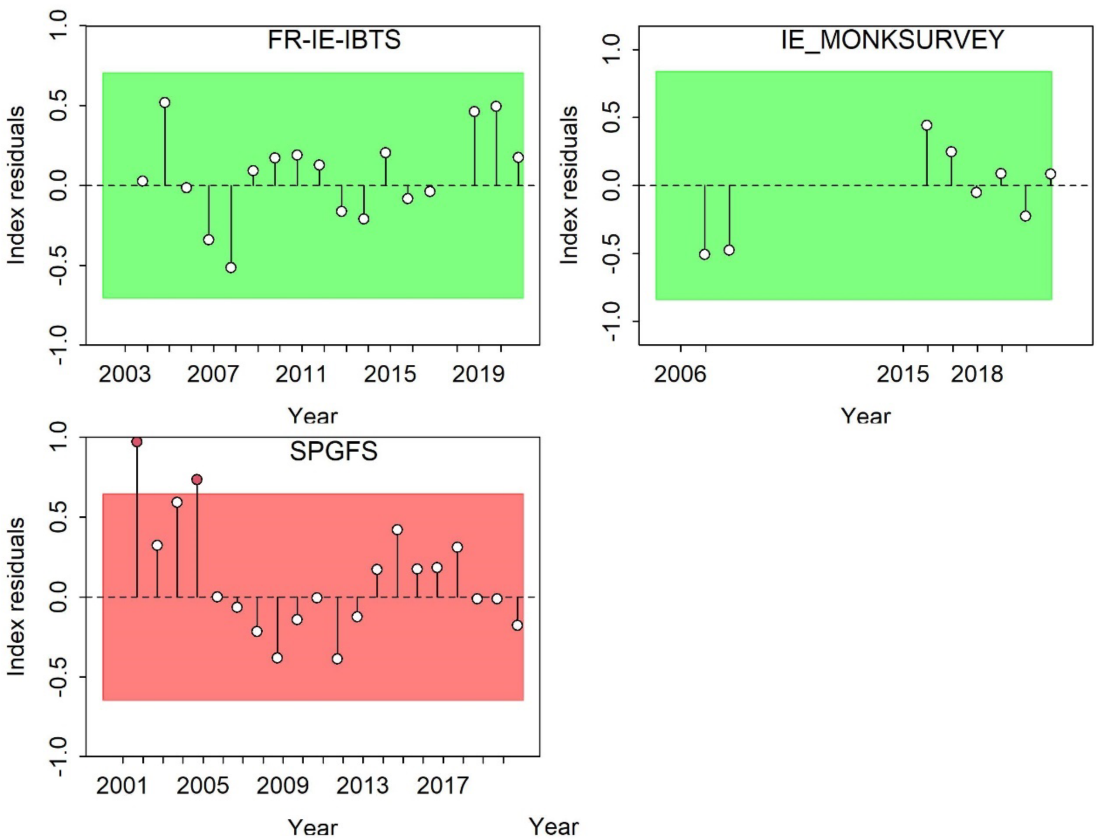


Figure 5.10. Runs test results of the surveys. Green means pass and red not pass. Red points means that those observed values are out of the confidence interval of the estimated value.

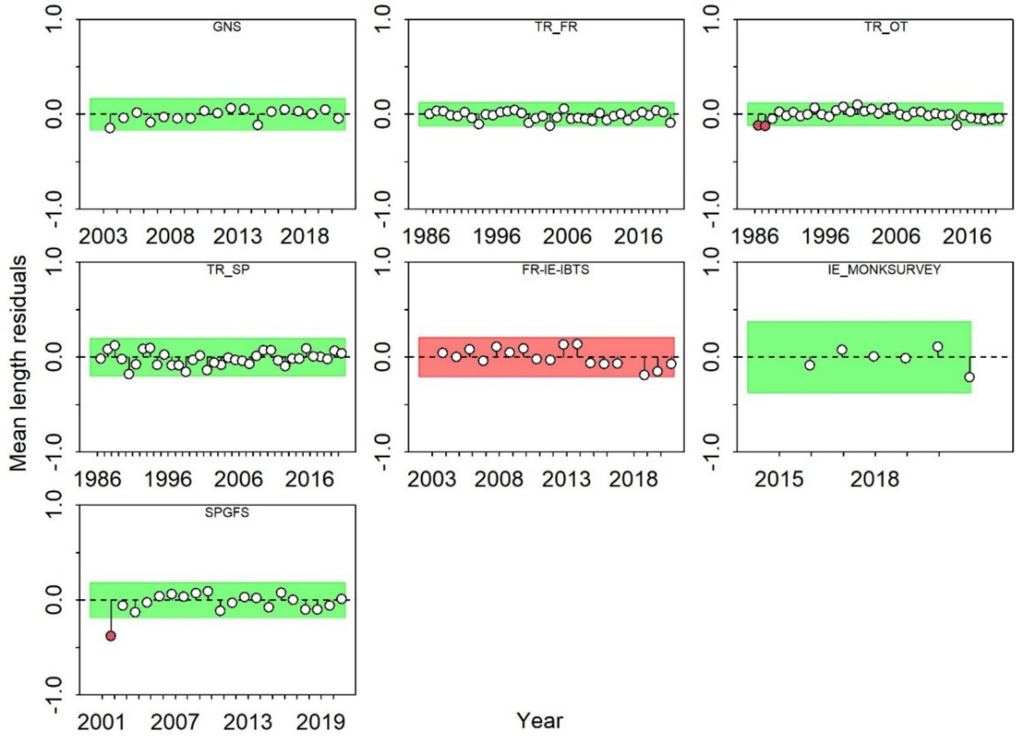


Figure 5.11 Runs Test results of the length composition. Red points means that those observed values are out of the confidence interval of the estimated value.

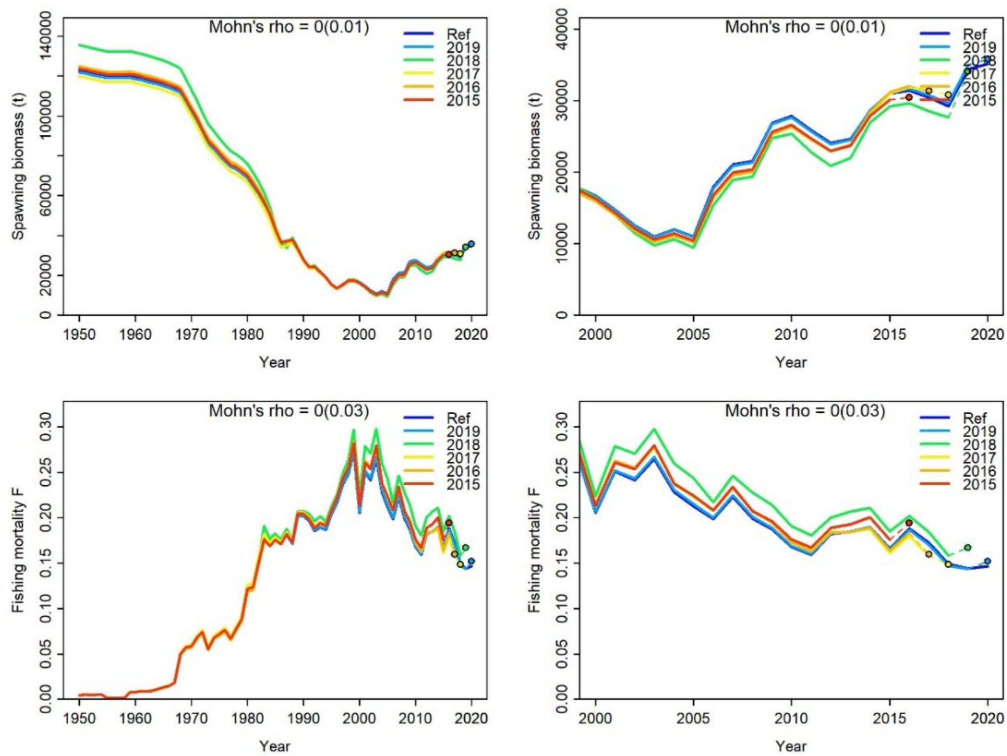


Figure 5.12. Retrospective pattern and forecast of SSB and F fishing mortality of the last 5 years. The figure also show the Mohn's rho values of the retrospective pattern and between brackets the values for the forecast.

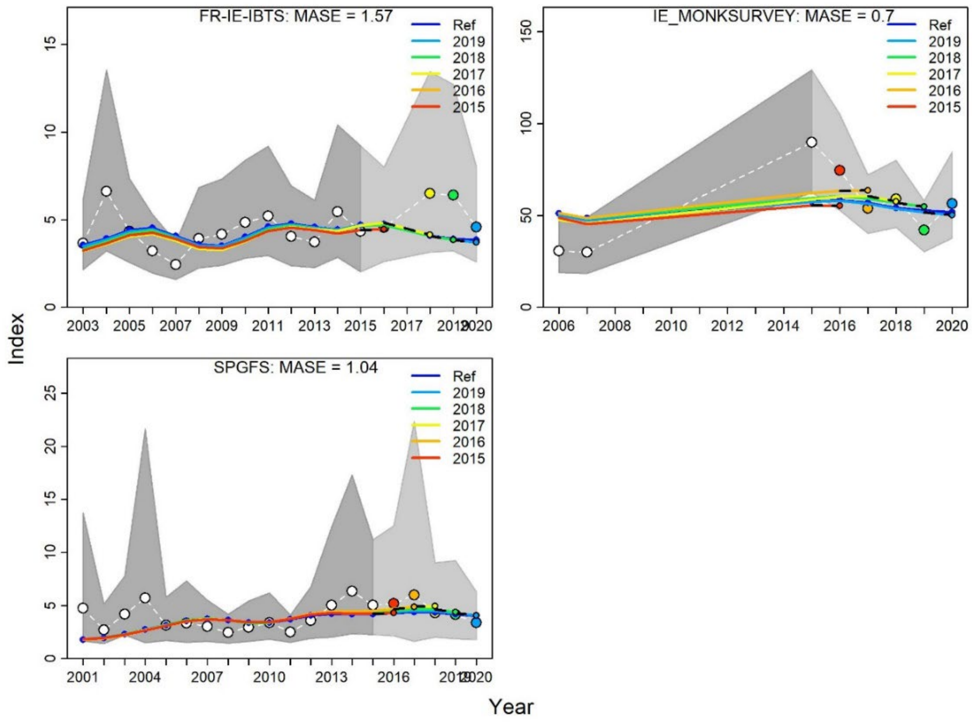


Figure 5.13. The hindcasting of the 3 surveys and the MASE values of each of them.

The jittering analysis shows that from 30 jittering only one model did not converge with the same results. So the model is quite stable.

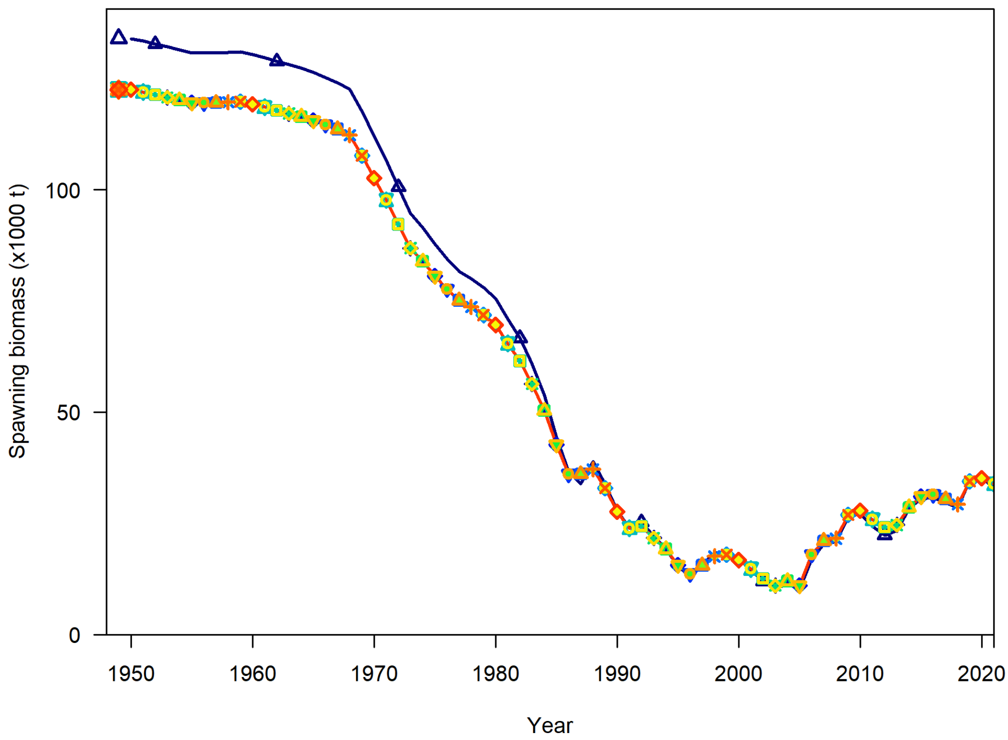


Figure 5.14. Results of the jittering of 30 runs.

5.5 Alternative runs and discussion

Different sensitivity analysis were performed and the best model for the assessment was chosen based on the different diagnostics: on the fits to the data (runs test), predictive power of the model (hindcasting), stability and also plausibility. Below is listed the different sensitivity analysis performed during the process. However, the sensitivity analysis was done continuously in the all process therefore some differences can be found between the different sensitivity analysis, where some of the scenarios were done assuming a cv of 0.2 for the catches in the time-series, logistic selectivity for all the fleets, length composition of the commercial fleets downweighted by 0.1, time block in the IBTS survey but not in the TR_SP fleet, monksurvey fixed, SPGFS second parameter fixed…

Although some of the diagnostics on the IBTS survey were improved there was not any reason to assume a time block for the survey. So during the development this setting was modified. The time block in the TR_sp was included due to the lack of data on the smallest fish after 2007.

The comparison of the diagnostics is done based on the results with models with similar settings. The models with stars in the name are the reference within the models following those settings. The model with name *** base case is the final assessment model which has been mentioned as base case in the all section.

Biology (Table 5.3)

- Name: L_{min}Fix. L_{min} fix at 18.9 cm based on the estimates by WD04. The fits to the length composition of the commercial fleets are much worst, but the fits to the IBTS joint index length composition are better.
- Name: mMalLorAge3. Natural mortality estimated by the model at age 3 with Lorenzen curve: The model estimated 0.39 a bit higher than what we assume, however, the Lorenzen curve estimates decreasing values of M with age while we assume a constant value of 0.36 for all the ages >= 3.
- Name: m40. Natural mortality assuming M = 0.4 at age 3 with Lorenzen curve. Similar outputs to the previous model.
- Name: L_{inf}Fem.Estimate L_{inf} for females: 135 cm. Smaller value than in the base case 165 cm. The largest fish caught ~ 180 cm.
- Name: L_{inf}Mal. Estimate L_{inf} for male: 95 cm. Similar to the assumed value in the base case 100 cm.
- Estimate K for females: 0.092 cm. Similar estimated values 0.112 cm (*no diagnostics available for this scenarios)

Selectivity

- Name:**. All of them logistic. The residual pattern of the length composition of the commercial fleets worst.
- Name: SPGFS splines. The retrospective pattern worst.
- Name: RandomWalkAllFleets. The retrospective pattern worst.
- Name:Without random walk. Worst hindcasting properties.
- Name: LocalMin. Cv of the catches 0.2 the all time-series. The model underestimates the observed landings.
- Name: Global min. The model shows two convergency points depending on the starting values. In the global minimum the model estimates high selectivity in big fish, so the fits of landings are very good but the discards are underestimated and the fit to the length composition of the discards of TR_FR shows bimodal shape. When the model converge with TR_FR high selectivity in the smallest fish then the fits to discards and discards

length composition are better but the landings of TR_FR a bit underestimated. The difference in likelihood between both models was 13 units. However, the estimated biomass for white anglerfish was similar to the black anglerfish when the catches on white anglerfish are 3 times higher. The results of the global minimum were not very plausible neither compared with the estimated reference points with the previous assessment model. This is shown in the section of "Selectivity: sources and explanations".

- Name:WithoutTB. Here the time block of the IBTS was removed. The retrospective pattern got worst. However, there was no justification to set a time block in this survey, so the final settings did not consider it.
- Name:Without downweight LC. Without downweighting the LC of the commercial fleets the MASE values of the IBTS survey increased considerably and also the retrospective pattern.
- Name: Monkfree. Here the selectivity parameters of the monksurvey were estimated by the model. Assumming logistic selectivity, the model was estimating very high standard error for these parameters, therefore, under this setting the monksurvey parameters were kept fixed.
- Name: Without Random Walk. The MASE values of the IBTS survey were worst, although the retrospective pattern were better compared with the model with this settings (Name:*).
- Name: WithRandomWalk2007. Starting random walk in 2007 was resulting in worst retrospective pattern, although better MASE value for the 3 fleets compared with the model Name:*.

Table 5.3. The diagnostics on the settings of the parameters related with biology. The name of the run is a personal reference to find the run.

Name	Convergence	Total_LL	N_Params	Runs_test_IBTS	Runs_test_MONK	Runs_test_SPGFS	MASE_IBTS	MASE_MONK	MASE_SPGFS	Retro_Rho	Fore-cast_Rho	RetroF_Rho	Fore-castF_Rho
Base case	0.00168352	−9113.11	391	Passed	Passed	Failed	1.57	0.705	1.04	−0.0025	0.012918	0.00173	0.0302
LminFix	0.00308211	−8024.61	389	Passed	Passed	Failed	1.8197462	0.73122569	0.96840914	−0.03864818	−0.03203956	0.0117361	0.21491934
cv01_Lmin-Free	0.00336378	−9113.26	391	Passed	Passed	Failed	1.50949084	0.72551615	1.06077859	0.00856623	0.01850801	−0.02084086	0.00677703
Below logistic selectivity, dw01, time block IBTSsurvey													
Logistic	0.008799	2109.85	378	Passed	Passed	Failed	0.98510492	0.76172705	1.15349762	−0.06716675	−0.03626767	0.01736313	−0.08952271
m40	0.00608031	2102.19	378	Passed	Passed	Failed	0.99287077	0.74940308	1.18236581	0.15801367	0.20091446	−0.16123708	−0.24010401
mMalLor-Age3	0.00226161	2245.66	379	Passed	Passed	Failed	1.95497777	0.78102461	1.1003111	0.11036475	0.1151278	−0.05539304	−0.11724225
L_{inf}Fem	0.00091171	2099.68	379	Passed	Passed	Failed	0.95049806	0.73774119	1.13637496	−0.10904512	−0.09545552	0.09889442	0.01795552
L_{inf}Mal	0.00246355	2098.14	378	Passed	Passed	Failed	0.917006434	0.750233842	1.1840225	0.175464121	0.21827151	−0.166321282	−0.247145646

Table 5.4. The diagnostics on the settings of the parameters related with selectivity.

Name	Run	Conver-gence	Total_LL	N_Params	Runs_test_IBTS	Runs_test_MONK	Runs_test_SPGFS	MASE_IBTS	MASE_MONK	MASE_SPGFS	Retro_Rho	Fore-cast_Rho	RetroF_Rho	Fore-castF_Rho
***Base case														
***	FinalModel	0.00168352	−9113.11	391	Passed	Passed	Failed	1.57	0.705	1.04	−0.0025	0.012918	0.00173	0.0302
cv02														
AllSpline	ASp0	0.00232195	−9252.65	393	Passed	Passed	Failed	1.64845561	0.74339252	0.66082922	0.1836211	0.22193145	−0.16232388	−0.21788672

Name	Run	Convergence	Total_LL	N_Params	Runs_test_IBTS	Runs_test_MONK	Runs_test_SPGFS	MASE_IBTS	MASE_MONK	MASE_SPGFS	Retro_Rho	Forecast_Rho	RetroF_Rho	ForecastF_Rho
LocalMin	VS91_ramp3_2016_2015sp_dch	0.00325105	−9148.93	391	Passed	Passed	Failed	1.82027162	0.77675145	0.7704905	0.03770356	0.05254709	−0.04741164	−0.16294026
GlobMin	VS91_ramp3_2016_2015sp_dch_jitter2	0.00118167	−8909.33	391	Passed	Passed	Passed	1.57154339	0.72869228	0.88132147	−0.04158928	−0.03476663	−0.06730243	−0.04264944
**Logistic all-dw 0.1-TB in IBTS-fixedMonk-SPGFS 2fixed														
**	BC_m12_2016	0.008799	2109.85	378	Passed	Passed	Failed	0.98510492	0.76172705	1.15349762	−0.06716675	−0.03626767	0.01736313	−0.08952271
WithoutTB	BC_m12_2016_woTB	0.00320853	2102.55	376	Passed	Passed	Failed	0.9914967	0.76774223	1.18331495	0.12106047	0.15813452	−0.13811473	−0.22620939
SPGFS spline	BC_m12_2016_spgfsSpline	0.00065772	2109.84	110	Passed	Passed	Passed	0.87627006	0.78067454	1.17920553	0.15382937	0.18191085	−0.13623381	−0.15801687
RandomWalkAll Fleets	BC_m12_2016_ramp_RWAll	0.00160783	2153.36	414	Passed	Passed	Failed	0.91241636	0.76332691	1.21601467	0.15623795	0.19172861	−0.16970162	−0.22767926
Without downweight LC	BC_m12_2016wdw	0.00510181	6380.56	378	Passed	Passed	Failed	2.77126365	0.89796163	1.32012836	−0.21164443	−0.21884827	−0.15161542	−0.16722147
MonkFree	BC_monkfree_m12_2016	0.0104789	2088.42	380	Passed	Passed	Failed	0.9225132	0.87296783	1.16038292	0.33549827	0.41232278	−0.25405742	−0.31788132
*below is assumed monksurvey month 1 yr+1 and data LC 2016 removed														
*	BC	0.00091428	2015.75	378	Passed	Passed	Failed	1.29799284	1.80148863	2.11819012	0.09754744	0.13061045	−0.11719757	−0.20274001

Name	Run	Conver-gence	Total_LL	N_Params	Runs_test_IBTS	Runs_test_MONK	Runs_test_SPGFS	MASE_IBTS	MASE_MONK	MASE_SPGFS	Retro_Rho	Fore-cast_Rho	RetroF_Rho	Fore-castF_Rho
without Random walk	BC_wRW	0.00088635	2043.68	339	Passed	Passed	Failed	1.44795557	1.73210733	2.0252687	0.02415793	0.03346978	−0.04083596	−0.16030253
With Ran-domWalk2007	BC_RW2007	0.00172396	2003.84	370	Passed	Passed	Failed	0.9914967	0.76774223	1.18331495	0.12106047	0.15813452	−0.13811473	−0.22620939

The base case model shows very good stability and convergency skills as well as very stable retrospective and forecast pattern. However, the hindcasting of the IBTS has a MASE value of 1.57 >1. This is probably due to the poor fits of the model in the 2018 and 2019 years where the IBTS joint index shows an increase in biomass while the other two surveys do not show the same pattern, so for the model is difficult to fit those data.

5.6 Remaining issues

The model shows some bias in the fits of the males length distribution in the IBTS joint survey that could be improved with more knowledge in the biology of this species such as growth and natural mortality.

One of the issues found during the development of the model is the lack of fit of SPGFS survey (although the model pass the runs test on this survey) as well as the low prediction skills on the IBTS joint index. It would be interesting to try a model with different areas. In that case, the IBTS index could be divided in the two indices that could described the trends by area and then the fits as well as the hindcasting of these surveys could be improved. Nevertheless, during WKTADSA a 2 area model was tried as sensitivity analysis, considering SPGFS as different area due to the weird length distribution of this survey and assuming that the Spanish trawlers were fishing there, however, the pattern was not improved, and the Spanish trawlers length distribution was closer to the length distribution of the other fleet (all of them aggregated) than to the survey. So afterwards only a one area model was explored. However, very little is known on the movement patterns of the white anglerfish for the development of a model with different areas and therefore, it would be very difficult to get robust and stable model for this species under those assumptions.

Another important issue that should be considered in the next benchmark is the stock unit. Different studies indicate the probably the stock unit is not defined correctly and that the three white anglerfish stock defined in the Atlantic should be assessed as well as managed as a unique stock.

5.7 Reference points

5.7.1 ICES approach to setting reference points

Reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks[7] (Published 1 March 2021). The ICES R package *msy* was used (EqSim approach).

An FLR stock object was created from SS outputs using the R library ss3om. This assessment only has one season but two sexes. EqSim works on a single season, single-sex stock object, therefore the sexes were combined. SSB was calculated from the stock numbers and weights-at-age and the *female* maturity ogive. Note that SS interprets SSB in a 2-sex model as the female-only SSB but the reference points were calculated relative to the combined-sex SSB.

F and recruitment in the FLStock object were checked against the SS output (and matched closely).

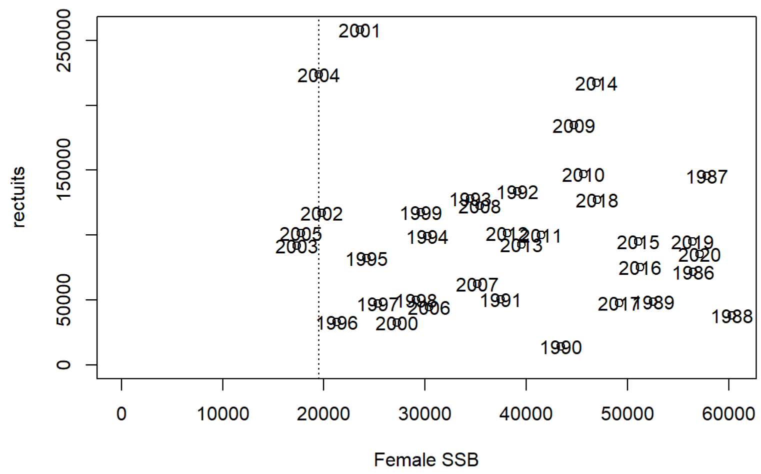
5.7.1.1 Stock–recruit relationship

In order to be consistent with the SS assessment, the stock–recruit relationship estimated by SS was used for estimating reference points (except for PA reference points which are based on a segmented regression). The values of R_0, B_0 and h were translated to the traditional a and b parameters of the classic Beverton–Holt curve (see Mangel, 2010 Fish and Fisheries for equations). However, in order to be consistent with the combined-sex SSB, the parameter B_0 (which is for females-only in SS output) was converted to a combined-sex B_0 by using the ratio of combined-

[7] ICES. 2021. ICES fisheries management reference points for category 1 and 2 stocks. Technical Guidelines. In Report of the ICES Advisory Committee, 2021. ICES Advice 2021, Section 16.4.3.1. https://doi.org/10.17895/ices.advice.7891

sex biomass over female-only biomass in the first year of the assessment (which was close to unexploited).

5.7.1.2 Stock type and Blim

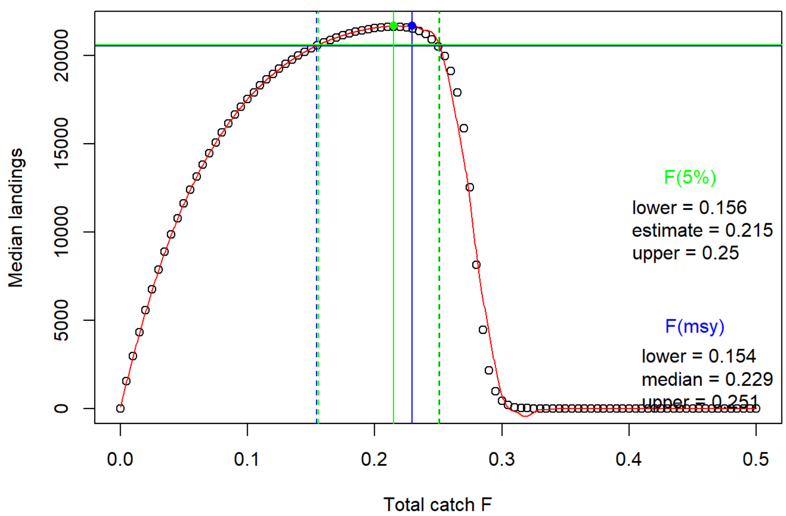


The stock–recruit relationship was examined for the period with length data only (1986 onwards). The stock type was identified as type 1 (spasmodic) or type 5 (no evidence of impaired recruitment). B_{lim} is defined as the lowest SSB with large recruitment (2004) for type 1 and as the lowest observed SSB (2003) for type 5. There was very little difference between the two options and the 2004 SSB was chosen as B_{lim} (19 524).

5.7.1.3 PA reference points

B_{pa} is estimated as B_{lim} plus model uncertainty. The estimate of error around SSB in the last year of the model was 0.153. This was considered to be very close the default value of 0.2 and therefore, better to use the estimated value within SS3, resulting in $B_{pa} = B_{lim} * \exp(1.645 * 0.2) = 25{,}113$

F_{lim} is estimated by simulating a stock with a segmented regression S–R relationship, with the point of inflection at B_{lim}, thus determining the F which, at equilibrium, yields a 50% probability of SSB > B_{lim}. This simulation is conducted without inclusion of a $B_{trigger}$ and without inclusion of assessment/advice errors.



The segmented regression simulation resulted in a large drop in yield for F values above 0.25. Therefore, F_{lim} was estimated at the relatively low value of 0.259. As this was inconsistent with F_{pa} (estimated later; using the BH SR and resulting in a much flatter yield curve) and because F_{lim} is not used for advice, it was decided to leave the F_{lim} reference point undefined.

5.7.1.4 FMSY and Btrigger

F_{MSY} is initially calculated based on an evaluation with the inclusion of stochasticity in a population and fishery as well as assessment/advice error but without the MSY $B_{trigger}$ advice rule. For this simulation the BH stock–recruit function with fixed B_0 (both sexes); R_0 and h parameters was used. The ICES default settings were used for cvF = 0.212; phiF = 0.423; cvSSB = 0 and phiSSB = 0. This resulted in an initial estimate of F_{msy} = 0.184.

The final simulation implements the ICES advice rule which should be evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having less than 5% annual probability of SSB < B_{lim} in the long term. The evaluation includes assessment/advice error and stochasticity in population biology and fishery selectivity. $B_{trigger}$ is defined as B_{pa} = 25113.

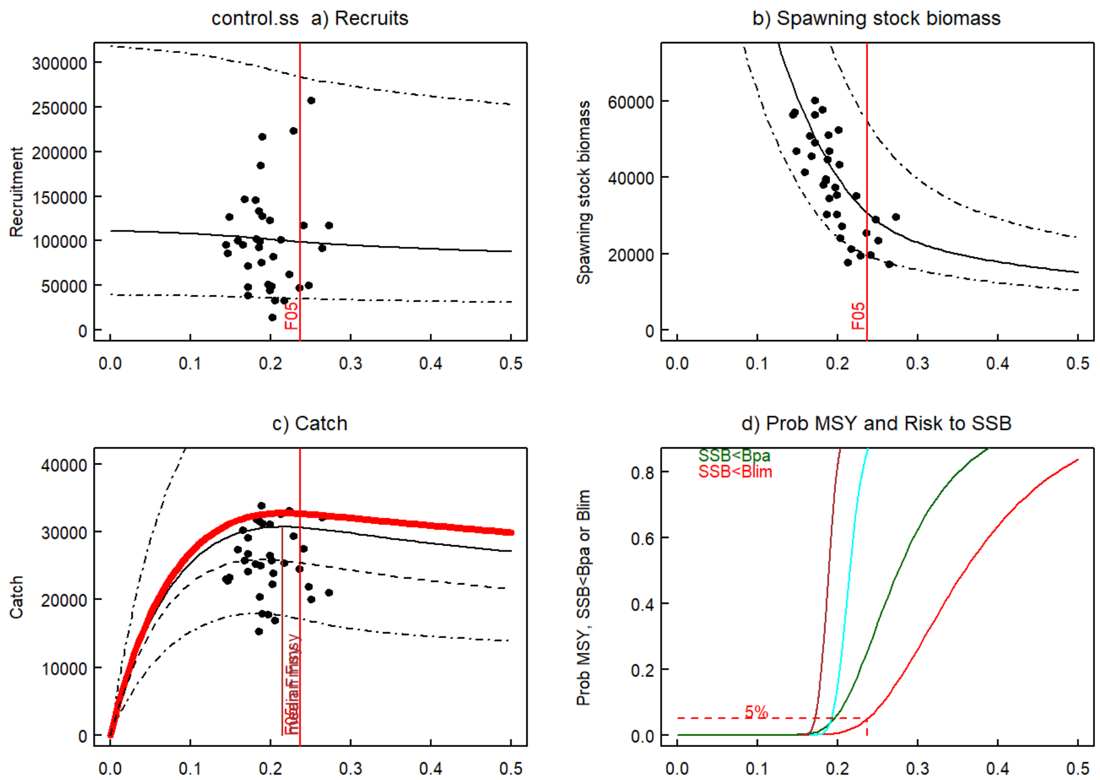


Figure 5.15. The final simulation (fixed Beverton–Holt SR and including advice rule). The x-axis shows F. Recruitment is almost independent of F due to the relatively high steepness assumption (top left). Equilibrium SSB is lower than the recently observed SSB (~50000), suggesting that SSB (and yield) will continue to increase at current levels of F close to 0.15 (top right). The yield curve (bottom-left) is quite flat-topped and fishing at Fmsy results in very close to fall below B_{lim} (bottom right). Note that the choice of stock–recruit relationship is influential in these results (i.e. segmented regression indicates a strong reduction in yield at F>0.25).

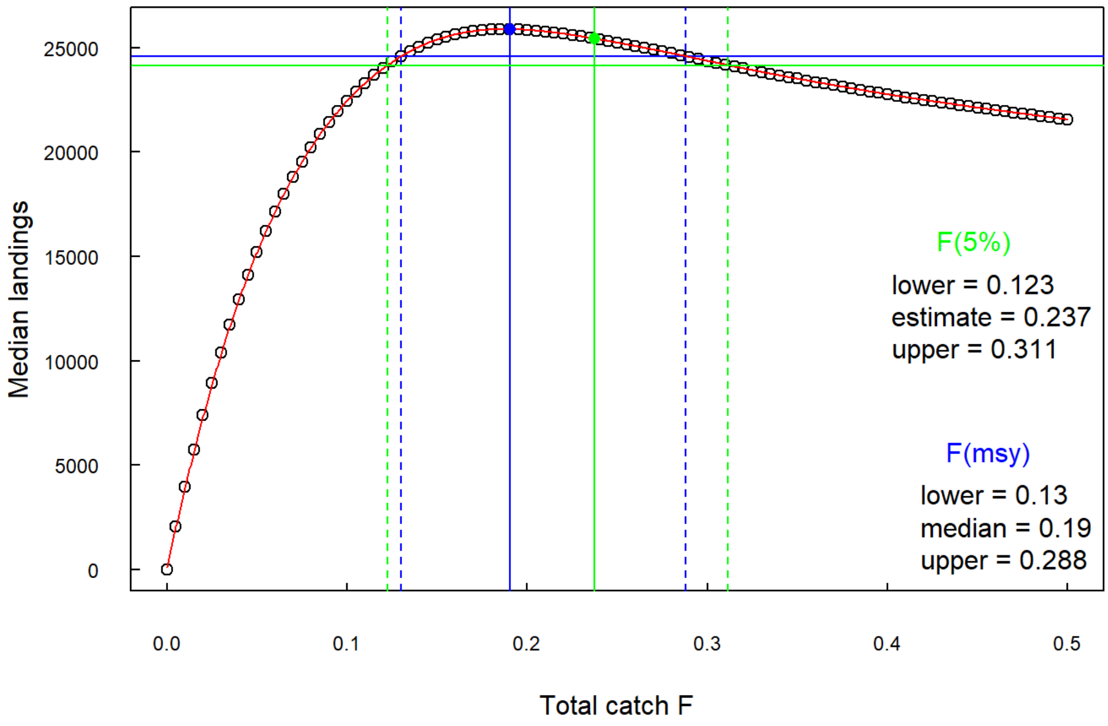


Figure 5.16. Fmsy is estimated at 0.19 in the final simulation with a range of 0.13–0.288. The upper range is over F_{pa} and therefore it assumed F_{upper}= F_{pa}=F0.5= 0.237.

The final reference points are as follows:

Reference point	Value	Rationale
B_{lim}	19525	SSB(2004); lowest SSB with high recruitment
B_{pa}	25113	B_{lim} with assessment error
MSY $B_{trigger}$	25113	B_{pa}
F_{lim}	Undefined (0.259)	F with 50% probability of SSB>B_{lim} (segreg without $B_{trigger}$), This is inconsistent with F_{pa} (which was estimated using a different stock–recruit relationship) and therefore F_{lim} will be undefined
F_{pa}	0.237	F with 95% probability of SSB ≥ B_{lim} (BH with $B_{trigger}$)
F_{MSY}	0.19	Stochastic simulations (BH with $B_{trigger}$)
$F_{MSYLower}$	0.13	Stochastic simulations (BH with $B_{trigger}$)
$F_{MSYUpper}$	0.237	The estimated value for FmsyUpper was over F_{pa} value, therefore, we assume $F_{MSYUpper}$ = F_{pa}
B_{MSY5pc}	25278	5% probability of SSB < B_{lim}

5.8 Forecast assumptions

The following are default forecast options. The working group will review these annually and adapt as necessary:

- Mean weights-at-age, maturity-at-age: These are fixed, so the values from the last year can be used;
- Discard proportions-at-age: average last 3 years;
- Exploitation pattern: average last 3 years;
- F status-quo average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year;
- F in the intermediate year: F status-quo;
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship;
- Recruitment in the last data year(s): if the working group believes these are not accurately estimated it can be replaced with the recruitment predicted from Stock Synthesis stock–recruit relationship.

5.9 References

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Annex 1: List of participants

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Annex 2: Resolutions

The benchmark workshop on anglerfish (*Lophius budegassa, Lophius piscatorius*) and hake (*Merluccius merluccius*) (WKANGHAKE) was chaired by Giuseppe Scarcella (CNR) and Massimiliano Cardinale (SLU), and reviewed by invited external experts Lisa Ailloud (NOAA), Matthew Smith (NOAA), and Dean Courtney (NOAA). The benchmark participants met online 23–25 November 2021 for a data workshop, and 14–18 February 2022 for a five-day assessment methods workshop. For all stocks in this benchmark, it was proposed to use Stock Synthesis (SS) as the assessment method. See also the work presented in WKTADSA[8] that was done in preparation of this benchmark for further details on model development. WKANGHAKE worked to:

8. As part of the data workshop:
   a) Publish an ICES data call for information on length and maturity data from sampled catches for hake to assist in validating the maturity ogive. Collate and analyse submitted data;
   b) Consider the quality of data proposed for use in the assessment;
   c) Examine the raising of discards in collaboration with representatives from WKMIXFISH;
   d) Make a proposal to the benchmark on the use and treatment of data for each assessment, including discards, surveys, life history, fishery-dependent, recreational, etc.;
   e) Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality.
9. In preparation for the assessment methods workshop:
   a) Following the data workshop, produce working documents to be reviewed during the benchmark assessment workshop at least 14 days prior to the meeting.
10. As part of the assessment methods workshop, agree to and thoroughly document the most appropriate:
    a) Method for conducting the stock assessment;
    b) Method and values for fisheries and biomass reference points that follow the best available science (i.e. taking into consideration the recommendations made by WKREF1 and WKREF2) and are in line with ICES guidelines (see ICES Technical Guidelines on reference points[9]);
       (i) If additional time is needed to conduct the work and agree to reference points, a short additional reference point workshop will be scheduled to conduct this work.
    c) Method for conducting the short-term forecast.
11. As part of the assessment methods workshop, knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. A full suite of diagnostics (regarding data, retrospective behaviour, model fit etc.) should be examined as a whole to evaluate the appropriateness of any model developed and proposed for use in generating advice.

[8] https://doi.org/10.17895/ices.pub.8004

[9] https://doi.org/10.17895/ices.advice.7891

12. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach see WKLIFE X[10] should be put forward by the benchmark;

13. Update the stock annex as appropriate; and

14. Develop recommendations for future improvements of the assessment methodology and data collection.

The benchmark will report by 18 March 2022 for the attention of ACOM.

[10] https://doi.org/10.17895/ices.pub.5985

Annex 3: Working documents[11]

Summary of working documents related to northern hake and issue list

Working documents

Working Document 01: Length-weight relationship parameters for Northern hake using linear models.

The objective of this study was to analyse if the current length-weight relationship parameters used in the assessment model of Northern Hake (ICES 1991) are still appropriate.

Using linear models and the dataset compiled for MEVA project in 2020, we estimated the length-weight relationship parameters for Northern Hake stock by sex, area (ICES area 7, 8 and 6) and year (from 2001 to 2019). The results indicated that there were differences in the length-weight relationship by sex, area and year. The weight of females was higher than males. The fishes in Area 8 had higher weight than fishes in areas 6 and 7. The weight of the fishes was lower in the most recent years. There was a clear temporal trend in the estimated mean weight of individuals, with lower weights in recent years. It was agreed to used three year blocks to model the variability of weight, using the data in those years to estimate the length-weight parameters.

A detailed description of this analysis is given in a working document presented to during the workshop.

Working Document 02: Maturity ogive for Northern hake using general binomial models.

The objective of this study was to verify if the current maturity ogive parameters used in the assessment model of Northern Hake (ICES, 2010) are still adequate to be used in the assessment and if there have been changes over time. The high increase in biomass in recent years could have produced an increase in the length at maturity.

Using the general binomial model and the spawning period data compiled by AZTI, the maturity ogive of Northern hake by sex and year was estimated (from 2001 to 2021, no data for years 2016 and 2020 was available) for area 8. The results indicated that there were differences in the maturity ogive by sex and year. The males matured at lower sizes than females. The fishes matured at earlier length in the past than in the most recent years. Overall, there were high differences between the values used historically and the values obtained from this study to define the maturity ogive of Northern hake. According to this study, the individuals mature earlier than historically is assumed.

The dataset used in this study is the most complete dataset we have to analyse the maturity ogive of Northern Hake. However, these data did not cover the whole distribution area of the stock. Thus, although this study showed that the individuals mature earlier than assumed in the assessment further analysis are needed to verify if the same happens in the whole distribution areas.

A detailed description of this analysis is given in a working document presented to during the workshop.

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[11] Working documents can be found in full below the four summary sections.

Issue list

The ‘base case’ for the model configuration of northern stock of hake is the configuration used in the assessment of the stock in 2021 in WGBIE (ICES, 2021). The input files are in the ‘Data’ folder of the meeting SharePoint.

In the table below different hypotheses (model configurations) in terms of data and model settings are listed. The performance of those alternative configurations will be evaluated using diagnostics and guidelines in Minte-Vera *et al*. (2021) and Carvalho *et al*. (2017, 2021) to detect model misspecification and discriminate between models. When introducing additional model complexity that do not lead to significant changes in the performance of the model the alternative model will be discarded in favour of current model configuration (base case).

Without modelling the stock development there are several things we know about the stock and fishery development that will help identify misspecification in model runs:

1. Fishing effort is believed to have decreased considerably during the last decades.
2. Biomass indices increased sharply from 2008 to 2016 and decreased since then. The catches had similar trend with a maximum in 2016, comparable to the historical maximum. The high increase in biomass produced an expansion of the stock to the North Sea. The subsequent decrease in biomass could be motivated by the high catches or the incapacity of the ecosystem to maintain the stock
3. The stock has not been able to maintain maximum catches around 100 thousand tones in two historical periods, around 1960 and around 2016. Thus, maximum sustainable yield should be below this limit. There was a stable period of catches around 60 000 tonnes. However, it was followed by a decrease in the catches and a recovery plan for the stock in 2004.

Issue	Comment
Age Data	There is no validated criterion to age hakes. Length data will be used solely.
Stock identity	Stock identity is unknown. Has been referred to SIMWG and WGAGFA – no resolution before this benchmark. Keep stock definition as is for now.
Maturity Ogive	Maturity ogive was calculated in 2010 using data only from Bay of Biscay and using a knife-edge curve with L50 = 42.85 cm. In the workshop time-series of L50 estimated using AZTI’s data (Bay of Biscay) was presented. L50 shown an increasing trend in the most recent years that could be due to both, change in the way resting individuals are assigned and a real trend in the biological process. After the working group a deeper analysis of data were conducted using data from the data call and DATRAS. There are differences between labs difficult to explain. It seems that resting individuals, difficult to distinguish from immature ones, are assigned systematically to immatures in some cases which leads to high L50 estimates. Further work will be conducted to ensure right L50 estimate can be obtained. With the high increase in biomass in the last two decades increases in L50 due to denso-dependence is not discarded but needs to be confirmed with data. Here 3 possible scenarios are presented but only the most likely will be tested based on available evidence. **Alternative scenario 1**: Overall maturity ogive estimated from data. **Alternative scenario 2**: Maturity ogive estimated from data with a temporal trend. **Alternative scenario 3**: No maturity data are used, biomass from certain age group used as a proxy of reproductive potential.

Issue	Comment
Length weight relationship	The length weight relationship used in the base case has parameters α=0.00513 and β=3.074 and was estimated in the 1980s. In a working document presented during the benchmark a trend in the estimated mean weight at length over time was observed. It was proposed to use 3-year blocks using the mean value in each block. **Alternative scenario**: 3-year blocks with 3 year mean value.
Growth parameters	In the 'base case' configuration L_{inf} and K are both fixed. L_{inf} = 130 cm and K ~0.17. De Pontual *et al*. (2013) based on tagging data proposed L_{inf} = 125 cm and K = 0.17. In a working document presented during the workshop Cerviño *et al*. (2021) proposed to calculate L_{inf} based on a meta-analysis on different hake species and life invariants. In this case L_{inf} is derived from maturity ogives. For northern hake, during the workshop inconsistencies were encountered in maturity data that needs to be further analysed. **Alternative scenario 1**: L_{inf} = 125 cm, if an accurate maturity ogive can be constructed for the stock the life invariants approach will be tested to check if 125 cm is consistent with biology theory. If not, L_{inf} obtained using life invariants will be considered. K = 0.17. **Alternative scenario 2:** Estimate K internally in the model. The model will be able to estimate K but it could impact negatively on the retrospective pattern.
Natural mortality	In 'base case' scenario M = 0.4 for all ages is used, the value is not based in scientific evidence. **Alternative scenario 1:** A mean value of M based on life invariants (Starting from L50 in the maturity ogive or L_{inf} = 125, depending on the quality of maturity data). **Alternative scenario 2**: Lorenzen model with intermediate value equal to that in scenario 1.
Steepness	Steepness is equal to 0.99 in the 'Base Case' which is considered inappropriate. As sigmaR is big enough to give flexibility to the model to estimate recruitment deviations adequately, the impact of different steepness values in the historical development of the stock is low. Steepness impacts in the estimation of virgin biomass, reference points and projections. Steepness value in FishLife package is equal to 0.68. From a precautionary perspective is better to use a value below the real one that overestimate it because the risk is lower. The benchmark chair proposes to use a two-stage profiling to tune steepness and SigmaR. **Alternative scenarios**: Test different values of steepness and based on the two-stage profiling and other model diagnostics select the most sensible value.
Initial condition	'Base Case' assumes that in 1978 the stock was in equilibrium to the mean catch in 1978–1982. This assumption may be wrong and impact on the estimation of the productivity of the stock. ***Alternative scenario:*** Reconstruct the time-series of catch back in time to start from an (almost) non-exploited state. There is some information on Spanish landings back to 1900, but rough assumptions will be necessary to split the catch between southern and northern stocks and to infer international landings from Spanish landings. Historically Spain has been the most important country in the fishery. The rational for this scenario is that it is better to have a rough assumption about historical catch and start form unexploited condition, than assume the stock was in equilibrium to a certain unknown catch at some point in the historical period.

Issue	Comment
Weight of the likelihood components	The amount of length data in the model (7 fleets + 7 surveys, 4 seasons, annual lfd data since 1978, seasonal since 1990) produces a big imbalance in the composition of the likelihood of the model, 97% of the likelihood comes from the LFD. This makes the model a bit 'insensitive' to other data sources. We have tried Dirichlet approach, and it only results in a small correction in one of the fleets. We have also down-weight the LFD component to see the impact. When the LFD component is multiplied by 0.01, the surveys are better estimated, and the abundance estimates at the beginning of the series are more consistent with 'a priori' expectations. Weighting of likelihood components need to be further investigated based on existing literature and in deep analysis of model performance. ***Alternative scenario:*** Alternative weights based on existing knowledge will be tested.
Irish Survey	A new Irish survey starting in 2016 was presented during the workshop. This index has a wide coverage along Celtic Sea and targets bigger individuals than EVHOE and IE-IGFS. The index could be useful to have more information on big individuals and sex ratio for sex-separated model- ***Alternative scenario***: Inclusion of this index will be tested, and performance of the model analysed.
OTHER fleet	OTHER fleet that accounts for catches in the northern part of the stock distribution (ICES divisions 3, 4 and 6) was a minor fleet in the past but with the expansion of the stock its contribution to the total catch is around 30%. This fleet includes catches from different gears like trawlers and gillnetters. During the workshop it was considered necessary to disaggregate this fleet into two segments, Trawlers and Non-Trawlers. The disaggregation is only possible since 2013 when Intercatch was first used for reporting catch data. ***Alternative scenario***: An alternative scenario is proposed with two new fleets, OTHER fleet as it is now until 2012. Since 2012 we introduce two new fleets, OTHER-TR and OTHER-NTR-
Selectivity	When all the fleets have dome-shape selectivity the abundance estimates in most recent years are too high. The 'base case' has two fleets with logistic selectivity. ***Proposal***: Maintain logistic selectivity in the two fleets for the moment and when the new configuration is almost final test what happens changing them to dome shape.
Discards	Discards are not raised externally; even if discards are estimated internally they could be underestimated. It was proposed to check the data and raise the discards externally in some cases where no samples are available, and discards are likely to occur. **Alternative scenario**: Discards data raised externally.
Sex disaggregated configuration	Hake is a dimorphic species with very different growth pattern by sex, while females reach more than 130 cm it is rare to observe males above 80 cm. A first attempt to adjust a sex-disaggregated model with data from SP-PORCUPINE survey has been made. However, the results are not satisfactory. The abundance estimates in most recent years are too high.

Issue	Comment
	More work is needed in the sex-disaggregated configuration, adding new irish survey could help. As EVHOE survey targets juveniles where sex determination is difficult it does not provide many data but could also help. Not clear what would be better, to work in the sex disaggregated configuration first and then work in the other issues, or the other way around. ***Alternative scenario:*** Sex disaggregated configuration of the model.

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Summary of working documents related to southern hake and issue list

Working documents

<u>Fleets and indices review</u>

The last stock assessment model for the southern Atlantic hake (*Merluccius merluccius*) stock was carried out in GADGET with data from 1982 to 2020. This model was rejected in 2020 mainly due to problems with the retrospective pattern and other alternatives were explored. The current model in progress is Stock Synthesis, which progress was already presented in the WGBIE 2021. In this new model, the main differences on the input data for fleets and indices (surveys and CPUEs) in terms of catches and Length Frequency Distributions are: historical mixed fleet (1948–1981), modern fleets separated data (1994–2020), new standardized CPUE indices for Spain and Portugal, sex separated data for Spanish and Portuguese surveys and discards of the trawl fleets. In the working group, the next main issues have been addressed: 1) Split the historical mixed fleet (which has no LFD) in two fleets in order to give them the LFDs of existing ones. 2) Combine separated fleets from the periods 1982–1993 and 1994–2020 by setting in SS a different group plus for each period (80+ and 100+, respectively). 3) Combine a Spanish CPUE for big individuals (longline, gillnet) and test the combination of another one for trawlers with their associated LFD or by mirroring the other fleets LFDs. 4) Use sex separated data in SS to construct the sex separated model and to estimate the sex ratio of the stock. 5) Assume 0 discards for trawlers before 1991. All the available fleets and indices data (catch and LFDs) for the stock can be seen in the document SouthernHake_1-CatchDataReview.html.

There is only Portuguese catch data from 1948 to 1971. Spanish data are not reliable because Spanish catch statistics were recorded without considering the origin of the catch but the harbour of landing. This means that catch assigned to 9.a were caught both in 9.a and in the North of Africa and catches assigned to 8.c were caught in the whole 8 area. It is worth to notice that this situation was extended until 1986. Current available data for Spain from 1972 to 1986 was estimated at the beginning of the 1990s based on experts' experience. Taken this limitation in consideration Spanish catch data for 1948 to 1971 was estimated assuming the same catch ratio between the countries as the mean observed in the period 1972 to 1981. However, the quality of these data is weak and must be considered in the SS model.

See Working Document 03.

Length-weight relationship review

The current length-weight relationship that has been used for the southern stock was carried out in 1999. This relationship provides global (not time-specific) estimates of the *a* and *b* parameters ($W_i = a\ L_i^b$, $i=1, \ldots, N$, being *N* the total sample size). More precisely, the actual values are *a=0.00659* and *b=3.01721*. Hence, a review of the length-weight relationship has been done addressing: (i) estimation of global (not year specific) *a* and *b* using the updated length-weight data, (ii) estimation of year specific *b* (and common *a*), and (iii) estimation of global *a* and *b* by sex. The time-series of predicted weights along the years for the lengths *20, 30, ..., 90, 100 cm* have been derived from (ii). The year variability of the series is almost negligible supporting that year specific *b* estimates are not required. The curves for females and males derived from (iii) are very similar for the range of lengths for which data of both sexes is available. All these results led to conclude that the proposition of a model not counting for sex differences can be suitable. The final proposal is to update the *a* and *b* values using the estimates derived from the global model (i) using data from 2003 to 2019. This period corresponds to years for which the sample sizes of both countries are considerable. The updated values are: *a=0.00377* and *b=3.16826*.

See Working Document 10. Details of the analysis are reported in the working documents section as WD10_*Southern_Hake_LengthWeightStudy.html* (all the code is on the Software section as *Southern_Hake_LengthWeightStudy.Rmd*).

Maturity ogives combining Portuguese and Spanish data

A review of the maturity data analysis has been carried out to address the following issues: (i) the change from a common maturity ogive to a female maturity ogive which is expected to provide a more realistic measure of the stock reproductive potential, and (ii) the inclusion of the Portuguese maturity data that was not included in the model previously due to the unbalanced sampling (compared to Spain) and because of the latitudinal length-at-maturity gradient. Issue (i) has an immediate solution, whereas (ii) requires the following discussion. Previous analysis provides evidences that in Portugal the maturity occurs at lower lengths than in Spain. In fact, a regression logistic model (generalized linear model) has been fitted explaining the maturity (binary response, immature/mature) using the length and the country factor leading to two statistical different ogives one for each country.

The maturity data covers from 1980 to 2019, however, while the data for Spain cover the entire period, we have missing Portuguese data for some years. Furthermore, the samples sizes by year for each country are not balanced. For that reason, the modelling ignoring the country is not a suitable option. Other option can be a weighted average of the country ogives, but for that it is necessary to decide which weights must be used. After some research, we have found a possible solution using a Bayesian approach. Our proposal is a bivariate Bayesian regression model using the integrated nested Laplace approximation (INLA) (Rue *et al.*, 2009) approach in the R-INLA software (https://www.r-inla.org/).

The bivariate model response considers separately two maturity variables, each for each country. The two response variables are explained using length and year covariables. The model formulation in terms of covariables depends on the aim: - (i) a standard year combined maturity ogive or - (ii) a combined maturity ogive by year. On (i) the common predictor for the two responses is equal to an intercept plus a linear effect of the length plus a year random effect. The year random effect is changed by a year factor for (ii) approach. The model carried out a combined estimation of all the parameters of the common predictor providing a combined maturity to introduce in the stock assessment model. It is important to mention that year covariable has the following categories: 1980–2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017–2019. We define 1980–2000 and 2017–2019 groups since for such years IPMA information is missing and IEO sample size is low. The model using the year factor without grouping has been also fitted but the L_{50} (length at 50% maturity) time-series shows huge jumps from one year to the next. Hence, the smoother using the year categories 1980–2000 and 2017–2019 is considered a suitable choice and our proposal to introduce the maturity ogive parameters in the stock synthesis model.

See: Working Document 09. A whole description of this analysis can be found under: WD09_*Southern_Hake_MaturityStudy.html* (all the code is on the Software section as *Southern_Hake_MaturityStudy.Rmd*).

<u>Estimating biological parameters (L_{inf}, k and M) with Bayesian hierarchical analysis based on life-history invariants.</u>

Hake stocks in ICES area can be considered "data poor" stocks in terms of biological information, being this one of the main difficulties to get a good assessment model. Difficulties to estimate growth, as well as the usual problems in estimating M compromise a good quality assessment model. However, there is a lot of biological information in similar species that can help to fill this gap. Life-history invariants theory and hierarchical Bayesian models can be combined to better understand biological processes needed in most stock assessment models (maturity, growth and natural mortality) providing the required parameters together with their statistical structure (posteriors). As an example of this approach we use the two European hake stocks in the Northeast Atlantic Ocean. The Bayesian hierarchical analysis provides posteriors for the main biological L_{inf}, k and M. In the case of Southern hake, for which sex maturity at length data are available sex separated parameters are also provided. However, these results cannot be used directly in SS and further work is required to implement these in the SS model. Options to do it include fix some of them and allow SS to estimate others, use the posteriors as SS priors or combine these two options.

Data	L_{inf}.mean	L_{inf}.sd	k.median	k.CV	M.median	M.CV
North combined	123.416	18.267	0.164	0.107	0.279	0.129
South combined	97.613	16.183	0.189	0.114	0.32	0.134
South female	122.175	17.374	0.165	0.103	0.28	0.127
South male	79.61	12.28	0.212	0.104	0.361	0.126

Preliminary estimates

Warning! An error in the database of *Merluccius* information was found an we are now revising these data to guaranty that the selected records accomplish the quality required for this kind of analysis. Results presented here should be considered preliminary although the methodology proposed are the definite one.

A whole description of this analysis can be found in Working Document 03.

<u>Portuguese LPUE Standardization</u>

At previous benchmark workshop (WKROUND, 2010), Cardador and Jardim (2010) presented a standardization LPUE model for hake (*Merluccius merluccius*) only considering the positive catches of hake with a Gamma generalized linear model (with log link). The explanatory variables were *year* (as factor), *area* (north, southwest, south and no specified area), *engine power* (nine levels, in 100 kW class intervals, ranging from 100–1000 kW), *trawl duration* (5 levels, in 4-hour class intervals equivalent to 1 to 5 hauls in average per day), *log total catch classes* (6 levels), *proportion of hake in the total catch* (low, medium and high), *métier* (assigned to each record based on the predominance of some species (HOM – horse mackerel, CEF – cephalopods, WHB – blue whiting and MIX – other, according to the cluster analysis presented in Silva et. al 2009). The final LPUE is predicted considering one reference level of each factor.

In this work we tested various models to improve the Portuguese hake trawl LPUE model taking also into account the null observations present in the dataset. A GLM assuming a Tweedie distribution was considered adequate to model the hake LPUE since a reasonable explained deviance was obtained with the advantage of accounting for the information given by the zero-valued observations.

Further details on the analysis are reported in the Presentations section under "Southern-Hake_*PT standardized LPUE_Summary of results.pdf*" document.

<u>Spanish fleets CPUE standardization.</u>

The Southern stock of European hake (Merluccius merluccius) is fished by a Spanish multi-gear fleet operating in the Cantabric-Northwest fishing ground. The fleet includes vessels using trawls (bottom, midwater and pairs), gillnets ("volanta"), and bottom-set lines targeting different portions of the population, from smaller individuals by the trawlers to larger specimens by the hooks. The objective of the analysis was to standardize the hake catches from the Spanish fleet operating in Iberian waters (8.c and 9.a) using two sources of data.

Data were obtained from i) onboard observers (OAB) for 3 trawl métiers (baka, jurelera and pareja) and 1 gillnet métier (volanta) from 2003 to 2020, and from ii) logbooks (DEA) for the bottom-set longlines from 2009 to 2020. Data included for each haul or fishing operation *i* the catch, the vessel characteristics (LOA = Length overall), fishing operation information (HD = haul duration, FT = fishing time, DE = haul depth) and spatio-temporal data that varied depending on the source. The standardization process was based on fitting mixed-effects models assuming a Gamma distribution with a log link using the INLA approach as follows:

For OAB data: $C_i = \alpha + Year_i + Quarter_i + LOA_i + HD_i + DE_i + u_i$ with u_i ~ GMRF(0,$\sum$)

For DEA data: $C_i = \alpha + Year_i + Quarter_i + LOA_i + FT_i + a_r + \epsilon_i$ with a_r ~N(0,σ_a^2)

"Hot spots" of hake catch mostly occurred in Galician waters and to the east of the Cantabric Sea. Catch typically increased with vessel length, with the exception of the pairtrawlers, and with duration of the fishing operations, with the exception of the gillnetters. Hauls performed in deeper waters were associated with less catches, but for the gillnet. Catches were generally higher in winter and spring months and were roughly stable since 2009, though a slight increase was also apparent for otter trawls and longlines.

The 3 trawlers are combined in a unique index for small fish and the gillnet and longline, targeting larger fish, are also combined weighted them by the inverse variance. These combinations will be explored in SS calibration.

Further details on the analysis are reported in the Presentations section under "Southern-Hake_SpCPUE_Otero et al _WKAngHake_Benchmark_2021.pdf"

Issue list

Stock identity	
Issue	**Northern and southern Atlantic hake stocks are a single stock.**
Description	Stock ID area, hybrids (SIMWG and WGAGFA). There are not clear boundaries in North and South 8.c 9.a. No biological reason to separate both stocks.
Proposed solution	Presumably not resolved before benchmark.
Work to do	Very future: join both stocks in a spatial SS model.
Hypothesis to test	None.

Catch	
Issue	**Which catch data must we use?**
Description	Period 1948–1971: there is only Portuguese data. Period 1972–1981: No length no fleets. Only yearly catch by country. Period 1972–1985: Spanish data estimated in 1990s by Sp experts. No document found. Period 1982–1993: new data disaggregated by fleet and length distribution. Yearly and 80+ cm. Period 1994–present: the same as usual, seasonally data with LFD 100+ cm. Evaluate fleet groups proposal.
Proposed solution	Period 1948–1981: use ratio Spain/Portugal to extend historical fleet catch data. Divide historical fleet (1948–1981) in trawlers and volpal by mirroring the selectivity (LFD) of the modern fleets. Combine fleets 1982–1993 with fleets 1994–2020.
Work to do	Ask and review Punzón work on historical catch review. Check length distributions to combine fleets Extend modern fleets to the past: Divide current historical fleet with ratio/proportions of catches in modern fleets. Construct 2 artificial historical fleets and mirror selectivity
Hypothesis to test	Sensitivity analyses with truncated catch time-series (e.g. 1948–20; 1972–20; 1982–20) Downweigh older data

Discards time-series	
Issue	**Incomplete discards time-series.**
Description	Discards. Complete data after 2003. Some gaps before. Assumed 0 before 1991. How to link? Cadiz Trawl discards inly available after 2005. Small (< 100 t) compared with whole stock (~2000 t)

Proposed solution	Assume zero discards for fleet trawlers before 1991. Volanta and Palangre does not have discards. Assume zero discards for Cadiz trawl fleet
Work to do	Assume zero discards before 1991. Probably some discards happened but there was a market for small fish . Identify and eliminate estimated discards (in 2014 benchmark) for the period 1991 to 2003. Decide how to address 2020 discards (low sampling)
Hypothesis to test	Allow SS to estimate discards in the period 1991–2020 for years without data.

LFDs landings and discards	
Issue	**Different plus groups in LFDs.**
Description	LFDs in 1982–1993 with 80+ cm. After 1993 the complete DB is available with all Ld data available. How to link fleets?
Proposed solution	Rick Methot said that it is possible to have different data bins for two periods in each fleet.
Work to do	Apply the correspondent settings.
Hypothesis to test	None.

Portuguese CPUE	
Issue	**Pt CPUE standardization**
Description	New std CPUE with zero catch data
Proposed solution	New model developed and presented to WKANGHAKE data meeting.
Work to do	Compare models 6 and 11 in relative scale. Explore correlations among variables. Select one CPUE model index and use it mirroring the LFD from trawlers.
Hypothesis to test	None.

Spanish CPUEs	
Issue	**Sp CPUEs standardization**
Description	New standardized CPUEs for the different Métiers.
Proposed solution	Important to have a good CPUE for big individuals (Volanta and Palangre fleets). Combine this as a single CPUE index. Regarding trawlers, try to group 2 trawls (pair and midwater). Check length distributions (SS out and Observed onboard)

	Test alternatives with SS.
Work to do	Combine indices by the inverse of the variance? Input them into SS. Check LDs and join the 3 trawl fleets. Report WG about CPUEs LDs (Discard Atlas) Explore data selection for LLS-DEF (PAL11, y LLS11). Test wheter both have the same effort measure and combine if possible. Otherwise select fleet > 12 m
Hypothesis to test	Combine in two CPUEs for big fish (gill+longline) and small fish (trawls) Test the use of the CPUE associated LFDs or mirror the modern fleet LFDs.

Length-weight	
Issue	**Review of the length-weight relationship.**
Description	Estimation of global (not year specific) length-weight parameters. Estimation of year specific parameters. Estimation of parameters by sex.
Proposed solution	No relevant differences by year neither sex. Update the length-weight parameters using the estimates derived from the global model (data from 2003 to 2019).
Work to do	Use parameters in SS.
Hypothesis to test	Update l-w parameters in SS and proceed. Check impact compared with previous model.

Maturity	
Issue	**Maturity Ogive values to use.**
Description	Maturity ogive using females. Inclusion of the Portuguese maturity data: (i) a standard year combined maturity ogive (not time specific). (ii) a combined maturity ogive by year. (iii) a combined maturity ogive by year categories (groups of years).
Proposed solution	Bivariate Bayesian regression model using INLA approach in the R-INLA software (https://www.r-inla.org/). The bivariate model response considers separately two maturity variables each one for each country. The model carried out a combined estimation of all the parameters of the common predictor providing a combined maturity. High variability of the L_{50} (length at 50% maturity) time-series from (ii). The smoother using the year categories is considered a suitable choice. The year categories have been derived from an exploratory analysis in accordance also with a structural change analysis.
Work to do	Introduced the maturity ogive parameters by each year category in SS.

Hypothesis to test	Update maturity logistic parameters in SS and proceed. Check impact compared with previous model.

LHI	
Issue	**Life-history Invariants for biological parameters estimation (by sex)**
Description	Life-history invariants and Bayesian hierarchical analysis to develop posteriors for L_{inf}, k and M.
Proposed solution	Perform the analysis from Lmat data.
Work to do	Input values in SS regarding different hypothesis. Review data selection.
Hypothesis to test	Develop a list of biological hypotheses for L_{inf}, k and M (use as priors, use as fixed, etc.). Fix L_{inf} and explore others. Priors to help SS to estimate unknow parameters. Explore different alternatives in SS. Lorenzen, M at age, single M.

Summary of working documents related to black anglerfish and issue list

Working documents

WD04 – Growth estimates for black and white anglerfish in 7, 8.a, 8.b, and 8.d and hake in 3.a, 4, 6, 7, 8.a, 8.b, and 8.d using cohort analysis of length–frequency distributions.

Age cohorts were identified from survey length frequency data in order to estimate growth parameters because no reliable direct ageing methods are available. The estimated parameters are intended to be used as priors or assumed values in Stock Synthesis models, as well as the basis for life-history-based analysis such as estimating M or maturity-at-age.

The estimated von Bertalanffy growth parameters are listed below:

Stock	Sex	L_{inf}	k	t0
Black anglerfish in 7, 8.a, 8.b, and 8.d	Both	132	0.097	-0.031
	Female	129	0.101	0.009
	Male	78	0.197	0.099

The male growth parameters are estimated with poor precision because large males are rare and it was agreed to investigate a method by Cerviño (2014) to improve the estimate of male growth parameters, based on the sex-ratio at length.

Working Document 05: Maturity - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

Length at 50% maturity (L50) was estimated from Irish Survey data. Age at 50% maturity is inferred from growth parameters estimated from length cohort analysis (see WD 04)

Stock	Sex	L50	A50 (approx.)

Black anglerfish in 7, 8.a, 8.b, and 8.d	Female	62 cm	Age 6
	Male	48 cm	Age 5

Alternatively, L50 was estimated using the regression between L50 and latitude, based on estimates from the literature and the current study. The stock ranges from 44.5°N to 54.5°N; in the middle of the stock range the expected L50 is as follows:

Stock	Sex	L50	A50 (approx.)
Black anglerfish in 7, 8.a, 8.b, and 8.d	Female	58 cm	Age 6
	Male	40 cm	Age 4

A third alternative could be to only use estimates from the literature that have been validated using histology. The slope of the regression with latitude could be used to correct for any bias resulting from the sampling region.

Working Document 06: Natural mortality - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

Natural mortality estimates were explored using a variety of methods. Methods using growth parameters yielded low estimates of M (0.15–0.16). Methods based on the age at first maturity resulted in intermediate estimates of M (0.26–0.37); methods based on GSI resulted in high M for females (0.45) and low M for males (0.11). The FishLife method (Thorson *et al.*, 2017) based on a range of life-history parameters and taxonomic hierarchy gave an intermediate estimate of M (0.32). Methods based on size-at-age (like Lorenzen) have very little prediction power for larger fish (for which predation is probably not the main cause of natural mortality). Therefore, it is proposed to use a fixed M for fish aged 4 and older and M estimated using the Lorenzen method for younger fish. The Thorsen estimate of 0.32 is proposed as a base case but values between 0.15 and 0.45 can all be considered plausible.

Issue list

The issue lists for white and black anglerfish are presented together (in the white anglerfish section) because the issues and proposed solutions are very similar for the two stocks.

Summary of working documents related to white anglerfish and issue list

Working documents

Working Document 04: Growth estimates for black and white anglerfish in in 7, 8.a, 8.b, and 8.d and hake in 3.a, 4, 6, 7, 8.a, 8.b, and 8.d using cohort analysis of length–frequency distributions.

Age cohorts were identified from survey length frequency data in order to estimate growth parameters because no reliable direct ageing methods are available. The estimated parameters are intended to be used as priors or assumed values in Stock Synthesis models, as well as the basis for life-history-based analysis such as estimating M or maturity-at-age.

The estimated von Bertalanffy growth parameters are listed below:

Stock	Sex	L_{inf}	k	t0
White anglerfish in 7, 8.a, 8.b, and 8.d	Both/Female	165	0.112	-0.084

	Fixed L_{inf} medium	130	0.159	0.031
	Fixed L_{inf} low	100	0.245	0.180

Separate parameters for males and females could not accurately be estimated because large males are rare. By fixing L_{inf} to intermediate and low values and fitting k and t0, plausible parameters for males were explored. It was agreed to further investigate a method by Cerviño (2014) to improve the estimate of male growth parameters, based on the sex-ratio at length

Working Document 05: Maturity - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

Length at 50% maturity (L50) was estimated from Irish Survey data. Age at 50% maturity is inferred from growth parameters estimated from length cohort analysis (see WD 04)

Stock	Sex	L50	A50 (approx.)
White anglerfish in 7, 8.a, 8.b, and 8.d	Female	90 cm	Age 7
	Male	58 cm	Age 4

Alternatively, L50 was estimated using the regression between L50 and latitude, based on estimates from the literature and the current study. The stock ranges from 44.5°N to 54.5°N; in the middle of the stock range the expected L50 is as follows:

Stock	Sex	L50	A50 (approx.)
White anglerfish in 7, 8.a, 8.b, and 8.d	Female	81 cm	Age 6
	Male	52 cm	Age 3

A third alternative could be to only use estimates from the literature that have been validated using histology. The slope of the regression with latitude could be used to correct for any bias resulting from the sampling region.

Working Document 06: Natural mortality - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

Natural mortality estimates were explored using a variety of methods. Methods using growth parameters yielded low estimates of M (0.15–0.18). Methods based on the age at first maturity resulted in intermediate estimates of M (0.22–0.28); methods based on GSI resulted in high M for females (0.45) and low M for males (0.11). The FishLife method (Thorson *et al.*, 2017) based on a range of life-history parameters and taxonomic hierarchy gave an intermediate estimate of M (0.36). Methods based on size-at-age (like Lorenzen) have very little prediction power for larger fish (for which predation is probably not the main cause of natural mortality). Therefore, it is proposed to use a fixed M for fish aged 3 and older and M estimated using the Lorenzen method for younger fish. The Thorsen estimate of 0.36 is proposed as a base case but values between 0.15 and 0.45 can all be considered plausible.

The issue lists for white and black anglerfish (in 27.78abd) are presented together because the issues and proposed solutions are very similar for the two stocks. Unless stated explicitly, the same proposals apply to both stocks.

Hypotheses are listed below where models with different settings/data will be compared using diagnostics which may help detect model misspecification (guidance in Minte-Vera *et al.*, 2021; Cavalio *et al.*, 2017; 2021). The hypotheses are structured so that the 'base case' is the preferred option. If diagnostics do not indicate a clear difference between two options, the base case will be taken forward. In this way the 'rules of the game' are specified beforehand and choices between alternatives are clearly justified.

Without modelling the stock development there are a number of things we know about the stocks that will help identify misspecification in model runs:

1. The two stocks of anglerfish have sustained annual landings between 20 and 40 thousand tonnes with no downward trends after the initial peak in the 1980s.
2. Fishing effort of the dominant fleets in the area has decreased considerably since the 1990s, in the period time landings have shown an increasing trend.
3. Biomass indices have increased substantially in recent years.

Point 1) indicates that the stocks have been sustainably exploited (they never collapsed) but it does not indicate whether or not long-term yield could be further improved by reducing fishing effort. Points 2) and 3) suggest that the recent reduction in fishing effort has led to an increase in biomass, so F in the past was likely higher than Fmsy but current F may be reasonably close to Fmsy (possibly below). Therefore, any models that indicate that the stocks are currently highly under or overexploited (e.g. less than 0.5*Fmsy or more than 1.5*Fmsy) are likely to be misspecified. Similarly, biomass is currently high, it is unclear how much of a further increase in biomass can be sustained by the ecosystem but any model that estimates B0 to be more than, say, 4 times current biomass is likely misspecified.

Making these assumptions is not the same as 'cherry-picking' a model configuration that matches our expectations; instead they are intended to identify broad problems with the specification of the model.

Issue list

Age data	
Issue	**No direct age data**
Proposed solution	Length-based model (without ALK data)
Stock identity	**Stock identity is unknown**
Proposed solution	Has been referred to SIMWG and WGAGFA – no resolution before this benchmark. Keep stock definition as is for now.

Surveys	
Issue	**Which sample size to use.** Use actual sample size or an artificial number (which allows manual scaling of the relative influence of each survey)?
Proposed solution	Agreed to use the actual number of hauls in each survey as the sample size input.
Work to do	HG to provide number of hauls per year for FR-IE-IBTS and IAMS.
Issue	**Biomass index or abundance?**
Proposed solution	Probably not important

Hypothesis to test	Base case: abundance indices Compare against: biomass indices
Issue	**Length frequency by sex?**
Proposed solution	This can be made available for FR-IE-ITBS and IAMS (MONK) surveys. Agreed that this would be useful considering the sexual dimorphism.
Work to do	HG to make available length data by sex for the 2 surveys. AU and HG to build base case models with separate biological and survey length data by sex.
Hypotheses to test	Base case: survey length data separated by sex Compare against: survey length data combined sexes
Issue	**Which indices to use?**
Proposed solution	Surveys have good coverage of the population, so no need to use fishery-dependent data. The following surveys will be included in the model FR-IE-IBTS as before but length data split by sex IAMS (MONK) as before but length data split by sex and remove the first two years as the survey coverage was different in those two years and the time-series is now long enough to be used without these years (6 years). SP-PORC only for white anglerfish as the catch numbers for black anglerfish are too low to build an index. Small white anglerfish show up in the index in some years but not in others; this is probably because small fish only occur in a small part of the survey area which may not be sampled each year. The proposal is to retain these fish and accept that they will result in large residuals. We understand why these residuals occur and it was considered better than to arbitrarily remove small fish unless they cause unsurmountable problems with fitting the model.
Hypotheses to test	(white angler only) Base case: include all length data from SP-PORC Compare against: Remove <40 cm fish Omit SP-PORC survey entirely (it covers only the porcupine bank area and this area is now also covered by IAMS).

Catch data	
Issue	**Which resolution of catch data?**
Proposed solution	Annual landings and discard data (data are available at quarterly resolution but these data seem very noisy; Some discard data were estimated on annual basis and split out across quarters) Single area. There are known differences between areas (27.7 vs. 27.8abd; shelf/slope and porcupine bank) but it was considered too complicated for a first benchmark using SS. This will be considered at future benchmarks. Multiple fleets. Initial models were set up using a single fleet but selectivity of bottom trawlers, gillnets and beam trawlers is clearly different. Although the proportion of these fleets is quite stable over time, this may not continue into the future. Catch data are not available by sex; survey sex ratios probably not suitable to split so use unsexed catch data.
Work to do	AU and HG to explore historic data to decide on fleet groupings. Gear only, split OTB in whitefish/*Nephrops*, split by country

Hypotheses to test	Base case: multiple commercial fleets Compare against: Single (combined) commercial fleet
Issue	**Which time-series of landings to use?** The official landings data shows a very sharp increase in French landings in the late 1960s. It is unclear if this was an emerging fishery or a change in reporting practices.
Proposed solution	Use official landings from 1920 to 1986, use ICES estimates after. The development of the landings after WWII shows a fairly typical pattern so there is no strong reason not to believe the data. These data are reported for the two species combined, so use country-specific species split. Also use country-specific fleet split to allocate landings to same fleet groupings as 1986 onwards.
Hypotheses to test	Base case: Official landings Compare against: Equilibrium landings before 1986
Issue	**Which assumptions to make about historic discards?**
Proposed solution	Discard data are available since 2003. Landings length data are available from 1986 and these data suggest that discarding occurred in the period 1986–2002 (very few small fish were landed). Before 1986 no length data available and in terms of tonnage, discarding is negligible, therefore assume zero discards before 1986. For the period 1986–2002 let the model estimate discards using a retention curve.
Issue	**Which sample size to use?**
Proposed solution	Sample size from InterCatch is unreliable as some countries merge samples and then split them out across strata, creating duplicate values for sample size. Actual sample sizes are reported in WGBIE and WGSSDS reports – these should be used.
Work to do	AU and HG to compile sample sizes from working group reports.

Recruitment	
Issue	**Recruitment timing**
Proposed solution	Spawning happens in the first half of the year so assume 1 Jan.

Selectivity	
Issue	**How to specify selectivity curves for fleets and surveys?**
Proposed solution	Use double normal by default as this is very flexible. Consider logistic selectivity for IAMS survey as it has good coverage of the stock area and depth range.
Hypotheses to test	Base case: double normal for all fleets and surveys Compare against: Logistic for IAMS survey only

Growth parameters	
Issue	**Fix growth or model estimate?** Early model runs converged on unrealistically low L_{inf} (e.g. considerably less than 80% of largest observed individual)

Proposed solution	Fix growth parameters
Work to do	HG: Growth parameters were estimated using cohort tracking in length data from surveys. These are likely to be dominated by females as the older male cohorts are 'drowned out' by the larger females. Male growth curves may be estimated using an approach published by Cerviño (2014). Possibly the model can estimate different growth curves for males and females using biphasic growth.
Hypotheses to test	Base case: fixed growth parameters for females, model estimated for males (based on sex ratio-at-length data) Compare with: fixed growth parameters, different for the sexes fixed growth parameters, same for both sexes model-estimated parameters, different for the sexes It may also be useful to explore biphasic growth settings using the age as maturity as a cut-off between the phases.

Maturity	
Issue	**Which age at maturity to use?**
Proposed solution	Only use histology studies / use expected value for latitude – to be decided

Natural mortality	
Issue	**Which assumption to make for natural mortality**
Proposed solution	Explore range of credible values of M (see WD). Use Lorenzen and fix M for older fish (Lorenzen works well for relatively small fish)
Hypotheses to test	Base case: Lorenzen with intermediate value for M for age 3 or 4 (same for both sexes) value to be decided (probably in the range of 0.30–0.35). Compare with: * Low M for both sexes (e.g. 0.15 or other value to be decided) * high M for both sexes (e.g. 0.45 or other value to be decided) * higher M for females than males (based on assumed mortality due to high GSI) * higher M for females let model estimate the difference between the sexes

Stock–recruit	
Issue	**Which stock–recruit parameters to use** Early runs where the model was allowed to estimate steepness usually resulted in unrealistically high values (0.99).
Proposed solution	Fix steepness. BH with fixed sigma R and steepness from FishLife. Risk is asymmetric so be cautious (better use lower steepness). Use 2-stage profiling (max has script).

Hypotheses to test	Base case: median estimates of sigma R and steepness from FishLife Compare against: lower CI of steepness (0.8?) extreme steepness (0.99) to explore behaviour with 'free' recruitment to explore the interaction between M and steepness (the main drivers of MSY) a factorial design of hypotheses will be explored. However the M options will be narrowed down to 2 or 3 first.

Virgin biomass	
Issue	**Sensitivity of virgin biomass (B0) to assumptions** The estimate of B0 is central to the estimation of MSY reference points; however, it is likely to be very sensitive to assumptions on steepness and natural mortality.
Proposed solution	A production model will provide an estimate of B0 which could be used to compare against the SS model Survey data can give an estimate of the highest observed density of anglerfish per km^2. This can be extrapolated over the full stock area to give an upper limit of B0
Work to do	Explore simple production model for both stocks Estimate maximum density and surface area of the stock distribution.

References

Cerviño, S. (2014). Estimating growth from sex ratio-at-length data in species with sexual size dimorphism. Fisheries Research, 160, 112–119.

Thorson, J. T., S. B. Munch, J. M. Cope, and J. Gao. 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications. 27(8): 2262–2276. http://onlinelibrary.wiley.com/doi/10.1002/eap.1606/full

WORKING DOCUMENT 01

Northern Hake stock

Length-weight relationship

Miren Altuna-Etxabe & Dorleta Garcia

25/11/2021

Introduction

In the current assessment model of Northern Hake, the parameters α and β of the length-weight relationship are based on ICES, 1991. Last year, the fishermen of the ICES area 7 reported their concern about the thin individuals they are capturing from year to year.

The objective of this study was to verify if the current length-weight relationship parameters used in the assessment model of Northern Hake (ICES 1991) are still appropiate to be used in the assessment model of Northern Hake.

Method

We estimated the length-weight relationship parameters for Northern Hake by sex, area and year using linear models where the slope and the intercept varied based on the coefficient analysed in each model (i.e. sex, area and/or year).

The formula to define the length-weight relationship is: $W_{(g)} = \alpha * TL_{(cm)}^{\beta}$.

The α and β values used in the assessment of Northern Hake are: $\alpha = 0.00513$ and $\beta = 3.074$ (ICES, 1991).

The basic model to estimate α and β is: $log_{10}(W_{(g)}) = log_{10}(\alpha) + \beta log_{10}(TL_{(cm)})$ which can be fitted using a linear model.

On the transformed scale α and β are: $\alpha = -2.290$ and $\beta = 3.074$.

Results

There were differences in the length-weight relationship by sex, area and year. The weight of females was higher than males. The fishes in area 8 had higher weight than fishes in area 6, and area 7 respectively. The weight of the fishes was lower in the most recent years. There was a clear temporal trend in the estimated mean weight of individuals, with lower weights in recent years.

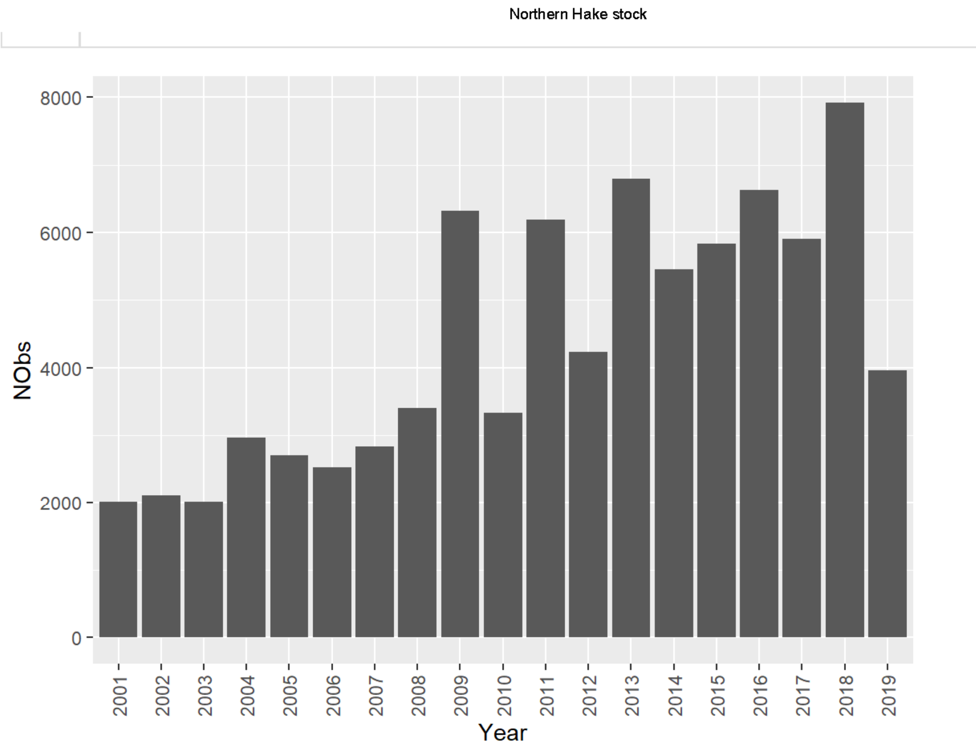
Used data | Fitted models | Summary

The data set compiled for MEVA project in 2020 was used. The data set comprised data from year 1996 to 2020. Since the number of observations for years 1996, 1997, 2000, and 2020 was low, we only used data from years 2001 to 2019. The length-weight relationship was analysed using the total length and ungutted weight data.

By year | By area

The number of observations by year.

Plot | Table



Number of observations by year

Conclusions

There was a clear temporal trend in the estimated mean weight of individuals, with lower weights in recent years. We concluded that the temporal variability in weight observed in this study must be included in the assessment model of Northern Hake. It was agreed to used three year blocks data to model the variability in weight in the assessment model, using the data in those years to estimate the length-weight relationship parameters.

References

ICES. 1991. Report of the Working Group on the Assessment of the Stocks of Hake. ICES CM 1991/Assess: 20. 181 pp.

WORKING DOCUMENT 02

Northern Hake stock

Maturity Ogive

Miren Altuna-Etxabe & Dorleta Garcia

25/11/2021

Introduction

In recent years, the population biomass of Northern Hake increase. This could have produced an increase in the length at maturity.

The objective of this study was to verify if the current maturity ogive parameters used in the assessment model of Northern Hake are still adequate to be used in the assessment and if there have been changes over time.

Method

The general linear binomial model, mature/inmature (1/0), was used to estimate the length at which 50% of the individuals of the Northern Hake are mature (L_{50}) by sex and year using the total length and maturity data of Northern Hake. The slope was assumed constant in each model.

Formula for maturity ogive: $p = \frac{100}{1+e^{-r \cdot (L-L_{50})}}$

The maturity ogive used in the assessment of Northern Hake, for both sexes combined are: $r = -0.2$ and $L_{50} = 42.85$ (ICES, 2010).

Results

There were differences in the maturity ogive by sex and year. The males matured at lower sizes than females. The fishes matured at earlier length in the past than in the most recent years. There were high differences between the value of L_{50} used historically and the estimates of L_{50} obtained from this study to define the maturity ogive of Northern Hake. According to this study, the individuals mature earlier than historically is assumed.

Used data | Fitted models | Summary

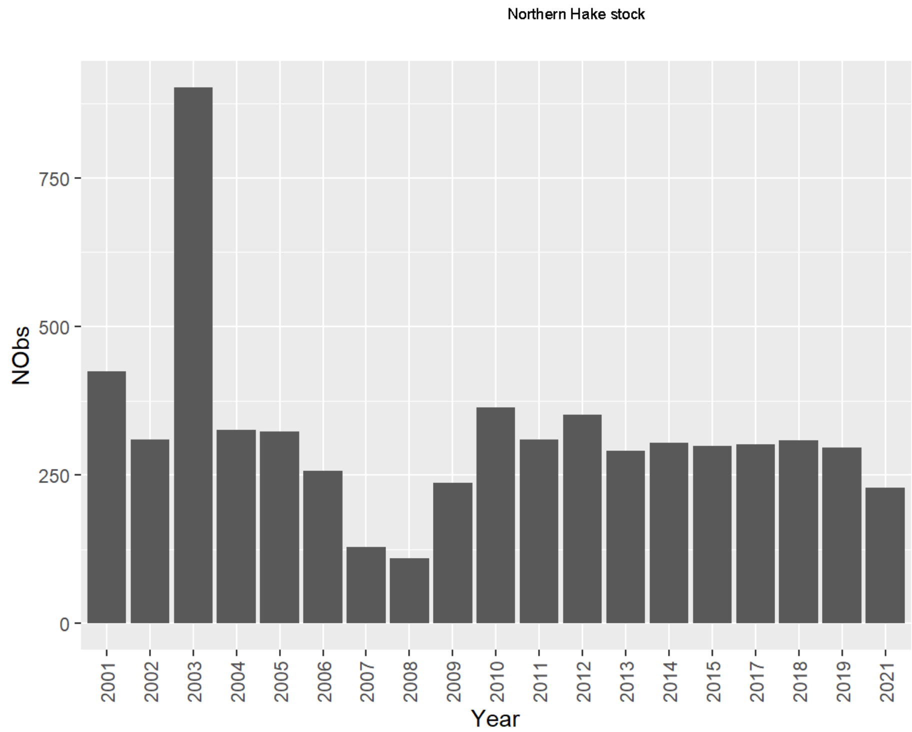
The data set compiled for AZTI was used. Most of the observations of this data set were from area 8. There were some observations from individuals in area 7 and north area, however, the scale used to define the maturity ogive in these two areas was uncertain. Thus, we only used data from area 8.

In this study, the spawning period data (from January to March) from year 2001 to 2021 (no spawning period data for years 2016 and 2020) were used.

By year

The number of observations by year.

Plot | Table



Number of observations by year

Conclusions

The data set used in this study is the most complete data set we have to analyse the maturity ogive of Northern Hake. However, these data did not cover the whole distribution area of the stock. Thus, although this study showed that the individuals mature earlier than assumed in the assessment further analysis are needed to verify if the same happens in the whole distribution areas. For that, maturity ogive of Northern Hake using data from area 6 and 7 must be analysed.

References

ICES 2010. Report of the Benchmark Workshop WKROUND, 9–16 February 2010, Copenhagen, Denmark. ICES.

WORKING DOCUMENT 03

Data evaluation workshop of ICES WKAngHake: Benchmark Workshop on anglerfish (*Lophius budegassa, Lophius piscatorius*) and hake (*Merluccius merluccius*). Virtual, 23 – 25 of November 2021.

Estimating biological parameters (Linf, k and M) with Bayesian hierarchical analysis based on life history invariants.

Santiago Cerviño, Catherine Michielsens, Fran Izquierdo, Marta Cousido and Maria Grazia Pennino.

Abstract

Hake stocks in ICES area can be considered "data poor" stocks in terms of biological information, being this one of the main difficulties to get a good assessment model. Difficulties to estimate growth, as well as the usual problems in estimating M compromise a good quality assessment model. There is a need of increasing stocks assessed and improve the quality of existing assessments. However, there is a lot of biological information in similar species that can help to fill this gap. Life history invariants theory and hierarchical bayesian models can be combined to better understand biological processes needed in most stock assessment models (maturity, growth and natural mortality) providing the required parameters together with their statistical structure (posteriors). As an example of this approach we use the two European hake stocks in the Northeast Atlantic Ocean. The Bayesian hierarchical analysis provides posteriors for the main biological Linf, k and M. In the case of Southern hake, for which sex maturity at length data are available sex separated parameters are also provided. However, these results cannot be used directly in SS and further work is required to implement these in the SS model. Options to do it include fix some of them and allow SS to estimate others, use the posteriors as SS priors or combine these two options.

Warning! An error in the data base of Merluccius information was found an we are now revising these data to guaranty that the selected records accomplish the quality required for this kind of analysis. Results presented here should be considered preliminary although the methodology proposed are the definite one.

Introduction

Biological parameters are one of the weakest areas in current hake ICES assessment models. Growth and M are relatively unknown and were set as constants (Linf=130 and M = 0.4) meanwhile k is estimated by the model based on the length distribution progression through quarters. There is information for maturity at length although this information is not used to fit the model. This information is used to calculate SSB after the model was fit.

The aim of this work is to provide more information regarding biological parameters for the SS hake models that are going to be developed in ICES WKANGHAKE 2022. This information will be based on life history invariants (LHI) theory using hake biological information from literature. LHI theory predicts that the relationship between some life history parameters is relatively constant. Evolutionary life history theory is developed in terms of allocation of resources to the competing ends of growth, reproduction and adult survivorship (Charnov and Barrigan, 1991). The goal of life history theory is to understand the variation in such life history strategies to explain the reproductive success. For instance, higher investment in current reproduction hinders growth and survivorship and reduces future reproduction, while

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investments in growth before maturity will pay off with higher fecundity in the future. Beverton and Holt (1959) and Beverton, (1992) provided empirical evidences that some relationships among parameters are relatively constant like Lm/Linf and M/k in different fish groups. Charnov (1993) developed the theoretical basis for this invariance relationship based on simple maths with VB growth curve, the exponential survivorship and some reproductive traits. Based on this theory, biological parameters might be built based on the expected value of these invariants and their variability estimated from other hake information.

Charnov and Berrigan (1991) present 3 patterns in life history. Charnov (1993) extends the theory explaining the role of these 3 invariants.:

1. M/k tend to be relatively constant in similar taxa (~0.6; Charnov and Berrigan, 1991)
2. Lm/Linf is relatively constant among similar taxa.
   2.1. Lm/Linf=1-exp(-k*m) (where m is age of maturity); if a group of species share the same Lm/Linf value they also share the same k*m.
   2.2. For species where M/k and Lm/Linf are constant, M is inversely proportional to m, i.e. M*m is constant
3. k and Linf are negatively correlated

Because of the limited information available on these biological parameters and the relationship between them for *Merluccius merluccius*, we use a meta-analysis approach whereby we rely on data from other related species to help estimate these relationships and associated parameters. In order to properly account for the variability between data from *M. merluccius* and the other species within this meta-analysis, a hierarchical modelling approach will be used whereby we estimated the parameters of interest simultaneous at the species level and at the meta-species level. In doing so, hierarchical models allow predicting the parameters for *M. merluccius* for which we have limited data, based on the estimates from all species combined and the similarities/dissimilarity between the individual species.

ICES assessment models for both hakes assume that most biological parameters are constant (Lmat 50% = 43.85cm; M=0.4 year-1 and Linf=130 cm) and only k for VonBertalanffy growth are estimated by the model. Length at maturity (Lm) is the unique parameter for which there is available information directly used in the assessment process. Since Lm may be estimated out of the model it may be the basis to develop a link among priors of different biological parameters following Charnov and Berrigan (1991) and Beverton (1992) LHI theory such as:

1. Prior for Linf from ratio Lm/Linf for hakes in literature.
2. Prior for k based on negative correlation between Linf and k from hake literature.
3. Prior for M based on constant relation M/k from hake literature.

Material and methods

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When doing meta-analyses, it is common to use a hierarchical approach (Liermann and Hillborn, 1997; Myers and Mertz, 1998; Myers and Mertz, 1998). Instead of using all the data from the different species combined (thereby placing larger weight on the data from species with more records), hierarchical models still allow to account for the differences between the different species, and at the same time giving higher weight to the data from *M. merluccius* depending on the amount of *M. merluccius* data available.

The analysis will be developed in 3 stages as described in figure 1. In the first stage the maturity information will be described; in the second stage the hake LHI meta-analysis based on hake information from literature will be developed and, in the third stage, the priors for Linf, k and M will be developed sequentially.

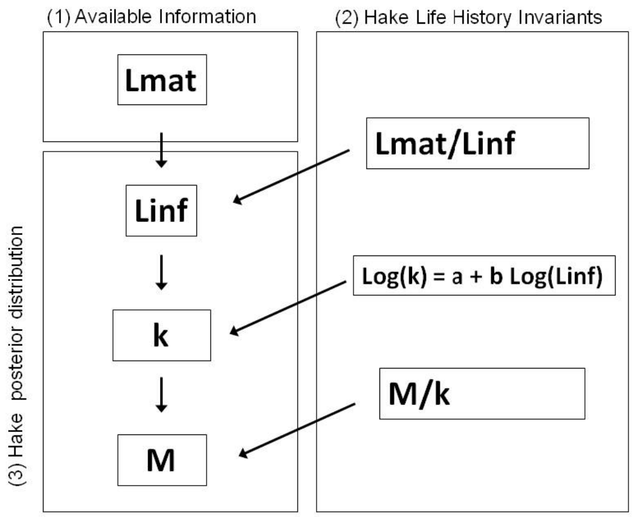

Figure 1. Hake meta-analysis structure

Maturity information

The first stage is having a maturity distribution for Northern and Southern hake. This distribution is built from available information. There are available maturity information from the Northern stock since 1987 (WKROUND, 2010) and from the Southern stocks the maturity ogives were estimated in WKANGHAKE. Length of 50% of maturity for both sexes combined is presented in figure 2. L50 mean and standard deviation for both time series were used to build the normal distributions.

For Southern Hake, there seems to be a trend in the data maturity data. Rather than deriving the distribution for L50 based on all the data whereby the earlier years

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indicate larger values for L50 than the later years, the time series has been split in 3 periods and only the last period has been used to estimate the distribution of L50.

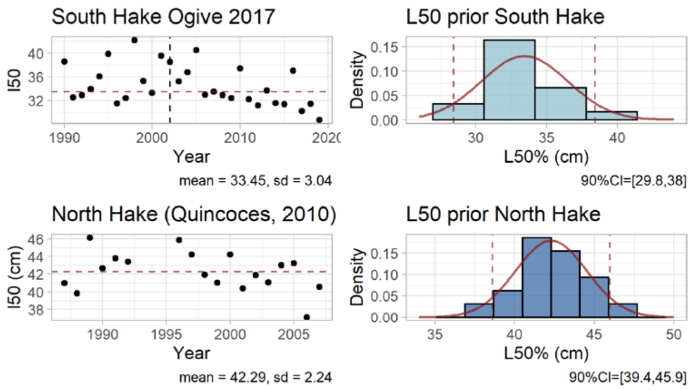

Figure 2. Maturity information from Northern and Southern hake. Time series in the left and L50 distribution with normal fit in the right.

Figure 2 left panel shows the L50 figures for Northern and Southern hake. These figures range from 36 to 46 cm with a mean of 42.29 and s.d. of 2.24 cm (Northern hake) and 29 to 42 cm mean ot 33.45 and s.d. of 3.04cm (Southern hake). Right panel shows the resulting female normal priors based on the mean and sd of the L50 figures.

Data review for Life history invariant analysis

The initial idea for hake data review was to use only information from the same specie (*Merluccius merluccius*) to develop priors for Northern hake assessment. However, after the initial review of this information we realized that practically all data are based in a growth model unbelievable. Hake data for the genus *Merluccius* was downloaded from Fishbase (Froese and Pauly, 2013). The total amount of records with life history data in FishBase was 188, although not all of them have all the needed data. A literature review was extended to add new data not already collected in FishBase this review provided 125 new records from the 12 hake species all over the world. The distribution of all the 211 finally accepted records by specie after deleting unrealistic *M. Merluccius, (*Those based in old assumed slow growth*)* records are presented in next figure 3.

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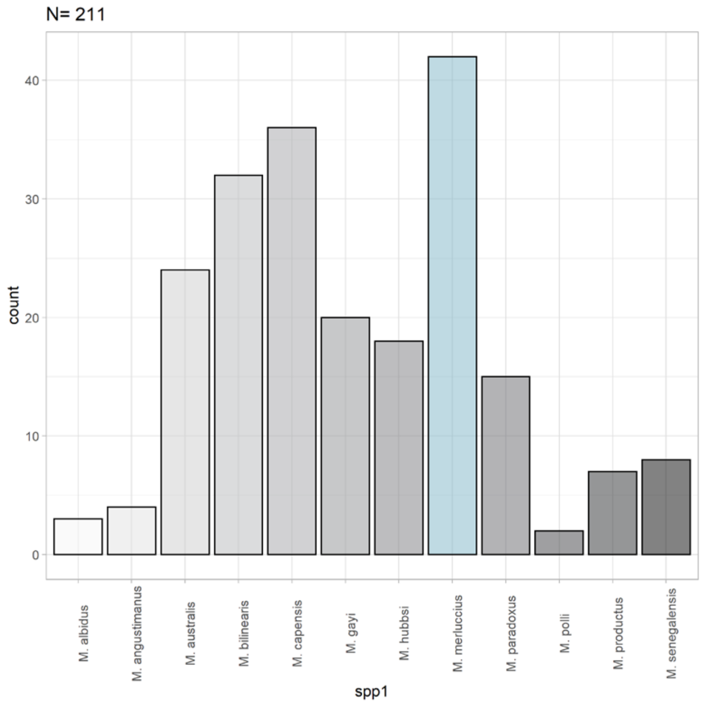

Figure 3. Distribution of records by species after deleting unrealistic records.

Linf from Lmat/Linf invariant.

Linf priors were estimated based on the life history invariant for the ratio Linf / Lmat. The total number of records with Linf and Lmat data was 29 (Figure 4); 6 belong to *M. australis* and only 3 to *M. merluccius*. The distributions of these ratios by specie are presented in figure 4 (right panel) showing two different groups: those with mean figures above 0. 5 and those with figures below. Among the species above 0.5, *M. australis* has 6 records with a mean around 0.75 and a narrow sd. The other 2 species with figures above only has 3 records.

There are certain requirements that need to be met to be able to include data within a Meta-analysis. One of those requirements is that the data from the different species need to be exchangeable, i.e. there should not exist any a priori information that would allow indicate that a particular species would be different from the other ones in the meta-analysis. *M. australis* however matures between 60 and 80 cm and growths until 80- 120 cm depending on the sex, while the other hakes mature between 20 and 50 cm and grow until 40-130 cm. So the knowledge that M. *australis* behaves differently, and thereby violates the assumption of exchangeability within the hierarchical meta-analysis requires us to exclude it from the analysis.

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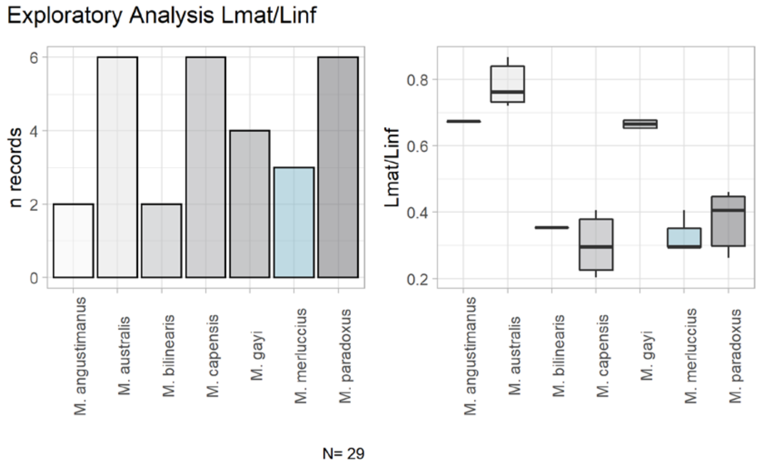

Figure 4. Number of records with Linf and Lmat data (left panel) and their boxplots (left panel)

A hierarchical Bayesian analysis was run to estimate the ratio of Lmat over Linf for *M. merluccius*. The model assumes that the species specific ratios ($Lmat/Linf_{sp}$) are normally distributed as follows;

$$Lmat/Linf_{sp} \sim normal(mu.sp.Lmat/Linf, var.sp.Lmat/Linf)$$

Whereby mu.sp.Lmat/Linf is the average ratio of Lmat over Linf for all species combined and var.sp.Lmat/Linf indication of the variance between estimates for the different species. The model predictions of $Lmat/Linf_{sp}$ have been compared against the observations (Lmat/Linf.obs) using a following normal likelihood function:

$$Lmat/Linf.obs_{i,sp} \sim norm(Lmat/Linf_{sp}, var.Lmat/Linf)$$

To run this analysis, uninformative priors have been placed on mu.sp.Lmat/Linf, var.sp.Lmat/Linf and var.Lmat/Linf. The resulting distribution for Lmat/Linf for *M. merluccius* can be seen in Figure 5.

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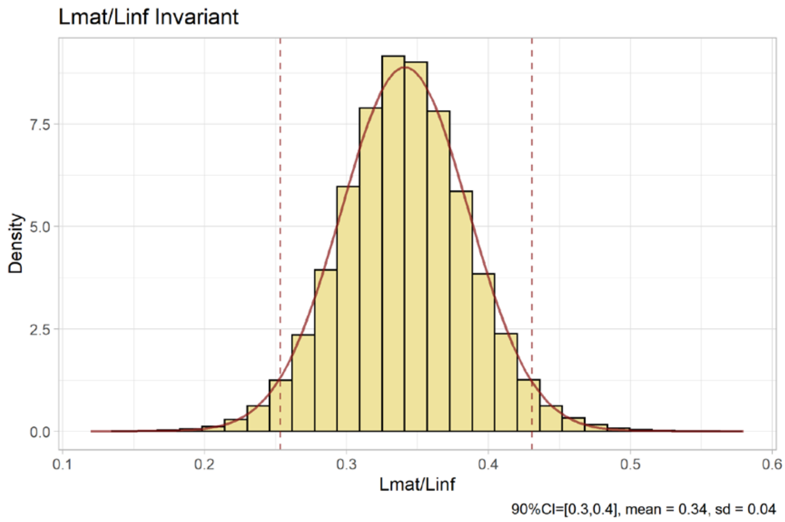

Figure 6. prior distribution for the ratio Lmat/Linf with 90% CI, mean and s.d.

Priors for Linf were developed as the cocient between Lmat distribution (Figure 2) and Lmat/Linf distribution (Figure 6) and are presented in Figure 7.

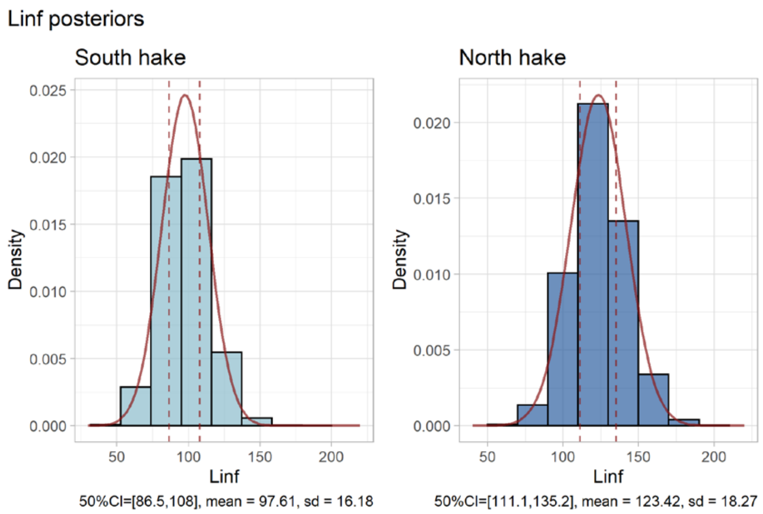

Figure 7. The probability distributions for the ratio Lmat/Linf with 50%CI, mean and s.d. for Norther hake (left panel) and Southern hake (right panel)

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Mean figures and 50% CI for Linf are 97.69 cm [86.5, 108] for Southern hake and 123.42 [111, 135] for Northern hake. These numbers are below the current Linf used within the stock assessment model model (130 cm). Linf=130 is however well within the full probability distributions for Linf. We have to keep in mind that Linf=130 had been based on data from female hake while this analysis was performed for males and females combined.

K from Linf-k invariant

K is modelled in the ICES models (SS3 and GADGET) as a Von Bertalanffy parameter. k prior estimation was based on the high negative correlation among Linf and k. Figure 8 shows the valid records with information on Von Bertalanffy fits providing data for Linf and k. Most *M. merluccius* were excluded since recent tagging studies have showed that k is about two times above those previously estimated (de Puntual *et al*., 2006; Piñeiro *et al*., 2007). Figure 8 shows the distribution of valid data for different hake species (left panel) and the plot of k vs Linf for all the data (central plot). This plot shows the negative correlation among both parameters which are linearized thorough log transformations allowing for a linear model able to predict k from Linf (right plot).

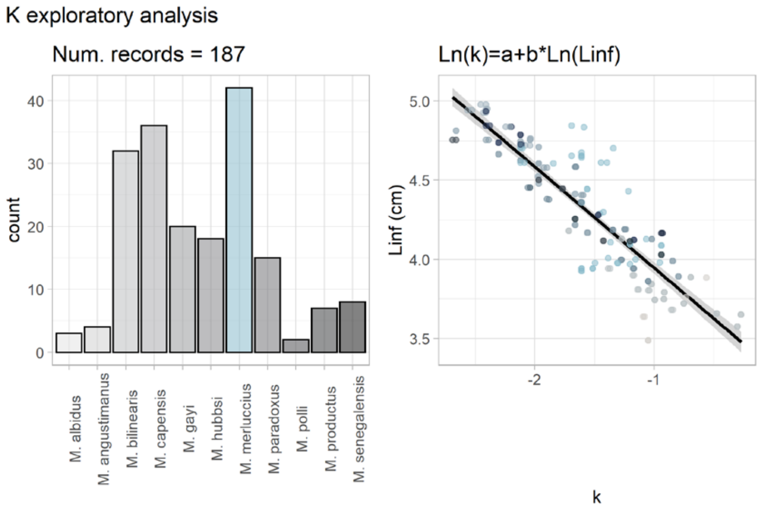

Figure 8. Number of records with information on k and Linf (left panel); Linf vs k log linear model (right panel)

A Bayesian linear regression model was developed to estimate k, with the relationship between k and Linf being expressed by the following equation:

$$log.k_{i,sp} = a_{sp} + b_{sp} * log(Linf.obs_{i,sp})$$

whereby $Linf.obs_{i,sp}$ are observations of Linf for individual species, a_{sp} and b_{sp} are species specific linear regression parameters. $k_{i,sp}$ are the species specific model

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predicted estimate. These estimates are compared against the observations on the logscale using the following likelihood:

$$log.k.obs_{i,sp} \sim norm(log.k_{i,sp}, var.k)$$

The stock specific values of the intercept a_{sp} and slope b_{sp} are defined by a mean (mu.a and mu.b) and variance (var.a and var.b) across species:

$$a_{sp} \sim norm(mu.a, var.a)$$
$$b_{sp} \sim norm(mu.b, var.b)$$

whereby mu.a, mu.b, var.a and var.be have been given uninformative priors, as well as var.k.

The resulting model for M. merluccius is used to predict the distribution for k for both Northern and Southern hake by using the a and b parameters for M. merluccius in combination with the distributions for Linf posterior obtained previously for Northern and Southern hake.

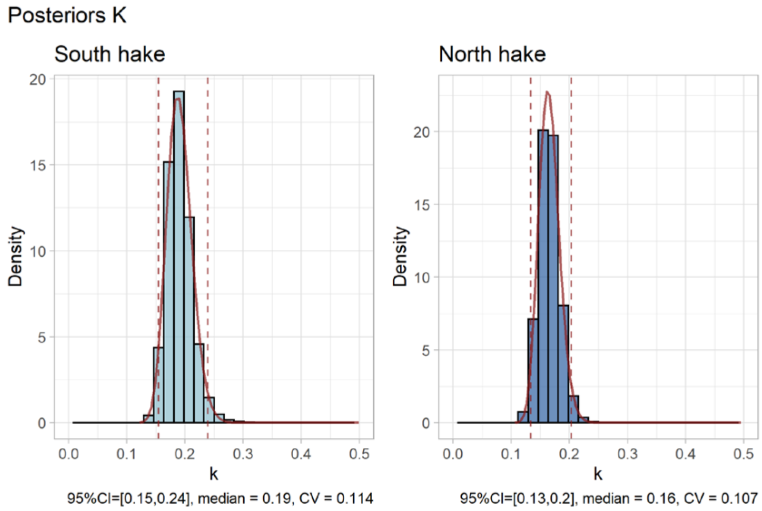

Figure 9. k priors for Northern hake (left panel) and Southern hake (right prior)

K median and 95% CI are 0.16 [0.13, 0.2] for Northern hake and 0.19 [0.15, 0.24] for Southern hake. These figures are similar to those estimated by both ICES models (around 0.17). However we have to take into account that k is the rate at which the population raises Linf and in this exercise Linf is well below ICES Linf (~100 vs. 130 cm).

M from M/k invariant

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Natural mortality is set as a constant parameter in time and length in hake ICES models. This estimation is based on the for the assumption that the ratio of M/k is relatively constant among similar taxa.

Figure 10 shows the hake species with records for k and M. As in the previous analysis most *M. merluccius* data were rejected because of wrong k estimation. All *M. australis* records were also eliminated. Many records with a typical 0.2 figure estimation without a justification were also eliminated. Finally only 25 records were used for this analysis. In the central panel of the same figure we can see the distribution of M/k rate for different species. In the left part of this plot we can see the total distribution with a median equal to **2 and CV=0.41**. Preliminary linear models with this data did not show a good fit and given the relatively low variability around the mean value it was decided to use the mean and s.d. of these figures to develop the informative priors for the M/k ratio.

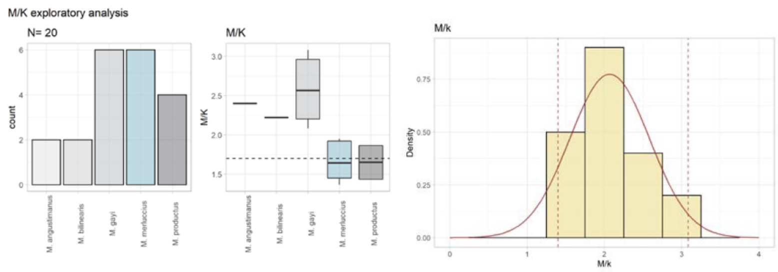

Figure 10. Records with information on M and k (left panel); a boxplot for this ratio M/k in every specie (central panel) and M/k distribution (right panel)

Priors for M were built based on the M/k distribution (Fig 10) and using a Bayesian model very similar to the model used to estimate Lmat/Linf. The model assumes that the species specific ratios are normally distributed as follows;

$$M/k_{sp} \sim normal(mu.sp.M/k, var.sp.M/k)$$

Whereby mu.sp.M/k is the average ratio of M over k for all species combined and var.sp.M/k indicates the variance between estimates for the different species. The model predictions of M/k have been compared against the observations (M/k.obs) using a following normal likelihood function:

$$M/k.obs_{i,sp} \sim norm(M/k_{sp}, var.M/k)$$

To run this analysis, uninformative priors have been placed on mu.sp.M/k, var.sp.M/k and var.M/k. The resulting distribution for M/k has been used in combination with the distributions for k for both Northern and Southern Hake to calculate the distribution of M as seen in Figure 11. The M estimated following Life History Invariants theory represents the expected M after maturity, that has median = 0.23 for Northern hake and 0.28 for Southern hake. In both cases the variability is very high because the

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sequential process from Lmat to M through Linf and k, accumulates the variability of all relationships.

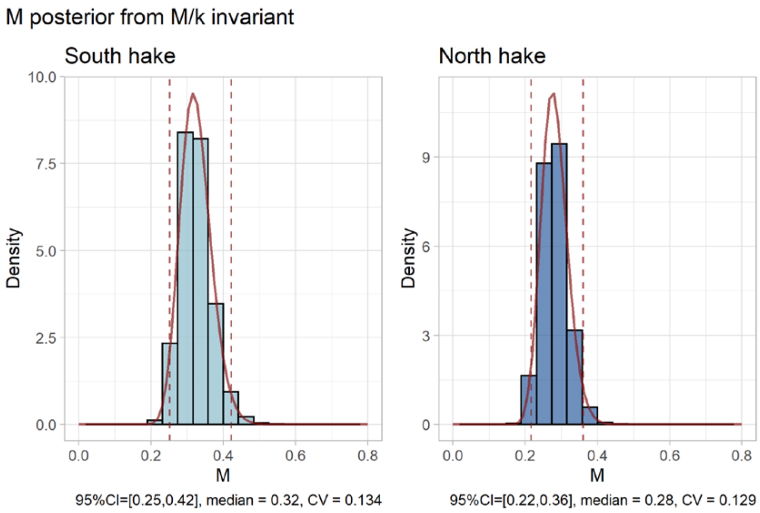

Figure 11. M prior distribution for Northern hake (left panel) and Southern hake (right panel)

Lorenzen (1996) point to the existence of an allometric relationship between natural mortality and body weight, in fish, of the form M = *a* + W ^ *b* where is natural mortality at weight W, *a* is mortality at unit weight, and *b* is the allometric exponent. Based on empirical studies with different populations Lorenzen found out the following parameters: b=−0.288 (90% CL[−0.315, −0.261]) and a=3.00 (90% CL[2.70, 3.30]) year−1. More recently Cook (2013) uses this equation in an assessment model for haddock getting the following parameters: a=3.69 and b=-0.305 and confirming the Lorenzen assertion that *b* is relatively constant among different species. Figure 12 shows the M estimated for Southern hake based on Lorenzen figures and hake parameters. The model produces high M at length figures for small hake (e.g. M= 1.8 for age 0 and M=3.5 for length 1cm) that decreases until 0.18 at length 130 cm or age 15.

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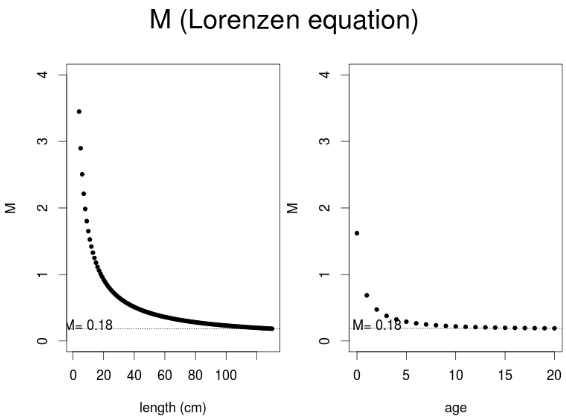

Figure 12. Lorenzen estimates of M at length and M at age.

Table 3. Summary of the developed priors for invariants.

Data	Linf.mean	Linf.sd	k.median	k.CV	M.median	M.CV
North combined	123.416	18.267	0.164	0.107	0.279	0.129
South combined	97.613	16.183	0.189	0.114	0.32	0.134
South female	122.175	17.374	0.165	0.103	0.28	0.127
South male	79.61	12.28	0.212	0.104	0.361	0.126

Discusion

Hake is a sex dimorphic species with different size at maturity and different growth in both sexes. Females mature larger than males and have larger sizes than males. The exercise performed here was done to estimate parameters for a model with sexes combined. So, the initial information for this sequential estimation was Lmat, which is the yearly L50% maturity for both sexes combined. And then, the estimated parameters for growth (k and Linf) and M correspond also to both sexes combined.

Caveats using life history invariants. Temperature as an important aditional information in mat-growth-M relationship. Lack of complete records with mat, growth, m and T. Multigroups approach (Pauly and others) vs reduced groups approach (here) => more information with less invariance vs less information with more invariance. Even that t° was not considered, the hierarchical Bayesian approach allows to consider the group (species) contribution together, i.e. each species LHI was analyzed independently and combined afterwards to provide a LHI value for European hake. Since each species has a different optimal temperature range and then different LHI variability the hierarchical approach allows giving more or less weight to species were LHI values are more or less variables. Furthermore, the hierarchical method provides more weight to the information coming from the European hakes

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than to other hakes. These two features of the methods reduce the impact of not considering the Tº in the analysis.

An assessment model like those performed for both hakes with SS3 or GADGET with sexes combined always have to make some assumptions. In this case, that Linf is equal to 130 cm and M=0.4. With these constant figures k is estimated by the model explaining the observed catches. The Linf estimated here showed figures around 100 cm, well below 130 cm set for ICES models. This is because Linf is estimated from a sex combined Lmat. Meanwhile in ICES Linf was mainly based on the higher observed hakes, which are females. Both approaches make different assumptions: (1) the ICES approach assumes that all hakes in the population might reach 130 cm. However we know that approximately half of the population, the males, rarely achieves 75 cm. However, since k (and also recruitment) was estimated to fit the past population productivity, it is expected that the final combination of model parameters for growth and mortality be able also to predict the future productivity. (2) On the other side, the approach presented here based on LHI would assume that all population achieves a Linf around 100 cm. In this case we lost the option of half of the population (females) growing larger and the other half growing shorter (See Cerviño, 2014) for comparisons among hake male and female growth and M parameters). Since fishing selection is mainly based on fish length this assumption might also have an impact on the productivity. Furthermore, there are a lot of catch data with figures well over estimated Linf that will be difficult to implement in the model with a short Linf. Which approach in better? ANY MODEL APPROACH BASED ON SEXES COMBINED WILL LOST AN IMPORTANT PART OF THE REALITY. In any case 130 cm seems to be an extremely large Linf, even for females, where mean historic northern hake Lmat is about 48 cm (Dominguez et al, 2008) and the mean Linf based on LHI would be around 114 cm.

To overcome this difficulty we have plan a sex separated model that requires different figures for Lmat, Linf, k and M, for males and females. The estimation process is the same than those for the sexes combined. Starting with the length of maturity (for males and females) we use the same invariant posteriors to estimate Linf, k and M for males and females. Figures obtained from this process can be used in the SS model in two different ways: (1) point estimation to fix some parameters or (2) priors to allow the model to estimate some parameters. Combination of fixed and estimated parameters can be explored. Furthermore, the sex ratio data can help to estimate some growth parameters since the observed sex ratio at length can only be seen whether males and females growth in a specific way

The approach also provides information for k and M. k is conditioned to Linf so it cannot be used as a prior if Linf is different. However the prior for the correlation among k and Linf might be used if required.

M/K is required by some data pour assessment methods (Hodryck et al, 2015...)

M presents figures around 0.3. This seems to be below current M (0.4) used in ICES models. The approach used by ICES follows the Hewitt and Hoenig (2005) approach based on longevity and assuming that hake lives around 10 years. This approach provides a mean M for all ages. However we have to consider that LHI approach

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provides M figures only for mature fish (above 40 cm aprox). M for immature fish should be estimated following other methods like Lorenzen's (1996). These approaches might be complementary predicting that immature hake (<40 cm) M should be higher than 0.4 in order to get the mean 0.4 predicted by Hewitt and Hoenig (2005). This is in agreement with other studies based on hake that predict a high M for small hakes because predation, being the main hake predators in this area the cetaceans (Saavedra etal XXX) and hake.cannibalism (Jurado-Molina et al., 2006, Smith, 1995). in both cases predating in inmature hakes.

An ulterior development of the natural mortality model will aim to the introduction of higher values for small hake based on the high predation mainly caused by cannibalism and dolphins. Literature review and preliminary analysis of Southern hake will provide the information for the M for this small hake. This model will include two parameters plus the usual constant M. At this time only the prior for the constant M was estimated. Lorenzen approach can also help.

Is many cases there is not information on length of maturity. However, with some minor corrections, the method can also be developed starting the chain with a proxy for Linf instead of Lmat. Information on Linf can be derived from lmax (Jensen, 1997; Froese???)

In summary, the ICES models cannot be able to estimate growth and M (apart of other parameters like recruitment, selection, etc), and is required to fix two of these parameters (Linf and M) allowing to estimate k. The approach presented here provide information to explore figures for these parameters that might be directly input in the model (M or Linf means); ranges to explore (e.g. inside a confident interval of 90%) or using the invariants distribution to set one of them once that other have been set.

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WORKING DOCUMENT 04

Growth estimates for black and white anglerfish in 7,8abd and hake in 3a,4,6,7,8abd using cohort analysis of length-frequency distributions.

Working document to WKAngHke – Data compilation workshop – Hans Gerritsen - Marine Institute

Summary

Age cohorts were identified from survey length frequency data in order to estimate growth parameters for three stocks for which no reliable ageing methods are available. The estimated parameters are intended to be used as priors or assumed values in Stock Synthesis models, as well as the basis for life-history-based analysis such as estimating M or maturity-at-age.

The estimated Von Bertalanffy growth parameters are listed below:

Stock	Sex	Linf	k	t0
Black anglerfish in 7,8abd	Both	132	0.097	-0.031
	Female	129	0.101	0.009
	Male	78	0.197	0.099
White anglerfish in 7,8abd	Both/Female	165	0.112	-0.084
	Fixed Linf medium	130	0.159	0.031
	Fixed Linf low	100	0.245	0.180
Hake in 3a,4,6,7,8abd	Both sexes	184	0.105	0.254

The male growth parameters are estimated with poor precision because large males are rare and it was agreed during the workshop to investigate a method by Cerviño (2014) to improve the estimate of male growth parameters, based on the sex-ratio at length.

Introduction

No direct age data is available for anglerfish or hake. This working document provides growth parameter estimates for the stocks of black and white anglerfish in areas 7,8abd and northern hake, by tracking cohorts over time in bottom trawl survey data in ices areas 7 and 8 (and 6a for hake). All three of these stocks experience large variability in cohort strength and strong cohorts can be tracked over time in the length frequency data. Length data from the IGFS-EVHOE survey and the Irish IAMS survey were used for this purpose.

In order to aid visualisation, length classes with below-average numbers of fish were coloured red and above-average numbers were coloured blue. Additionally, a loess smooth was applied to the length-frequency data. Finally, to help track the cohorts of older fish which are rarer (but heavier), the relative numbers-at-length are presented together with the relative weights-at-length. This results in plots like Figure 1. These plots were used to manually identify the modes of strong cohorts as shown in the figures. These data were then used to fit Von Bertalanffy growth curves, the parameters of which can be used as priors or assumed values in the proposed stock assessment models.

Anglerfish are thought to spawn mainly in winter and spring, while hake have a particularly protracted spawning season. Despite this, cohorts of young fish of all three stocks are quite distinct, suggesting that successful recruitment takes place over a relatively short period in the year (although perhaps this period may vary from year-to-year for hake). For convenience, the birth date of all three stocks is always assumed to be 1 January.

Black anglerfish in 78abd

Figure 1 shows the length frequency distributions of the IGFS-EVHOE index. The first cohort, which is assumed to be the 0-group (the survey takes place in Q4) is easily identified around 11cm for both sexes, with limited variation from year-to-year. The assumed 1-year olds vary considerably more in size and overlap somewhat with other age classes. The mean length of 1-year olds in Q4 was estimated to vary between 19 cm to 26 cm. In 2014 there was a strong mode around 16cm and it is unclear whether they were large 0-year-olds, small 1-year-olds or incorrectly identified white anglerfish. The mean length of assumed 2-year olds varied between 29 and 38cm. There are a few strong cohorts that can be tracked for 6 or 7 years and arguably up to age 8 (the assumed 2004 cohort). The two cohorts showed up very strongly in 2003 around 43 and 53cm but because this is the start of the time series, it is somewhat tricky to decide which age class to assign to these modes. The 43cm mode was compared to the mean length of 3 and 4-year-olds from cohorts that could be tracked from age 0 and it was concluded that this mode most likely corresponded to relatively large 3-year-olds. The 53cm mode was assumed to be 4-year-olds. The index is available for males and females separately but the differences in size are not obvious in this plot apart from the fact that large males are considerably less abundant than large females and therefore the male cohorts could not be tracked beyond age 4.

Figure 2 shows the equivalent plot for the IAMS index. This survey has a shorter time series and uses larger mesh gear and therefore does not fully select fish below approximately 20cm. Some modes can be identified below 20cm but these are likely to be only the largest 1-year-olds and therefore biased. Perhaps due to the short time series, no particularly strong cohorts are evident but some modes could be tracked. In some cases, the cohorts were more easily distinguished in either the the male or in the female length distributions.

Figure 3 shows the growth curves that were fitted to the modal lengths that were identified for the cohorts. The two surveys are in general agreement. The growth curve that was fitted to all data is slightly below that estimated by WKAngler in 2018 using a similar method. The female-only curve is almost identical to the curve fitted to all data and the male-only curve has a lower Linf but no male cohorts older than age 5 could be identified so the shape of this curve is less precise. However, this is in line with expectations as large fish (>65cm) are almost exclusively Female. Figure 4 shows bootstrapped estimates of the two main parameters: Linf and k. These are highly correlated and both parameters have considerable uncertainty but because they compensate each other, the mean length-at-age is estimated quite precisely for ages up to around 8 for females. For males the uncertainty in the mean length of the older ages is quite high.

White anglerfish in 78abd

Figure 5 shows the length frequency distributions of the IGFS-EVHOE index. The first cohort, which is assumed to be the 0-group (the survey takes place in Q4) is easily identified for both sexes and consistently around 16cm with limited variation. The second cohort was generally identified around 33cm. The assumed 2004 cohort seems to have been very strong and could be tracked for 5 years although it appears quite spread out in 2008. The 2010 and 2014 cohorts also appeared quite strong and could be tracked up to age 5. Differences between males and females were not apparent, apart from the nearly complete absence of males larger than 80cm.

Figure 6 shows the equivalent plot for the IAMS index. This survey has a shorter time series and uses larger mesh gear and therefore does not fully select fish below approximately 20cm. Some modes appear below 20cm but these are likely to be only the largest 1-year-olds and therefore biased. Only one particularly strong cohort was apparent (the assumed 2014 cohort – which also appeared strong in the IGFS-EVHOE index). Even so, it was tricky to track this cohort.

In contrast to the approach taken for black anglerfish, mean lengths were not assigned separately to the sexes. Instead, in order to estimate separate growth curves for males and females, a Powell-Whetherall analysis (TropFishR package) was performed on the length data. This resulted in an estimate of Linf of 130cm for females and 100cm for males. Growth curves were fitted to the estimated mean lengths of the cohorts by fixing Linf at 130 and 100cm and also by estimating Linf. Figure 7 shows the estimated growth curves. The estimated curve without fixing Linf is almost identical to that estimated by WKAngler in 2017.

Hake in 3a,4,6,7,8abd

Figure 8 shows that the first cohort (assumed to be 0-group in Q4) can be readily identified in the IGFS-EVHOE index. The mean length of this cohort is around 13cm but can be considerably higher (e.g. 2013 and 2019). This may be related to the extended spawning season that hake are believed to have. The next cohort (assumed 1-year-olds) is also readily identifiable; the 2019 cohort also has a relatively high mean length at age 1 but the 2013 cohort is around average. The 2-year-olds are quite difficult to distinguish but in some years the 3, 4 and even 5 year-olds were quite distinct. The 2008 cohort could be tracked up to age 7 although not in all years. This cohort was also consistently larger than average from age 1 onwards.

Figure 9 shows the equivalent plot for the IAMS index. This survey has a shorter time series and uses larger mesh gear and therefore does not fully select fish below approximately 20cm. Some modes appear below 20cm but these are likely to be only the largest 1-year-olds and therefore biased. Assumed 2-year-old fish were a bit clearer in this survey and the 2019 cohort is again well above average size.

Figure 10 shows the fitted growth curve. For ages 0-6 the current estimates of size-at-age are slightly lower than the assumed growth used in the current assessment; for older fish, the sizes are larger. The bootstrapped fits indicate that the precision of the estimated size-at-age is quite high. Hake are known to have sexual dimorphism in growth, but this was not apparent from the distribution of the modes in the length distributions, therefore only combined-sex growth parameters are presented.

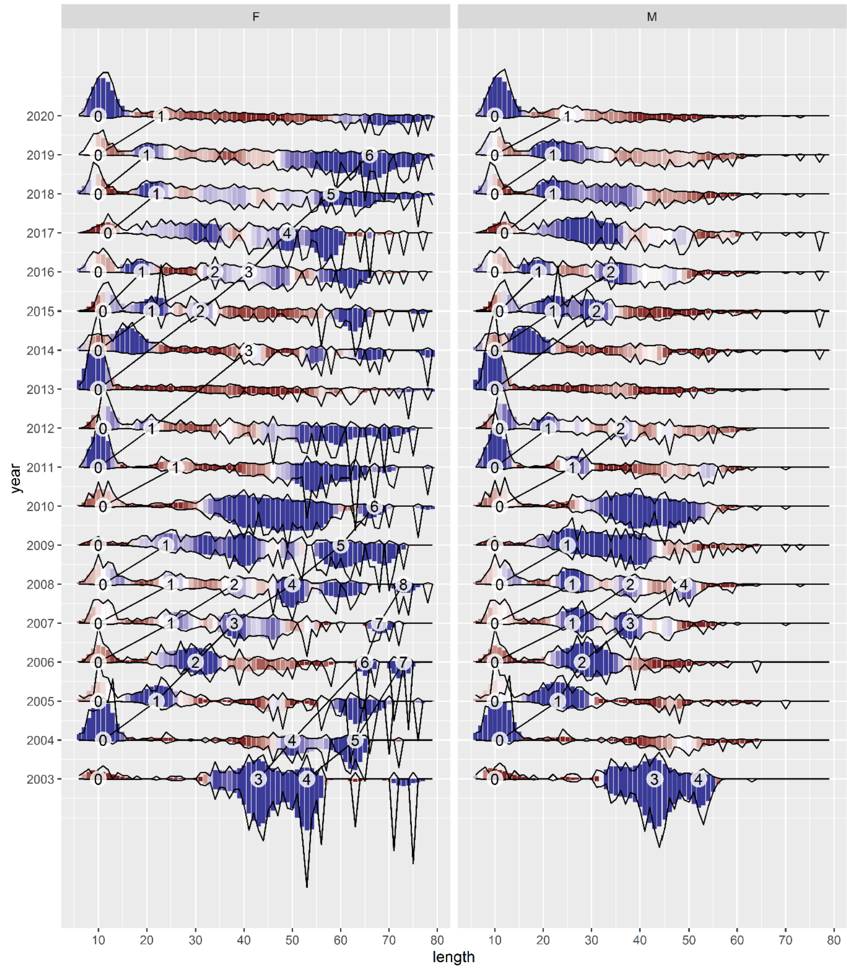

Figure 1. Black anglerfish. Length frequency distributions of black anglerfish from the IGFS-EVHOE index (females: left and males: right). For each year, the top line represents the observed relative catch numbers-at-length, while the bottom line represents the observed relative catch weights-at-length. The bars are loess smooths of the same. Blue bars represent above-average observations for a certain length class compared to other years, while red bars are below-average. The numbers in the translucent circles are the assumed mean length of strong cohorts that were identified 'by eye'.

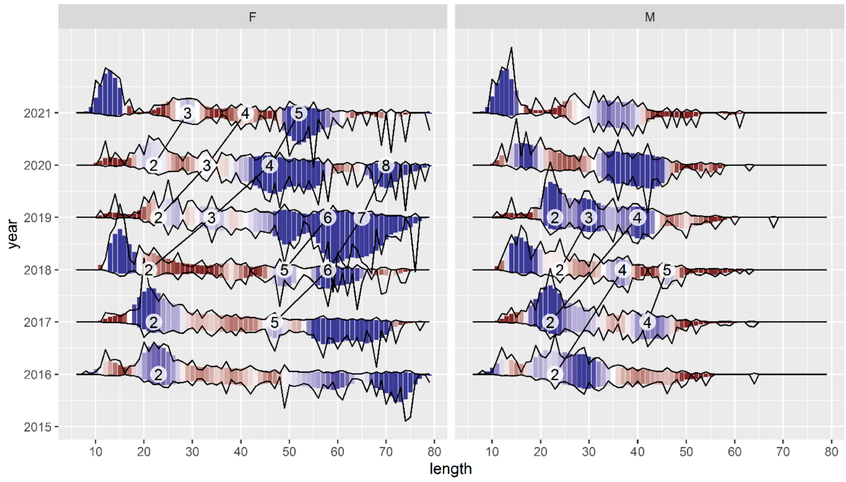

Figure 2. Black anglerfish. Length frequency distributions of black anglerfish from the IAMS index – see legend in the previous figure for more detail.

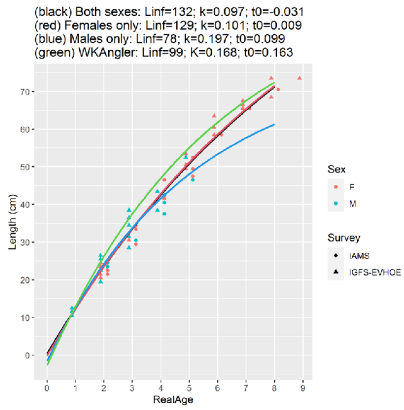

Figure 3. Black anglerfish. Mean lengths-at-age resulting from cohort tracking. A growth curve was fitted through all data (black). When only female data were used a nearly identical curve was fitted (red). Male-only data resulted in a lower Linf (blue) but there was no data for fish older than 5. At WKAngler 2017 a similar approach was used to estimate growth parameters. The current analysis indicates slightly slower growth for fish up to age 8 (but a higher Linf; resulting in a straighter curve). January 1st was assumed to be the birth date – the 'real age' is adjusted for this.

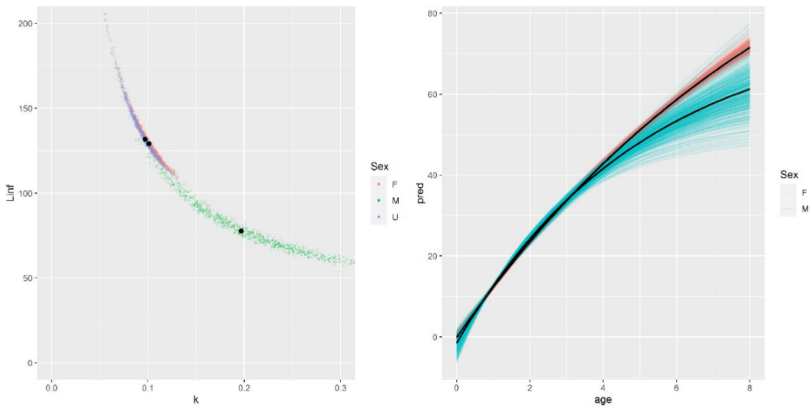

Figure 4. Black anglerfish. left: 1000 bootstrap estimates of the growth parameters. Linf and k are highly correlated and uncertain. Right: light curves show the growth curve for 500 bootstrap estimates; the shape of the curve is fairly precisely estimated for females up to age 8; the shape of the curve for older males is much more uncertain.

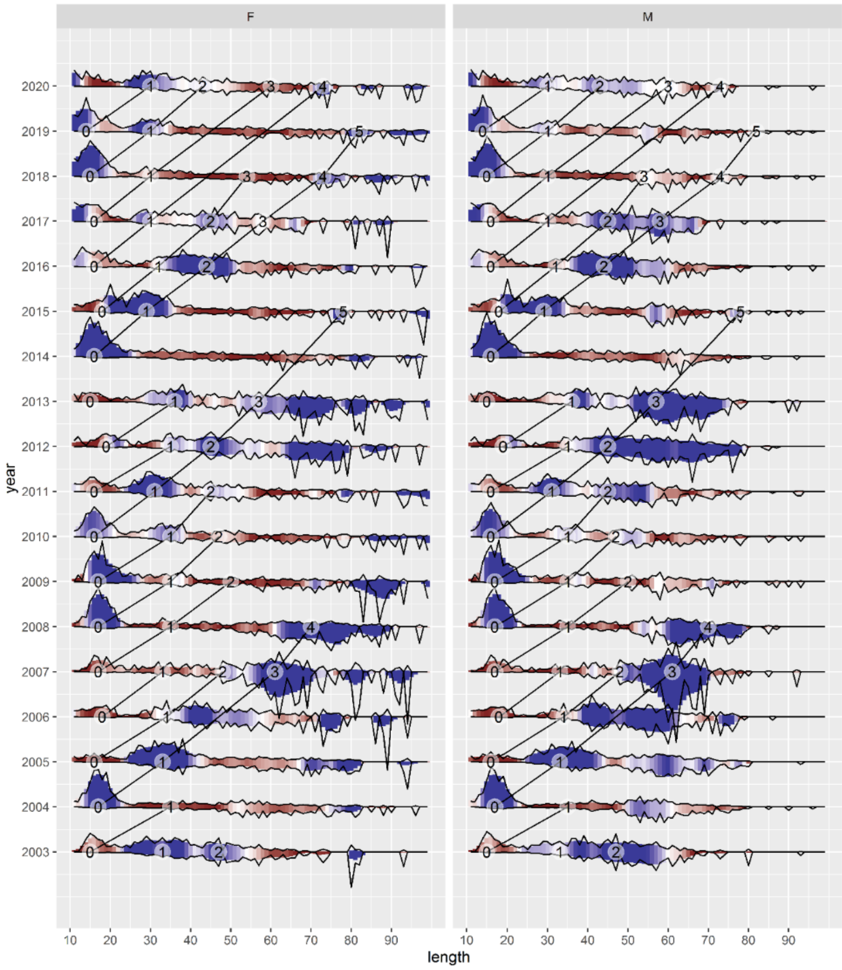

Figure 5. White anglerfish. Length frequency distributions from the IGFS-EVHOE index (females: left and males: right). For each year, the top line represents the observed relative catch numbers-at-length, while the bottom line represents the observed relative catch weights-at-length. The bars are loess smooths of the same. Blue bars represent above-average observations for a certain length class compared to other years, while red bars are below-average. The numbers in the translucent circles are the assumed mean length of strong cohorts that were identified 'by eye'.

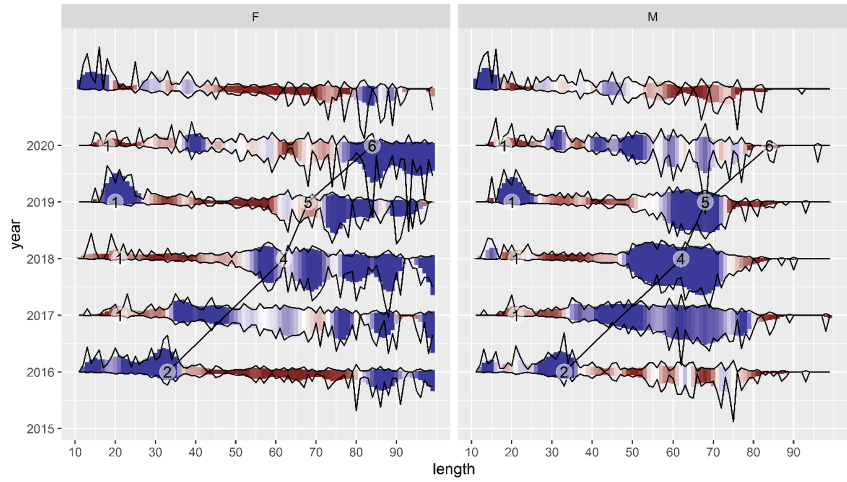

Figure 6. White anglerfish. Length frequency distributions from the IAMS index – see legend for the previous figure for more detail.

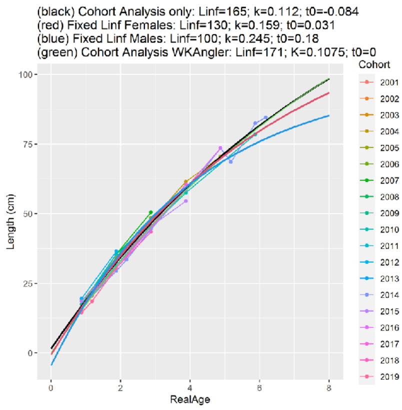

Figure 7. White anglerfish. Mean lengths-at-age resulting from cohort tracking. A growth curve was fitted through all data (black). Fixing Linf at 130 (assumed Linf for females) resulted in the red curve, which is very close to the black curve for the ages observed. Fixing Linf at 100 (assumed for males) resulted in the blue curve. The green curve is the one estimated at WKAngler 2017 using a similar approach. This curve is almost identical to the current results. January 1st was assumed to be the birth date – the 'real age' is adjusted for this.

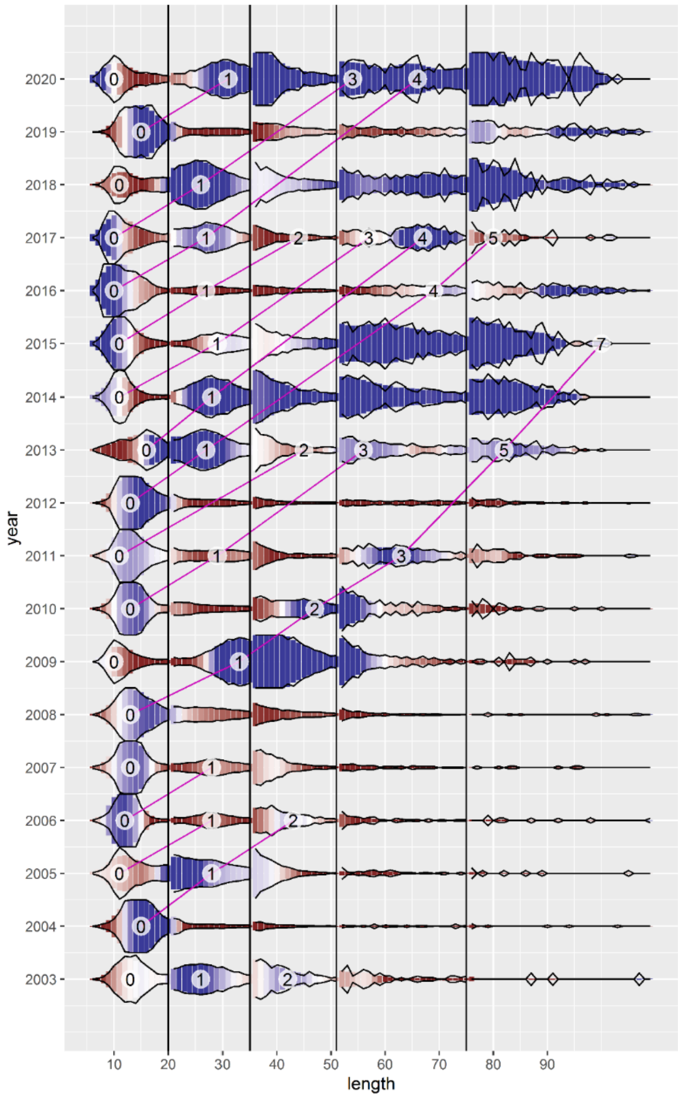

Figure 8. Hake. Length frequency distributions of from the IGFS-EVHOE index (due to the strong decline in abundance with increasing size, the scales are re-adjusted for 5 size groups, separated by vertical black lines). Blue bars represent above-average observations for a certain length class compared to other years, while red bars are below-average. The numbers in the translucent circles are the assumed mean length of strong cohorts that were identified 'by eye'.

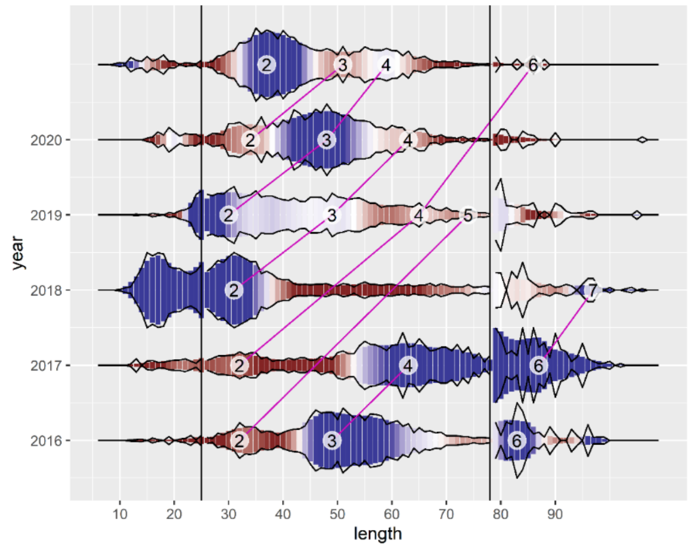

Figure 9. Hake. Length frequency distributions of black anglerfish from the IAMS index – see legend for the previous figure for more detail.

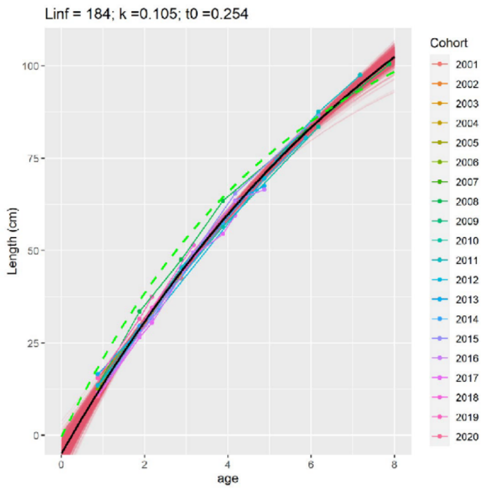

Figure 10. Hake. Mean lengths-at-age resulting from cohort tracking. A growth curve was fitted through all data (black). The dotted green line represents the current assumed growth curve (stock annex). The thin red lines are bootstrapped estimates. January 1st was assumed to be the birth date – the 'real age' is adjusted for this.

WORKING DOCUMENT 05

Maturity - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

WD to WKAnglerHake data compilation workshop – Hans Gerritsen, Marine Institute

Summary

Length at 50% maturity (L50) was estimated from Irish Survey data. Approximate age at 50% maturity is inferred from growth parameters estimated from length cohort analysis (see WD 04). Alternatively, L50 was estimated using the regression between L50 and latitude, based on estimates from the literature and the current study. The stock ranges from 44.5°N to 54.5°N with a mid-point of 49.5°N. A third alternative could be to only use estimates from the literature that have been validated using histology. The slope of the regression with latitude could be used to correct for any bias resulting from the sampling region.

		Survey data		Literature+ latitude	
Stock	Sex	L50	A50	L50	A50
Hake in 3a,4,6,7,8abd	Female	50cm	Age 3		
	Male	32cm	Age 2		
White anglerfish in 7,8abd	Female	90cm	Age 7	81cm	Age 6
	Male	58cm	Age 4	52cm	Age 3
Black anglerfish in 7,8abd	Female	62cm	Age 6	58cm	Age 6
	Male	48cm	Age 5	40cm	Age 4

Introduction

WKAngler(2018) reviewed the available literature on maturity of Lophius budegassa and piscatorius.

This working document provides updated maturity estimates from Irish surveys and places this in the context of the values from the literature. Irish sampling data is also presented for northern hake.

Surveys

Ireland has collected maturity data on a number of suvey series. In Q1 of 2004-2009 the biological sampling survey (BSS) took place in various regions with the express purpose of collecting maturity information for demersal fish. Since 2016 the Irish Anglerfish and Megrim Survey (IAMS) takes place in Q1 from the west of Scotland to the southern Celtic Sea at depths up to 1000m. And since 2003 the Irish GroundFish Survey takes place in Q4 of each year in the waters around Ireland up to around 200m depth. Figure 1 shows the spatial coverage of the surveys.

Commercial data

During Q1 a number of species (including hake) are sampled for maturity on observer trips and in the ports. No anglerfish data are collected from commercial sources.

Hake

For hake, there is considerable difference in the maturity ogives between the data sources (Figure 2). This may be a consequence of the seasonal timing of the sampling, the spatial location of the sampling and/or of variations in over the years.

The BSS and at-sea commercial sampling did not include many large fish and therefore estimating female maturity ogive from these data sources is problematic. The IGFS and IAMS both catch fish across the sizes over which they mature but they have quite different male maturity ogives. Possibly it is more difficult to distinguish virgin and resting males in Q4 than it is in Q1. Overall the male L50 is around 32cm and the female L50 is around 50cm.

The raw hake data are made available to the WKAngHake data compilation workshop for more detailed analysis: WKAngHake_2022_hke_northern_maturity.csv

White anglerfish

For white anglerfish there are also differences between the surveys (Figure 3). The IAMS estimates a lower L50 for males and a higher L50 for females than IGFS. This may be related to the timimg of the surveys, to the spatial distribuition of the surveys or the year ranges. It is possible that in Q1 it is easier to distinguish mature from virgin males.

Overall, the male L50 is around 58cm and the female L50 around 90cm (although anywhere between 90 and 100cm seems plausible).

Black anglerfish

Sample numbers for black anglerfish are relatively low but again, there seem to be differences between the surveys (Figure 4). Overall the male L50 is around 48cm and female L50 around 62cm.

Literature review

No new publications were identified so the WKAngler (2018) data were used to put the current results for anglerfish into context. Figure 5 shows that there is a clear trend between length at 50% maturity and latitude. The current results are broadly in line with the overall trend and would appear to be suitable for use in the assessment for these stocks.

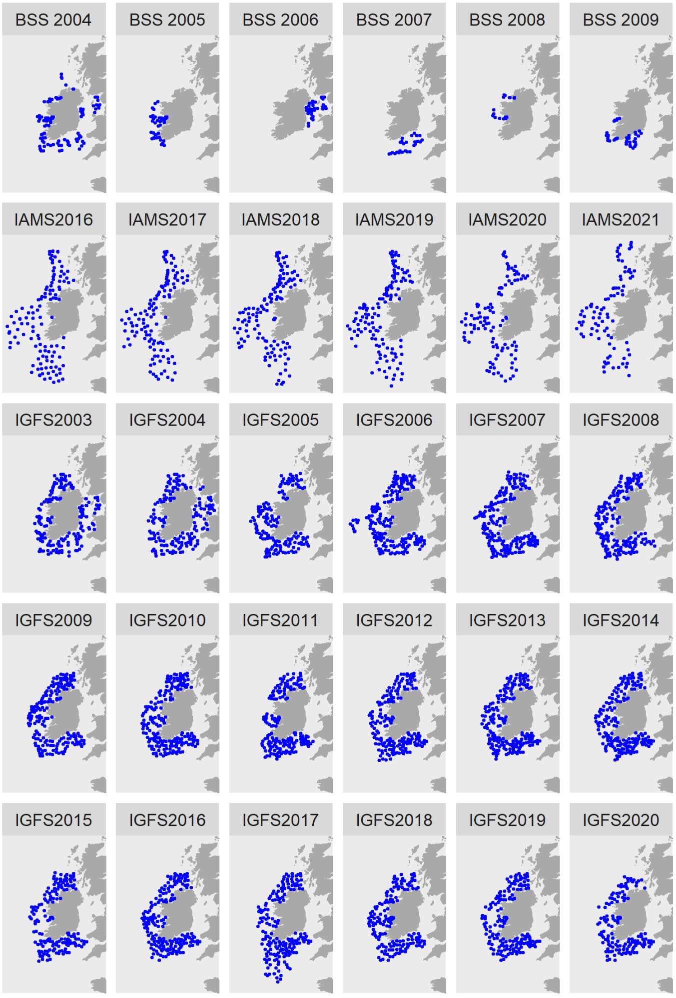

Figure 1. Survey coverage for the Q1 BSS and IAMS surveys and the Q4 IGFS survey.

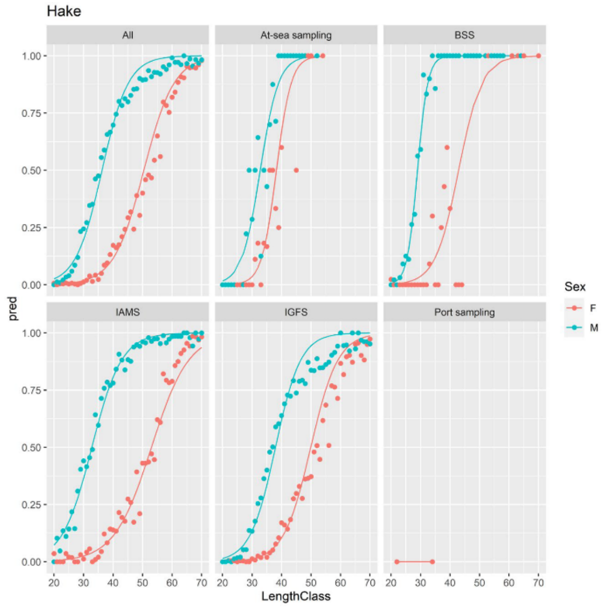

Figure 2. Maturity-at-length for hake (0=immature; 1=mature) from different sources. All sampling took place in Q1 exept IAMS, which takes place in Q4.

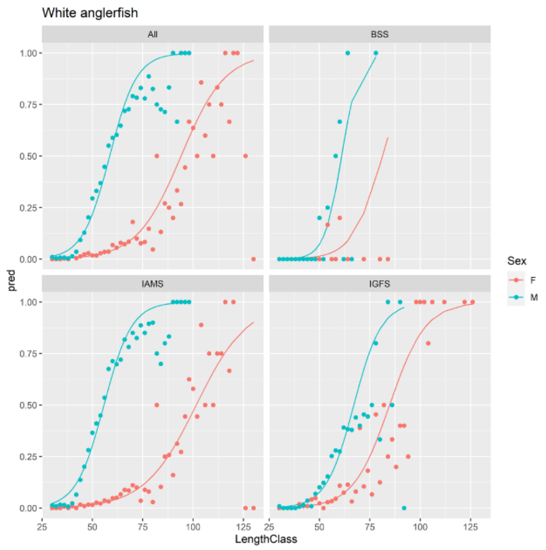

Figure 2. Maturity-at-length for white anglerfish (0=immature; 1=mature) from different sources. All sampling took place in Q1 exept IAMS, which takes place in Q4.

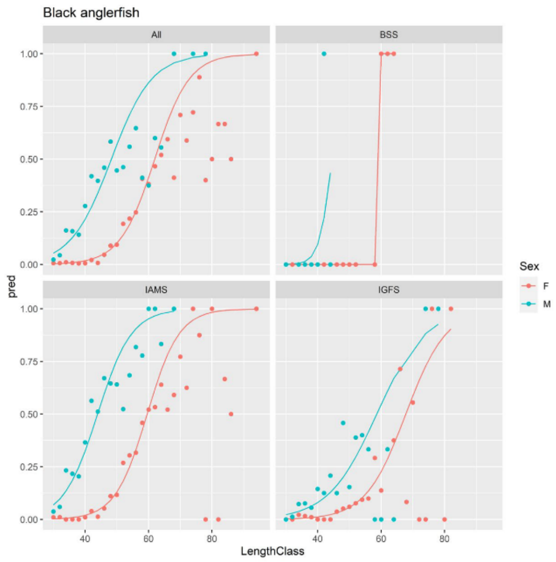

Figure 3. Maturity-at-length for black anglerfish (0=immature; 1=mature) from different sources. All sampling took place in Q1 exept IAMS, which takes place in Q4.

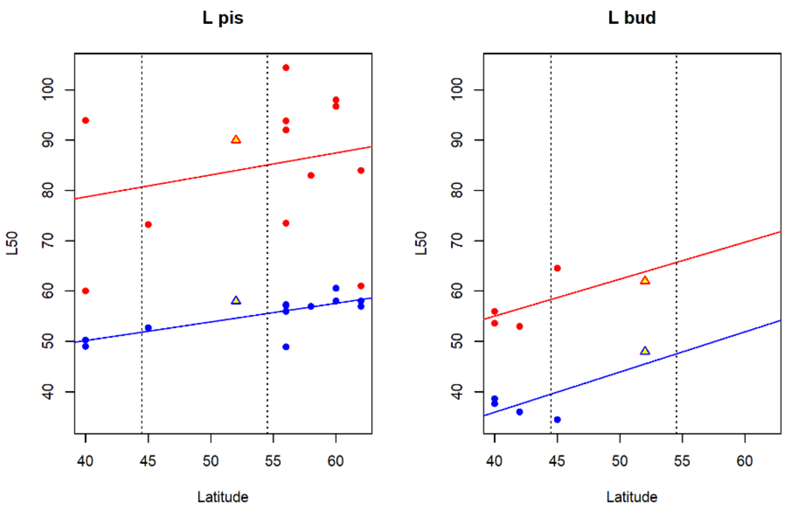

Figure 4. Literature values of ength at 50% maturity by latitude for male and female white anglerfish (left) and black anglerfish (right). The triangles represent the estimates from the Irish survey data.

Table 1. Overview of literature values for L50 of white anglerfish (Lpis) and black anglerfish (Lbud)

Reference	Area	Latitude	Species	Sex	L50
Dyb unpub in Thangstad 2006	W Norway	62	Lpis	F	61
Dyb unpub in Thangstad 2006	W Norway	62	Lpis	M	57
Dyb unpub in Thangstad 2006	Nsea	58	Lpis	F	83
Dyb unpub in Thangstad 2006	Nsea	58	Lpis	M	57
Offstad 2017	Faroe	62	Lpis	F	84
Offstad 2017	Faroe	62	Lpis	M	58
Landa 2014	8c,9a	42	Lbud	F	53
Landa 2014	8c,9a	42	Lbud	M	36
Colmenero 2017	NW med	40	Lpis	F	60
Colmenero 2017	NW med	40	Lpis	M	49
Alfonso-Dias 1996	W Scot	56	Lpis	F	73.5
Alfonso-Dias 1996	W Scot	56	Lpis	M	48.9
Laurenson 2003	Shetland	60	Lpis	F	98
Laurenson 2003	Shetland	60	Lpis	M	58
Duarte 2001	Iberian coast	40	Lpis	F	93.9
Duarte 2001	Iberian coast	40	Lpis	M	50.3
Gordon 2001	W Scot	56	Lpis	F	92
Gordon 2001	W Scot	56	Lpis	M	56
Quincoces 1998	Biscay	45	Lpis	F	73.2
Quincoces 1998	Biscay	45	Lpis	M	52.7
Azevedo 1996	Portugal	40	Lbud	F	56
Azevedo 1996	Portugal	40	Lbud	M	37.6
Duarte 2001	Iberian coast	40	Lbud	F	53.6
Duarte 2001	Iberian coast	40	Lbud	M	38.6
Quincoces 1998	Biscay	45	Lbud	F	64.5
Quincoces 1998	Biscay	45	Lbud	M	34.5
Larensen 2007	Shetland	60	Lpis	F	96.7
Larensen 2007	Shetland	60	Lpis	M	60.6
Larensen 2007	W Scot	56	Lpis	F	93.8
Larensen 2007	W Scot	56	Lpis	M	57.1
Larensen 2007	Rockall	56	Lpis	F	104.4
Larensen 2007	Rockall	56	Lpis	M	57.3
Ireland unpubl (this WD)	W Ire	52	Lbud	F	62
Ireland unpubl (this WD)	W Ire	52	Lbud	M	48
Ireland unpubl (this WD)	W Ire	52	Lpis	F	90
Ireland unpubl (this WD)	W Ire	52	Lpis	M	58

WORKING DOCUMENT 06

Natural mortality - ank.27.78abd, mon.27.78abd and hke.27.3a46-8abd

WD to WKAnglerHake data compilation workshop – Hans Gerritsen, Marine Institute

Summary

Natural mortality estimates were explored using a variety of methods. For all three stocks methods using growth parameters yielded low estimates of M. Methods based on the age at first maturity resulted in intermdiate estimates of M for the two anglerfish stocks and very high estimates for hake; methods based on GSI resulted in high M for anglerfish females and low M for anglerfish males and intermediate estimates for hake. The FishLife method (Thorson et al, 2017) based on a range of life-history parameters and taxonomic hierarchy gave intermediate estimates of M for all three stocks. Methods based on size-at-age (like Lorenzen) have very little prediction power for larger fish (for which predation is probably not the main cause of natural mortality). Therefore, it is proposed to use a fixed M for fish at ages where they are expected to be >1kg and M estimated using the Lorenzen method for younger fish. The Thorsen estimate is proposed as a base case but values between 0.15 and 0.45 (angler) or 0.4o (hake) can all be considered plausible.

Proposed base-case estimates of M

Stock	Age 1	Age 2	Age 3	Age 4+
Black angler	0.81	0.55	0.43	0.32
White angler	0.57	0.40	0.36	0.36
Hake	0.88	0.49	0.35	0.31

Introduction

For the purpose of stock assessment, M is usually a model input. However, observed natural mortality (M) data is available for only a relatively small number of stocks. There are a number of available methods to estimate M based on life-history information of a stock, for example:

- Longevity (e.g. oldest observed individual)
- Growth parameters (one or more parameters from the Von Bertalanffy growth function)
- Mean observed length or weight-at-age
- Maturity (or maturity and growth) or GSI
- A combination of life-history and other parameters

Most methods produce a single estimate of M that implicitly or explicitly applies to all life stages, only to juveniles or only to mature fish. There are also methods that are used to estimate M-at-age but the drawback of these is that not of these take into account life-history parameters other than size-at-age. All methods suffer from considerable uncertainty (i.e. they only explain a small part of the natural variation in observed M).

The R package fishmethods includes a number of methods to estimate M and the barefoot ecologist's toolbox http://barefootecologist.com.au/ lists some additional methods. No direct age data is available for black and white angerfish or hake, so methods using longevity were not explored. The life-history parameters used to estimate natural mortality for the three stocks are given in Table 1. Table 2 lists the methods and their estimates of M. Figure 1 shows the growth curves of the three stocks (based on cohort analysis of length frequency data; WD XX).

Methods based on growth parameters

Three methods were explored that are based on Von Bertalanffy growth parameters (Pauly 1980, Jensen, 1996,1997 and Then, 2015). The idea behind these methods is fish that grow quickly to a large size are subject to lower predation pressure than fish that have a low asymptotic length. The implication is that the relatively low estimates of M for large-bodied fish do not apply to juveniles.

The three methods tend to give similar results (Table 2) For all three stocks the methods based on growth parameters estimated M to be between 0.14 and 0.18. This relatively low M reflects the fast growth of the three stocks. However, this is not in line with estimates that use other life-history information, such as reproductive parameters.

Methods based on reproductive parameters

Two methods were explored that take the age at maturity into account (Rikhter-Efanov, 1976 and Roff, 1984). Fish that mature at an old age are expected to have low natural mortality while fish that suffer high natural mortality will have evolved to mature at an early age. These methods estimated high M for hake (>0.5) as it matures at a relatively young age (Table 2). The M estimates for both anglerfish stocks were moderate (0.22-0.37) as they mature relatively late.

The Gunderson-Dygert (1988) method is based on the Gonadosomatic Index of ripe fish. This could be highly relevant for anglerfish species as the females produce very large ovaries, which represents a considerable investment and is likely to have a cost in terms of natural mortality. Anglerfish females can have a GSI of 25% or more when they are ripe (Thangstad, 2006); this gives an estimated M of 0.45 for both species of anglerfish (the same GSI was assumed for both species; Table 2). The GSI of hake is estimated to be somewhat lower and M is estimated to be 0.37 using this method. These M estimates would only apply to the mature part of the female population as juvenile fish do not suffer spawning-related mortality. The GSI of ripe anglerfish males is considerably lower (around 5%) which would result in an M of 0.11 for mature males. GSI of male hake was not available. Obviously GSI is not the only factor determining M but for fish with a high GSI, spawning-related mortality is likely to be considerable; therefore, a low M for older anglerfish is not realistic.

Method based on life-history parameters, temperature and taxonomic hierarchy

Thorsen et al (2017) developed a method to simultaneously estimate a number of life-history parameters, including M, based on a multivariate model for eight variables obtained from Fishbase (seven parameters and temperature). The model predicts life history variables for all >32,000 fishes worldwide while accounting for similarity in the relationships among life-history parameters for fishes that are taxonomically related, explicitly representing residual error including correlations among parameters, and accounting for missing data. The model estimates a single value of M which presumably does not apply to the early life-stages where M is highly dependent on size.

This model is based on considerably more data than any other method of estimating M and would be expected to give the most accurate estimates. Thorsons method estimates M = 0.32 for black anglerfish, 0.36 for white anglerfish and 0.31 for hake. All methods described here suffer from very low precision but Thorson's method is the only one that provides confidence intervals. The 95% confidence intervals for hake are relatively narrow (0.24-0.40) but those for the two angerfish stocks indicate that the true value of M could be anywhere between half and twice the point estimate.

Methods based on size

Finally, there are a number of methods that are based on size (which are generally extrapolated to size-at-age within a stock although the methods are generally based on data of mean size of fish of each stock or, in some cases, juveniles and adults of a stock). Table 2 lists the estimates from three of those methods. Chen and Watanabe (1989) propose a 'bathtub'-shaped maturity-at-age curve which is a combination of a decreasing curve which results from decreasing M as fish get larger, a stable phase and a senescence phase where M increases due to 'old age'. This seems to be a sensible approach but Chen and Watanabe provide actual data to support their model. Additionally, their proposed model for the senescence phase only 'works' for a narrow range of growth parameters and results in the log of a negative number for the growth parameters of the stocks examined here, therefore only the initial phase is presented in table 2. The methods by Gislason et al (2010) and Lorenzen (1996) are widely used in stock assessment to obtain M estimates. The former is based on length-at-age, while the latter is based on weight-at-age. Gislason gives higher M estimates at young ages than Lorenzen for all three species. Anglerfish are relatively heavy for their length and due to their shape, a small anglerfish is probably a less likely prey than, say, a herring of the same length. For this reason, the Lorenzen method (based on weight) may be more appropriate for anglerfish. Hake have more a 'classic' fish shape so either method may be appropriate.

Lorenzen (1996) used a reasonably large dataset of empirical natural mortality data for fish in a variety of ecosystems, including oceans/seas. Figure 2 reproduces the dataset for fish living in marine environments and it shows a very strong relationship between size and M. Small fish generally suffer very high natural mortality, which presumably is driven by predation. However, for fish larger than around 1kg there is no clear relationship between size and M. This is particularly clear when the data are plotted on the natural scale (Figure 2). When a segmented regression is fitted, the resulting fit has a breakpoint around 1kg and a slope close to 0 for fish larger than this breakpoint.

Conclusion

The methods based on growth parameters are likely to under-estimate M for anglerfish, because they do not take into account the relatively high age at maturity and high cost of reproduction associated with a high GSI. The methods based on reproductive parameters generally do not account for the fact that both anglerfish and hake fairly quickly attain a size where they are too large for most predators to eat. Thorson's method accounts for multiple life-history parameters as well as the taxonomic hierarchy of species and would therefore be expected to be the most accurate method for mature fish. For younger and small fish, the Lorenzen method is very convincing, considering the strong relationship between M and size for fish up to around 1kg. Both black angerfish and hake reach a weight of 1kg between the ages of 3 and 4 while white anglerfish are expected to reach that weight between ages 2 and 3. It is therefore proposed to use Lorenzen estimates for ages 1 to 3 for black anglerfish and hake and for ages 1and 2 for white anglerfish and Thorsen for older ages.

The proposed 'base case' natural mortality for the three stocks is given below (Natural mortality at age 0 is an abstract concept depending on whether mortality is counted from the egg, larvae etc.; SS allows M=0 for age 0).

Method		**Lorenzen**	**Lorenzen**	**Lorenzen/ Thorsen**	**Thorsen**	**95% CI Thorsen**
Stock	**Age 0**	**Age 1**	**Age 2**	**Age 3**	**Age 4+**	**Age 4+**
Black angler	0	0.81	0.55	0.43	0.32	0.16-0.67
White angler	0	0.57	0.40	0.36	0.36	0.19-0.69
Hake	0	0.88	0.49	0.35	0.31	0.24-0.40

It should be noted that the predicted values of any of these methods are highly uncertain due to the high level of natural variation in M. Therefore, the sensitivity of the assessment model and reference points needs to be evaluated against this uncertainty.

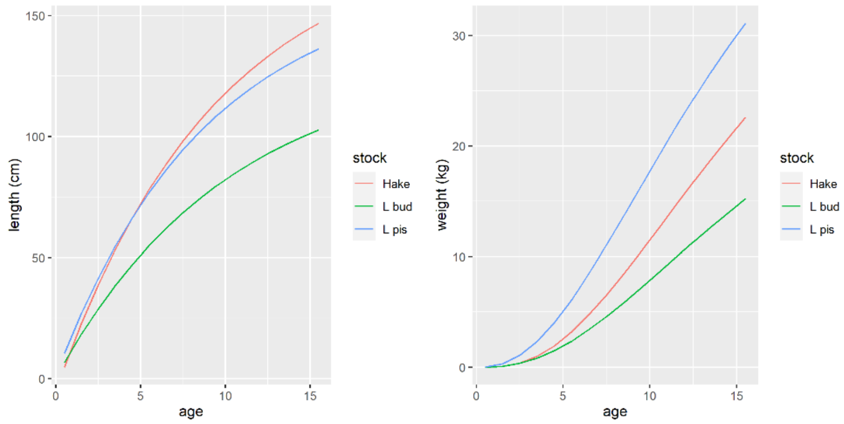

Figure 1. The growth curves of the three stocks (based on the parameters from table 1) left: length-at-age (cm) and right: weight-at-age (g)

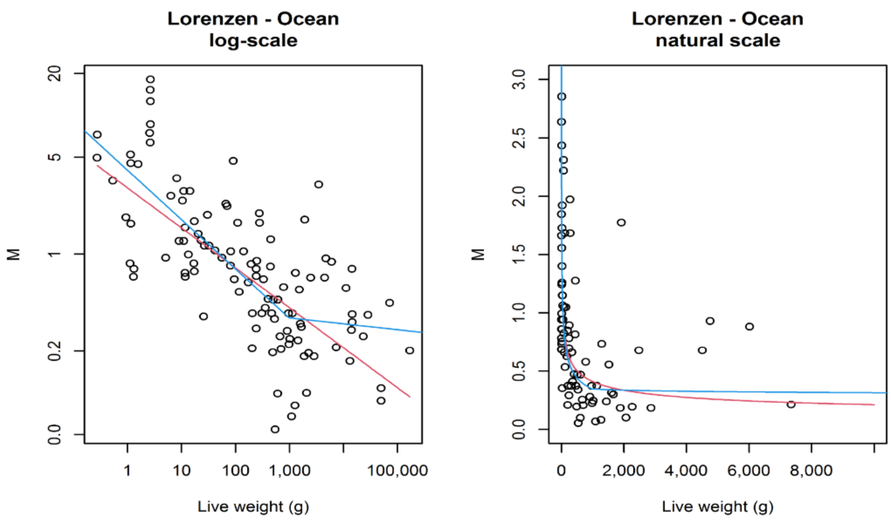

Figure 2. Observed natural mortality vs live weight for marine fish from Lorenzen (1996). Lorenzen fitted a linear regression to the log transformed data (red line). However, a segmented regression gives a slightly better fit and shows that after the breakpoint (around 1kg) there is no strong relationship between M and size. This is particularly clear when the data are plotted on the natural scale (right).

Table 1. Life-history parameters used to estimate natural mortality. Units in g, cm, years and °C. Ank is black anglerfish (L budegassa); Mon is white anglerfish (L piscatorius) and Hke is hake (Merliuccius merluccius)

Parameter	Ank	Mon	Hke	Source
Length-weght: a	0.0177	0.0284	0.00503	IAMS survey data
Length-weght: b	2.95	2.83	3.07	
VonBertalanffy: Linf	132	165	184	Length Frequency Analysis (working doc to WKAngHke 2022)
VonBertalanffy: k	0.097	0.122	0.105	
VonBertalanffy: t0	-0.031	-0.084	0.254	
Age at maturity: Amat	6	7	3	Female L50 (62;90,50cm) converted to age
Water temperature: T	10	10	10	[ROMS model]()
Gonadosomatic Index: GSI (ripe fish only)	F:25% M:5%	F:25% M:5%	F:20%	Thangstad, 2006; Ofstad & Laurenson, 2007; Domingues-Petit 2010
VonBertalanffy: Winf	a*Linf^b			
Length at age: Lage	Linf * (1 - exp(-k * (age - t0)))			
Weight at age: Wage	a*Lage^b			

Table 2. M estimates for the three species using various methods. The parameters used for each method are given below the name of the method. See main text for references.

Methods based on growth parameters				
Method		**Pauly**	**Jensen**	**Then**
Stock	Age	Linf, k, T	k	Linf, k
Black anglerfish	Does not apply to juveniles	0.16	0.16	0.15
White anglerfish		0.16	0.18	0.15
Hake		0.15	0.17	0.14

Methods based on reproductive parameters					
Method		**Rikhter**	**Roff**	**Gunderson**	
Stock	Age	Amat	Amat, k	GSI Fem	GSI Male
Black anglerfish	GSI does not apply to juveniles	0.26	0.37	0.45	0.11
White anglerfish		0.22	0.28	0.45	0.11
Hake		0.53	0.85	0.37	

Method based on life-history para and taxonomic hierarchy				
Method		**Thorsen**	**Thorsen 50% CI**	**Thorson 95% CI**
Stock	Age	7 life-history parameters, temperature and taxonomy		
Black anglerfish	Does not apply to juveniles	0.32	0.23-0.45	0.16-0.67
White anglerfish		0.36	0.26-0.49	0.19-0.69
Hake		0.31	0.28-0.35	0.24-0.40

Methods based on size-at-age

Stock	Method Age	Chen k, t0	Gislason Lage, Linf, k	Lorenzen Wage	Lorenzen segreg Wage
Black anglerfish	1.5	0.70	1.78	0.81	0.80
	2.5	0.45	0.85	0.55	0.50
	3.5	0.33	0.54	0.43	0.37
	4.5	0.27	0.39	0.36	0.34
	5.5	0.23	0.30	0.32	0.33
	6.5	0.21	0.25	0.29	0.33
	7.5		0.21	0.26	0.33
	8.5		0.18	0.25	0.32
	9.5		0.17	0.23	0.32
	10.5		0.15	0.22	0.32
	11.5		0.14	0.21	0.31
	12.5		0.13	0.20	0.31
	13.5		0.12	0.20	0.31
	14.5		0.12	0.19	0.31
	15.5		0.11	0.19	0.31

Stock	Method Age	Chen k, t0	Gislason Lage, Linf, k	Lorenzen Wage	Lorenzen segreg Wage
White anglerfish	1.5	1.77	1.52	0.57	0.59
	2.5	0.69	0.75	0.40	0.36
	3.5	0.45	0.48	0.32	0.34
	4.5	0.34	0.35	0.27	0.33
	5.5	0.28	0.28	0.24	0.32
	6.5	0.24	0.23	0.22	0.32
	7.5		0.20	0.21	0.31
	8.5		0.18	0.19	0.31
	9.5		0.16	0.18	0.31
	10.5		0.15	0.18	0.31
	11.5		0.14	0.17	0.31
	12.5		0.13	0.16	0.30
	13.5		0.12	0.16	0.30
	14.5		0.12	0.16	0.30
	15.5		0.11	0.15	0.30

Stock	Method Age	Chen k, t0	Gislason Lage, Linf, k	Lorenzen Wage	Lorenzen segreg Wage
Hake	1.5	0.86	2.20	0.88	0.88
	2.5	0.50	0.92	0.54	0.49
	3.5	0.36	0.55	0.41	0.35
	4.5	0.29	0.39	0.34	0.34
	5.5		0.30	0.29	0.33

6.5	0.24	0.26	0.32
7.5	0.21	0.24	0.32
8.5	0.18	0.22	0.32
9.5	0.16	0.21	0.31
10.5	0.15	0.20	0.31
11.5	0.14	0.19	0.31
12.5	0.13	0.18	0.31
13.5	0.12	0.18	0.31
14.5	0.11	0.17	0.30
15.5	0.11	0.17	0.30

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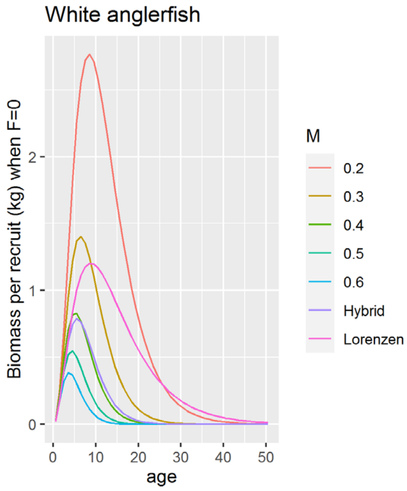
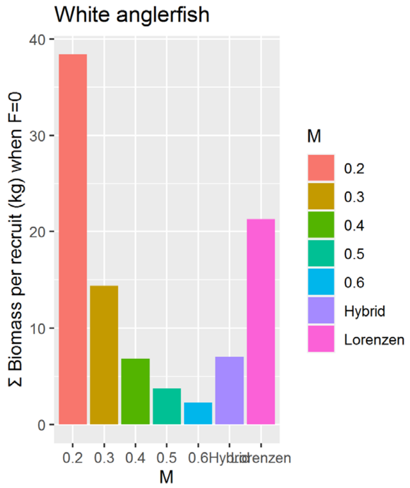
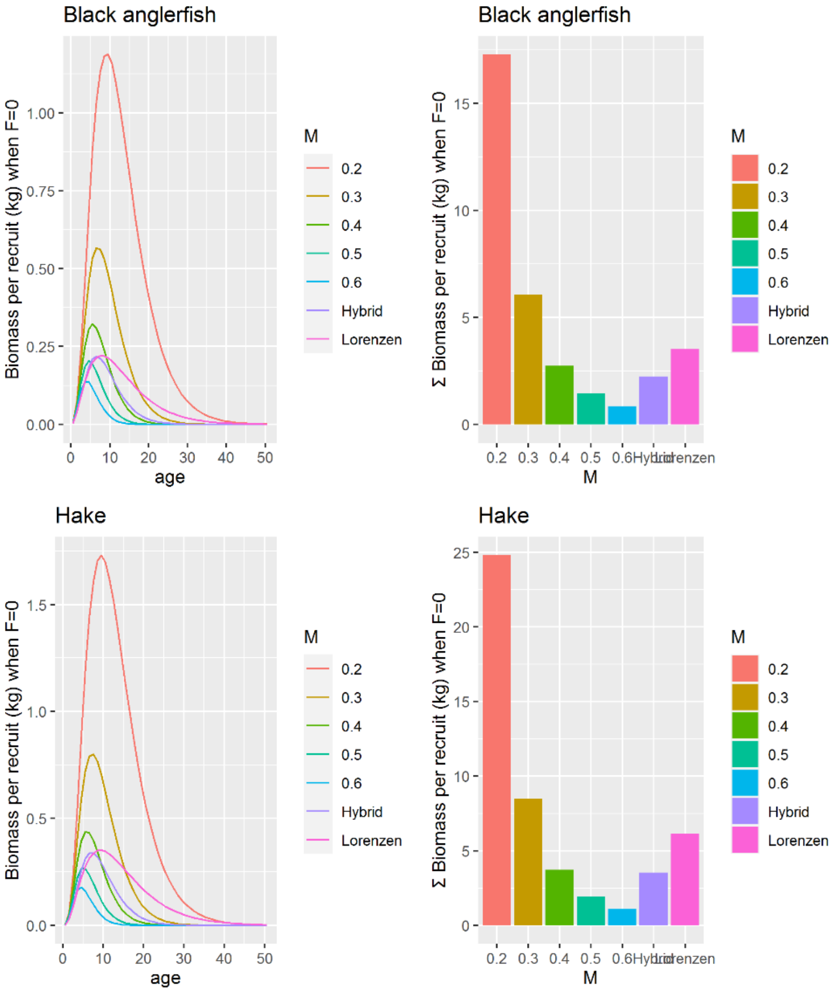
Some additional plots to be discussed

- At different levels of M, the unfished biomass per recruit was estimated (F=0, so M=Z). If you have a stock that keeps growing fast into old ages (all 3 stocks have pretty much linear growth in weight) then you can get a lot of biomass in your older fish when M is low. This will affect the estimate of B0 (virgin biomass), which is determined by weight-at-age, natural mortality and the stock-recruit curve. Here we ignore the SR as we are looking at biomass per recruit but it still gives an impression of B0 (although higher recruitment at higher biomass will exaggerate the patterns seen here).
- For white anglerfish, the choice of M between 0.2 and 0.6 can lead to more than a 10-fold difference in unfished biomass per recruit. Lorenzen estimates give high M at the youngest ages but very low M for old ages (0.15) so the impact of the unfished biomass is similar to an overall M of around 0.25. The hybrid Lorenzen-Thorsen has higher M for older fish and consequently a relatively low estimate of unfished biomass.
- For the other two stocks, the lorenzen estimate is more similar to the hybrid M.







Black anglerfish
Biomass per recruit (kg) when F=0
age
M
0.2
0.3
0.4
0.5
0.6
Hybrid
Lorenzen
Black anglerfish
Σ Biomass per recruit (kg) when F=0
M
Hake
Biomass per recruit (kg) when F=0
age
Hake
Σ Biomass per recruit (kg) when F=0
M

WORKING DOCUMENT 07

hke.27.3a46-8abd – New proposed tuning index: IAMS

Working document to WKAngHake – Hans Gerritsen – Marine Institute – version 1

Summary

A new survey index is proposed for inclusion in the assessment. The Survey covers the central part of the stock distribution and its full depth range. The survey takes place in Q1 every year since 2016.

Irish Anglerfish and Megrim Survey index for hake.

Ireland has carried out the Irish Anglerfish and Megrim survey every year in Q1 since 2016. The survey is designed to estimate abundance of anglerfish and megrim with the highest densities of survey hauls in areas with high abundance of the target species. The distribution of the target species overlap to a large extent with that of hake and it is likely that this survey can produce a reliable index for hake as well.

The survey covers the southern part of ICES area 6a, areas 7bcjk and the western part of 7gh; station positions are random-stratified (Figure 1); the depth range is from around 50m to 1000m. The survey takes place in the central distribution area of the hake stock and covers the area where around 55% of the landings are taken from. Therefore, the survey can be considered to cover an important part of the stock distribution.

The survey uses a relatively large mesh gear and the catchability of small hake is low. Medium and large hake are caught in large numbers and on nearly all survey hauls.

The time-series is relatively short and covers a period with relatively low contrast in biomass. However, the index has shown to be able to track strong and weak cohorts over time (WD XX – hake growth parameters from length data). Therefore, even with only 6 years of data, it might provide useful information to the assessment model.

Catches in numbers and weight were standardised by swept area (the mean wing spread multiplied by the distance over ground for each haul). Figure 2 shows the standardised catch weights at each station.

A biomass index was calculated (Figure 3; Table 1) as well as a length-frequency index (Figure 4; Table 2). Either or both of these indices could be included into the stock assessment model.

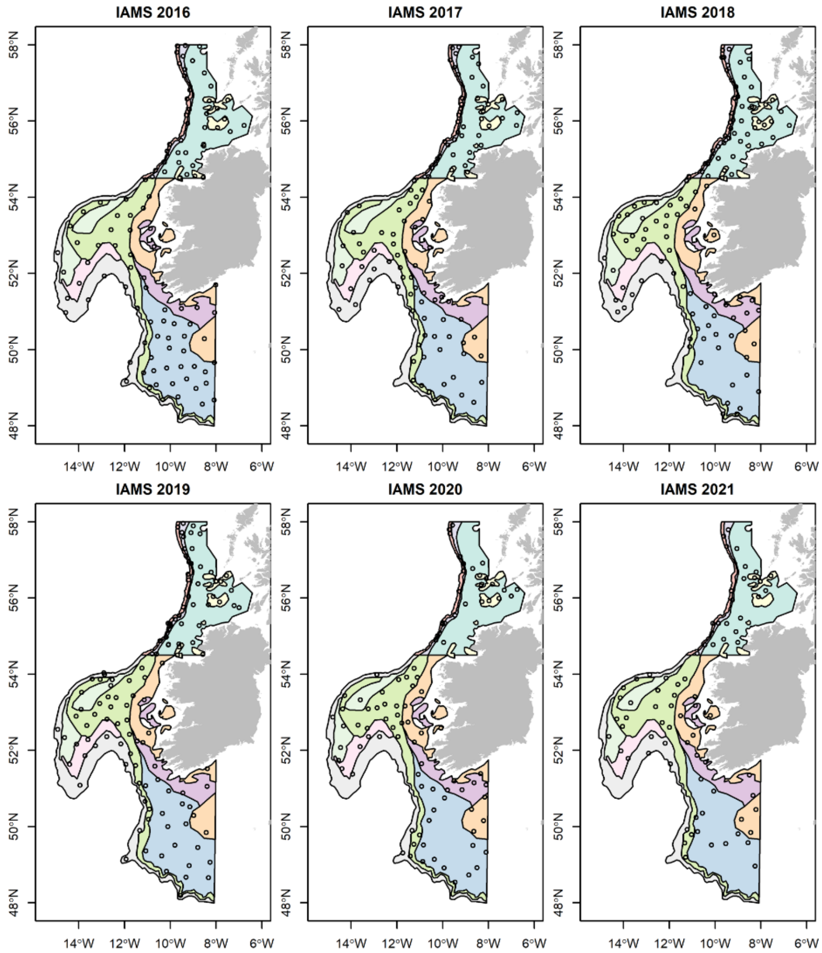


Figure 1. Survey coverage and stratification.

Figure 2. Standardised catch rates of hake (kg/lm2)

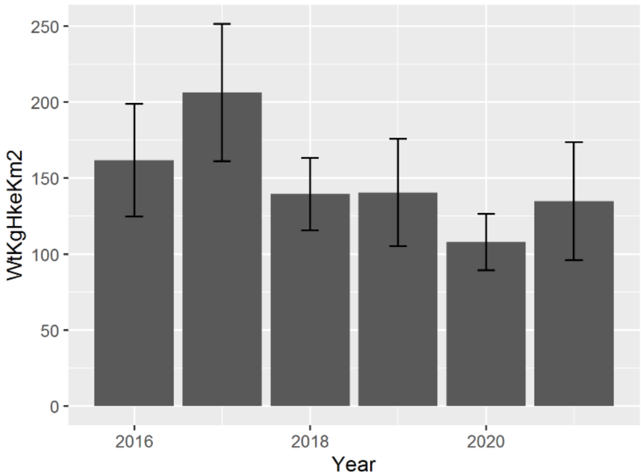


Figure 3. IAMS biomass index.

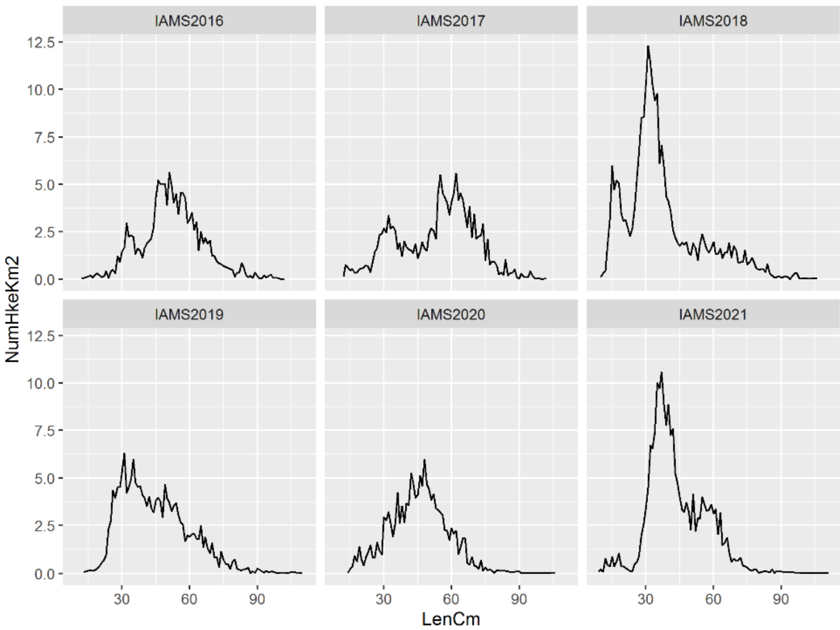


Figure 4. Length distribution of hake on the IAMS.

Table 1. IAMS biomass index (kg per km^2) with standard error. The mean date of the survey is also given as well as the number of hauls.

CruiseName	Year	MeanDate	Hauls	Kg/Km^2	se
IAMS2016	2016	01/02/2016	107	161.82	37.18
IAMS2017	2017	14/03/2017	108	206.36	45.10
IAMS2018	2018	19/03/2018	116	139.57	23.82
IAMS2019	2019	27/03/2019	124	140.54	35.28
IAMS2020	2020	18/03/2020	94	107.88	18.49
IAMS2021	2021	10/03/2021	75	134.85	38.79

Table 2. IAMS index at length (numbers per km^2)

Year	2016	2017	2018	2019	2020	2021
Total N/km^2	138.4	153.8	233.9	171.3	138.5	195.6
Length (cm)						
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0938
10	0.0000	0.0000	0.1029	0.0000	0.0000	0.2203
11	0.0000	0.0000	0.3237	0.0000	0.0000	0.0938
12	0.0580	0.1638	0.4653	0.0000	0.0000	0.7835
13	0.0760	0.7584	1.7591	0.0791	0.0000	0.4552
14	0.1180	0.0000	3.1105	0.0000	0.0329	0.3570
15	0.0000	0.4772	5.9822	0.0000	0.2352	0.8804
16	0.1931	0.5460	4.7373	0.1831	0.3546	0.3735
17	0.0906	0.3333	5.2098	0.1389	0.9216	0.6361
18	0.0000	0.3575	5.0819	0.0000	0.6368	1.0403
19	0.3290	0.5246	3.4946	0.2448	1.3800	0.3626
20	0.0000	0.5807	3.0924	0.3878	0.7523	0.3806
21	0.1126	0.6166	3.1236	0.5746	0.4328	0.0000
22	0.1681	0.7351	2.6837	0.7122	0.8558	0.2073
23	0.4231	0.6676	2.2815	0.9833	1.0903	0.1361
24	0.0706	0.3751	2.6941	2.3131	1.4743	0.1180
25	0.4334	0.9381	3.7895	2.7807	0.8196	0.5017
26	0.5186	1.4373	5.4493	4.3601	0.8218	0.6112
27	0.3218	1.6460	6.7443	3.9622	1.6202	0.9200
28	1.2200	2.3430	8.5196	4.5363	1.1809	1.9900
29	0.9301	2.4057	8.5606	4.5394	0.9841	2.6205
30	1.4756	2.6874	10.1929	5.3209	2.9570	3.3770
31	1.6713	2.4668	12.2873	6.3076	2.7756	4.5045
32	2.9735	3.3709	11.3373	4.2480	3.2122	6.7215
33	2.2526	2.6695	10.2534	4.5167	2.6278	6.5519
34	2.3187	2.8071	9.4458	4.9513	1.9363	7.4313
35	2.2329	2.5775	9.8005	5.9837	2.6441	10.0072
36	1.3376	1.5846	6.1173	4.7870	4.2415	9.7252
37	1.6242	1.9115	7.0586	4.5572	2.6350	10.5944
38	1.4821	1.2230	5.9374	4.5901	3.5262	8.8568
39	1.1267	2.0007	4.3781	4.1222	2.6819	7.7879
40	1.6368	1.7158	4.1339	3.9657	3.6692	8.8605
41	1.8810	1.5834	3.5887	3.5252	3.5812	7.2675
42	2.0099	1.5284	2.5906	4.0232	5.2687	7.5970
43	2.1539	1.3743	2.2038	3.4534	4.7942	5.2113
44	2.7391	1.8529	1.9472	3.1901	3.9645	4.7808
45	4.3344	1.1183	1.7584	3.8213	4.1290	4.0021
46	5.2267	1.4928	1.9471	3.9884	5.1373	3.3385
47	5.0280	1.9657	1.8202	3.7843	4.5990	3.2213
48	5.0189	1.6189	1.9747	2.9388	5.9731	3.7184
49	5.0469	1.4988	1.4092	4.6694	4.6777	3.2154
50	3.9197	2.3767	1.2804	3.9701	4.4566	2.2758
51	5.6308	2.7000	1.9041	3.7016	3.8572	4.1593
52	4.8969	2.5729	1.6441	3.2671	4.1576	2.2250
53	4.0546	2.1403	1.0162	3.5546	3.3965	2.9017
54	4.5091	4.5368	1.8482	3.6990	3.3459	2.8589
55	3.4519	5.5090	2.3758	3.0587	3.1896	4.0068
56	4.5627	4.5368	1.9425	2.6527	3.0459	3.5912
57	4.5787	4.3449	1.6184	2.5758	2.2538	3.2751
58	4.3260	4.0482	1.4010	1.6680	2.2362	3.3140
59	2.9687	3.4134	1.6480	1.9892	1.7491	3.6150
60	3.1271	4.0525	1.9570	1.9131	2.3588	3.1286

61	3.5169	4.5542	1.3233	2.0597	2.0761	3.3614
62	2.6047	5.5936	1.3400	2.0641	2.2368	2.0504
63	3.0237	4.1756	1.6056	1.8132	1.0180	3.1788
64	1.5273	4.5553	1.1119	1.7780	1.3460	1.4709
65	2.5082	4.2021	1.3983	2.4820	1.8354	1.5908
66	1.9053	3.4141	1.4127	1.3735	1.8231	1.8643
67	2.1773	2.7301	1.9256	1.8854	0.5529	1.1187
68	1.8927	3.8345	1.1497	1.2774	0.4665	0.6150
69	2.0394	2.2119	1.7684	1.0505	0.8706	0.7883
70	1.2342	3.4364	1.5278	1.5652	0.4010	0.6748
71	1.2271	2.1343	0.8742	0.8493	0.3865	0.6893
72	0.9501	2.2568	0.9059	0.8555	0.2331	0.8268
73	0.8513	2.3208	0.9128	0.3483	0.7051	0.4170
74	0.8009	2.9287	1.5319	1.1341	0.1335	0.3954
75	0.7081	0.9983	0.7855	0.7100	0.3247	0.3166
76	0.6470	2.1115	0.8981	0.4837	0.1566	0.1900
77	0.6134	0.7772	1.1286	0.5051	0.2105	0.1339
78	0.5577	0.9430	0.8997	0.2344	0.1285	0.2233
79	0.4786	0.9318	0.5963	0.6238	0.0420	0.2066
80	0.1431	0.7225	0.5079	0.7499	0.1872	0.0267
81	0.3481	0.2549	0.0000	0.2622	0.1593	0.0000
82	0.3614	0.3582	0.5502	0.2033	0.0000	0.0000
83	0.8569	0.2454	0.3920	0.1668	0.0000	0.1425
84	0.6416	1.0215	0.7977	0.2289	0.1392	0.0000
85	0.2476	0.1901	0.3082	0.2462	0.1059	0.0558
86	0.1220	0.3204	0.1984	0.3117	0.0711	0.2188
87	0.1956	0.3558	0.0869	0.0128	0.0000	0.0181
88	0.0754	0.5352	0.1116	0.1233	0.0000	0.1143
89	0.3618	0.0888	0.1707	0.0383	0.0000	0.0000
90	0.1801	0.0529	0.0880	0.2709	0.1130	0.0000
91	0.0408	0.2967	0.1110	0.2003	0.0128	0.0000
92	0.0409	0.1416	0.1667	0.1081	0.0095	0.0000
93	0.2126	0.0000	0.1160	0.0335	0.0000	0.0000
94	0.0945	0.1122	0.0151	0.1330	0.0000	0.0000
95	0.0000	0.4172	0.1733	0.0769	0.0000	0.0000
96	0.2655	0.1849	0.3175	0.0996	0.0095	0.0000
97	0.0657	0.0297	0.3276	0.0985	0.0000	0.0000
98	0.0659	0.0411	0.0734	0.0543	0.0000	0.0000
99	0.0690	0.0541	0.0204	0.0128	0.0128	0.0000
100	0.0282	0.0148	0.0765	0.0000	0.0140	0.0000
101	0.0127	0.0000	0.0000	0.0605	0.0000	0.0154
102	0.0242	0.0411	0.0000	0.0000	0.0128	0.0000
103	0.0000	0.0000	0.0380	0.0000	0.0000	0.0000
104	0.0000	0.0000	0.0774	0.0065	0.0000	0.0000
105	0.0000	0.0000	0.0000	0.0934	0.0000	0.0000
106	0.0000	0.0000	0.0448	0.0000	0.0449	0.0000
107	0.0000	0.0000	0.0000	0.0478	0.0000	0.0000
108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
110	0.0000	0.0000	0.0000	0.0092	0.0000	0.0000
111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0156

WORKING DOCUMENT 08

hke.27.3a46-8abd – Revisions to the estimation of the IGFS index

Working document to WKAngHake – Hans Gerritsen – Marine Institute – version 1

Summary

The IGFS index is currently included in the northern hake assessment. This document describes a minor revision to the method of calculating the index as well as a revision in the way the length data are provided.

Irish Groundfish Survey index for hake.

Ireland has carried out the Irish Groundfish Survey (IGFS) every year in Q4 since 2003. The survey covers the southern part of ICES area 6a, areas 7bgj; station positions are random-stratified (Figure 1); the depth range is from around 50m to 200m (although there are a few deeper hauls).

Traditionally, the index was provided as a length-stratified index of abundance per swept area (average doorspread x distance towed). The estimation procedure is essentially unchanged except for some additional quality checks, replacing outlying values of doorspread with modelled values and the way missing strata are dealt with. The VIIbSlope stratum was not sampled in 2003,4 and 2011. This stratum consists of 6% of the survey area. In the years where this stratum was not sampled, the sample weights of the remaining strata were increased by 6% to account for the missing stratum. This implies the assumption that the missing stratum was similar to the average of the other strata in terms of density and length distributions.

Figure 2 shows the old and new indices for abundance per swept area as well as biomass per swept area (not previously provided). The difference between the old and new index are minor.

The length frequency data was previously not estimated following the survey design but simply provided as total catch numbers-at-length. The updated method provides length-stratified estimates of the length distributions. Figure 3 shows that in most years the differences are minor but in 2005 the new index estimates fewer recruits; in 2009 and 2018 the cohort of 1-year-olds (fish around 30cm) are stronger than previously estimated; in 2016 the new index estimates more recruits

The abundance and biomass indices are provided in table 1; either of these could be included in the stock assessment model. The length-frequency data are provided in table 2.

Separate length frequencies were also calculated by sex. This was done by building a series of sex-length keys. The first sex-length key was applied at the level of individual hauls. Due to the sampling design, not all length classes are sampled for biological parameters like sex at each haul (10-60% of length classes in the catch had biological data). Therefore, gaps were filled using a sex-length key was applied at the level of the spatial strata (in most years more than 70% of the length classes had biological data at this level). Finally any remaining gaps were filled using an annual sex-length key, which covered 100% of the length classes in the catch. Most hake under 18cm were classified as unsexed, because the gonads are insufficiently developed at that size to determine the sex. Nearly all unsexed individuals belonged to the first cohort, so the assumption was made that at that age the sex ratio was 50/50 and these fish were split evenly between the sexes.

Internal consistency of the old and new indices was investigated by assuming that all fish under 20cm belonged to the 0-group and all fish between 20 and 35cm were assumed to be 1-year-olds. The log catch numbers at ages 0 and 1 of the same cohort were then plotted against each other (Figure 4). The new index shows slightly improved internal consistency. 2018 remains an outlier, in this year almost no recruits were caught but in the next year a mode of fish around 25cm did appear. In 2005, recruitment was average but the 1-year-olds in the next year were below-average.

Conclusion

The quality control on the input data has been improved, as has the way to deal with outliers in doorspread. The length-frequency data is now provided using design-based estimators which makes them less susceptible to bias than previously. The new index shows a moderate improvement in the ability to track the first two cohorts.

Overall the new index estimates are thought to be more robust than before.

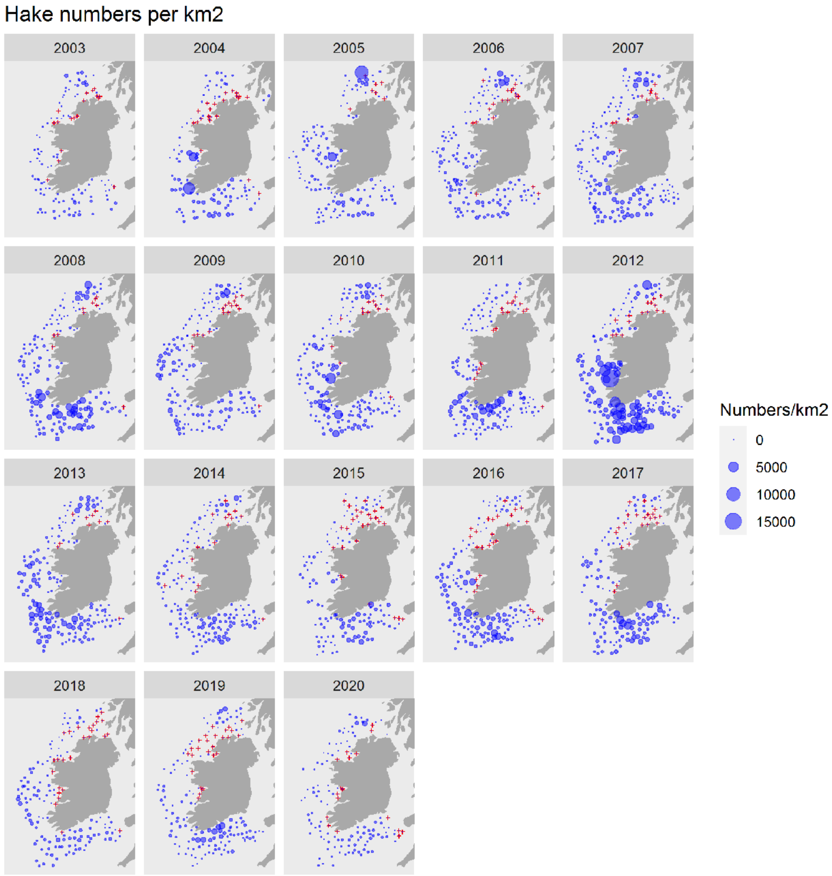


Figure 1a. Standardised catch rates of hake (numbers/km2)

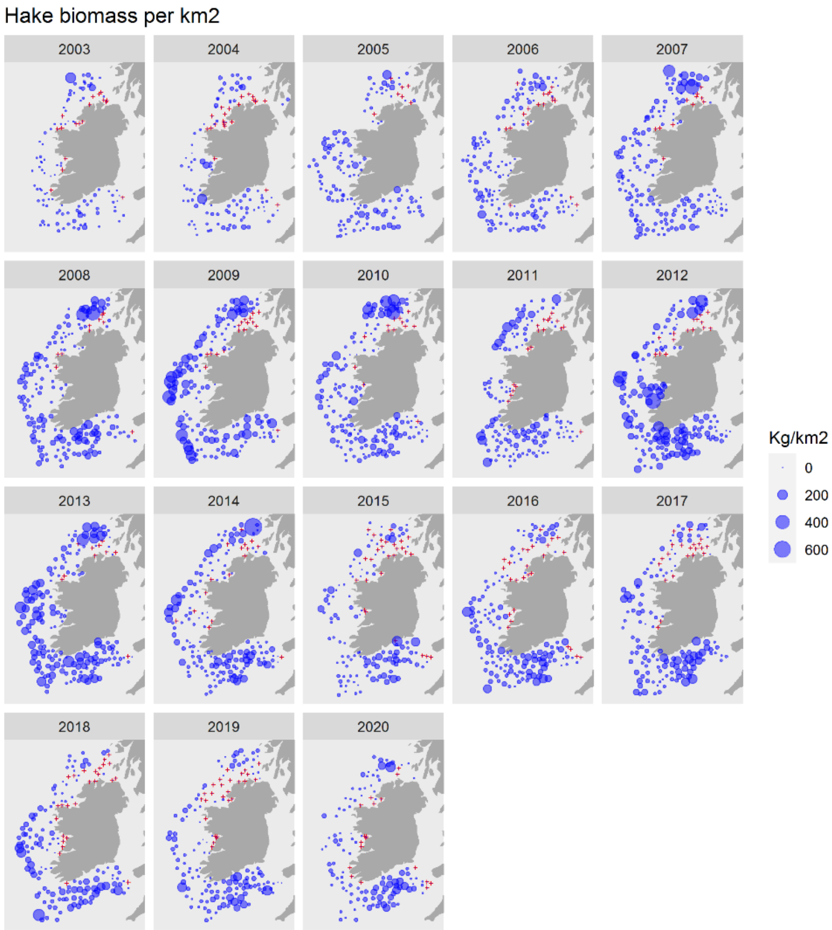


Figure 1b. Standardised catch rates of hake (biomass/km2)

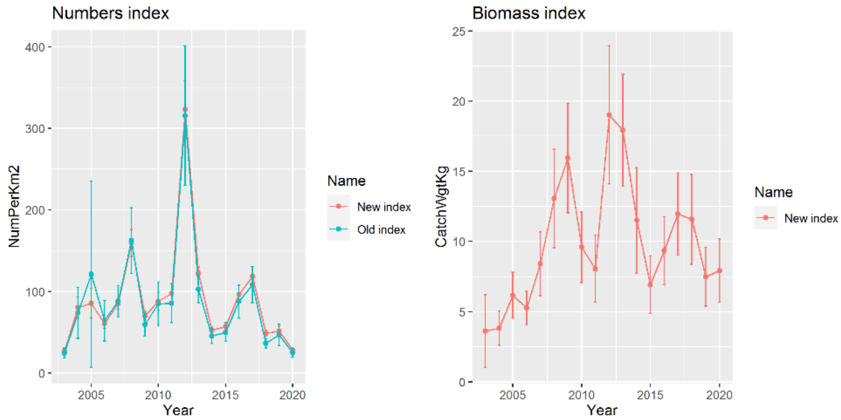


Figure 3. IGFS index by numbers (left) and biomass (right). The revised index is only marginally different from the index previously provided.

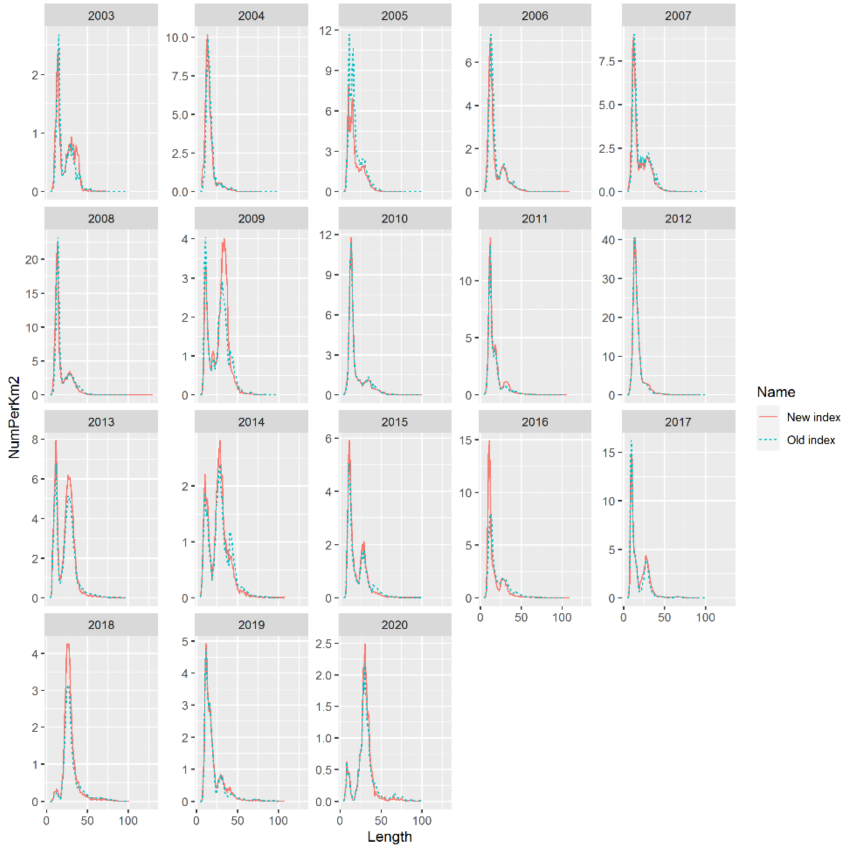


Figure 4. Length distribution of hake on the IGFS. The revised length frequency distributions are generally close to those previously provided but in some years there are differences in the estimated cohort strength.

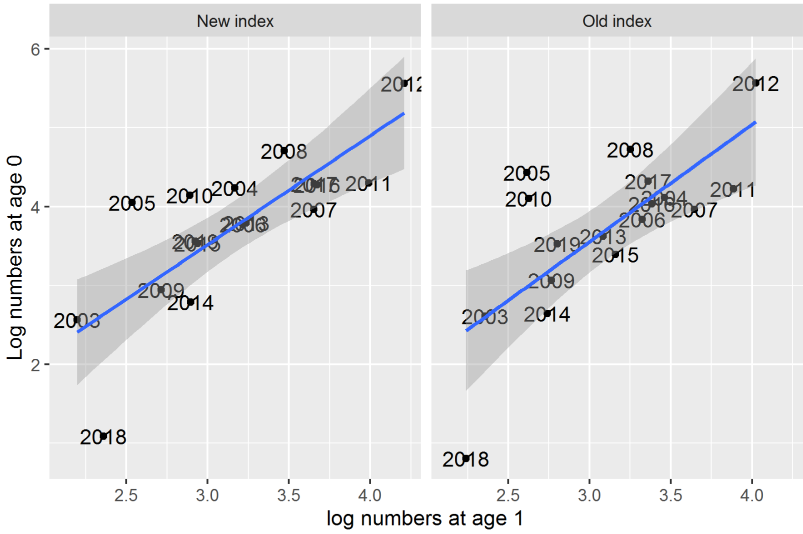


Figure 5. Internal consistency of old and new index. All fish under 20cm were assumed to be 0-group and all fish between 20 and 35cm were assumed to be 1-year-olds. The new index shows slightly improved internal consistency. 2018 remains an outlier, in this year almost no recruits were caught but in the next year a mode of fish around 25cm did appear. In 2005 recruitment was average but the 1-year-olds in the next year were below-average.

Table 1. IGFS biomass index (kg per km^2) and abundance index (numbers per km2) with standard error. The dates of the survey are also given as well as the number of hauls.

Year	NumHauls	MeanDate	MinDate	MaxDate	CatchWtKgkm2	CatchWtSe	CatchNoskm2	CatchNosSe
2003	118	07/11/2003	22/10/2003	02/12/2003	3.62	1.32	26.91	1.66
2004	124	27/10/2004	13/10/2004	21/11/2004	3.83	0.62	80.21	6.60
2005	140	05/11/2005	27/09/2005	28/11/2005	6.17	0.83	85.58	9.24
2006	168	08/11/2006	26/09/2006	01/12/2006	5.27	0.61	60.61	2.88
2007	171	30/10/2007	22/09/2007	27/11/2007	8.41	1.16	85.01	3.52
2008	166	29/10/2008	24/09/2008	28/11/2008	13.05	1.79	159.39	8.31
2009	164	29/10/2009	26/09/2009	30/11/2009	15.93	1.99	70.09	2.67
2010	176	14/11/2010	26/09/2010	19/12/2010	9.58	1.28	88.03	5.55
2011	159	08/11/2011	24/09/2011	16/12/2011	8.07	1.21	97.61	6.05
2012	172	14/11/2012	24/09/2012	16/12/2012	19.01	2.51	323.34	17.79
2013	176	01/11/2013	26/09/2013	30/11/2013	17.92	2.04	122.47	3.95
2014	170	13/11/2014	25/09/2014	16/12/2014	11.51	1.90	52.74	1.86
2015	147	08/11/2015	20/09/2015	16/12/2015	6.94	1.05	57.03	2.59
2016	172	16/11/2016	26/09/2016	17/12/2016	9.35	1.23	96.46	5.49
2017	149	07/11/2017	05/10/2017	08/12/2017	11.95	1.49	118.66	5.99
2018	153	18/11/2018	30/10/2018	11/12/2018	11.57	1.63	48.71	1.78
2019	161	20/11/2019	01/11/2019	12/12/2019	7.49	1.06	51.30	2.88
2020	127	20/11/2020	02/11/2020	10/12/2020	7.93	1.15	28.15	1.22

Table 2. IAMS index at length (numbers per km^2)

Length	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
4	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.005	0.036	0.006	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.048	0.027	0.075	0.046	0.000	0.103	0.113	0.000	0.086	0.037	0.013	0.006	0.000	0.000	0.000	0.039
6	0.027	0.316	0.196	0.237	0.432	0.139	0.020	0.246	0.153	0.083	0.386	0.246	0.041	0.098	0.148	0.014	0.012	0.168
7	0.067	1.439	1.582	0.878	0.637	0.770	0.096	0.596	0.604	1.116	2.372	0.510	0.461	0.598	1.389	0.055	0.125	0.292
8	0.175	1.546	2.461	1.424	0.998	2.460	0.527	1.011	1.606	2.475	3.490	1.248	1.736	3.271	7.404	0.084	0.847	0.621
9	0.477	2.118	5.615	2.915	2.947	5.680	1.841	1.748	3.238	5.239	4.699	1.738	3.331	8.403	14.892	0.244	1.513	0.429
10	1.030	4.513	7.828	4.365	5.782	9.690	3.011	3.759	6.987	10.229	6.061	2.210	5.136	13.722	14.394	0.275	3.434	0.463
11	1.235	6.635	4.568	6.288	8.248	16.257	3.313	6.486	12.111	18.898	7.932	1.810	5.912	14.929	8.926	0.252	4.920	0.432
12	1.931	9.214	4.440	7.147	8.905	20.345	2.630	9.378	13.766	30.548	6.871	1.666	5.208	9.631	5.649	0.336	4.912	0.328
13	2.271	10.191	5.081	6.199	7.682	22.162	1.939	11.795	9.349	40.007	4.027	1.755	3.578	5.749	4.642	0.289	3.605	0.123
14	2.437	8.745	6.523	4.761	5.973	14.833	1.442	10.260	5.118	40.302	2.489	1.524	2.533	3.600	4.377	0.228	3.213	0.093
15	1.185	7.794	6.919	3.415	4.105	7.023	1.023	7.052	4.423	35.272	1.173	1.049	1.767	3.018	3.640	0.135	2.798	0.027
16	0.955	5.324	4.103	2.373	2.628	4.535	0.832	4.507	3.783	24.806	0.920	0.819	1.513	2.846	3.179	0.091	3.072	0.019
17	0.597	4.827	3.985	1.569	1.647	2.848	0.699	2.734	4.004	21.215	1.001	0.734	1.079	2.428	1.918	0.094	2.718	0.038
18	0.296	3.382	2.194	1.182	1.243	2.220	0.625	1.818	4.376	17.367	1.243	0.515	0.950	2.059	1.388	0.299	2.121	0.097
19	0.295	3.018	2.034	0.734	1.521	1.714	1.027	1.356	3.941	11.951	1.539	0.354	0.851	1.529	0.885	0.582	1.861	0.202
20	0.320	1.663	1.798	0.564	1.802	1.913	1.123	1.353	2.910	10.082	2.004	0.569	0.705	1.102	1.508	0.772	1.460	0.194
21	0.313	0.915	1.858	0.692	1.377	1.988	1.044	1.211	2.504	6.861	2.606	0.702	0.569	0.829	1.762	1.405	1.025	0.284
22	0.346	0.957	1.739	0.579	1.655	2.384	0.740	1.096	1.526	4.743	3.479	1.040	0.634	0.844	1.858	2.383	0.874	0.498
23	0.460	0.497	1.493	0.572	1.519	2.672	0.814	1.120	1.168	3.371	4.402	1.240	0.661	0.682	2.373	3.064	0.443	0.503
24	0.643	0.383	1.667	0.840	1.676	2.286	0.818	1.118	0.685	3.343	5.111	1.911	0.983	1.016	2.468	3.879	0.412	0.734
25	0.575	0.569	1.553	1.016	1.285	2.758	0.925	0.916	0.507	3.078	5.681	1.894	1.428	1.443	2.866	4.260	0.413	0.785
26	0.662	0.517	1.859	1.053	1.691	3.121	1.238	0.855	0.553	3.020	6.191	2.324	1.789	1.925	3.470	4.259	0.579	0.906
27	0.796	0.606	1.864	1.165	1.681	3.123	1.999	0.659	0.666	2.973	5.993	2.595	2.018	1.758	4.370	4.263	0.734	1.357
28	0.816	0.586	1.840	1.254	2.011	3.460	2.170	0.791	0.806	2.938	6.079	2.812	1.773	1.797	4.110	3.687	0.726	2.107
29	0.711	0.457	1.982	1.093	2.017	2.925	2.718	0.833	1.082	2.812	5.738	2.392	2.113	1.728	3.813	2.928	0.839	1.981
30	0.933	0.560	1.424	0.980	1.919	3.040	3.123	0.967	1.139	2.707	5.333	2.098	1.661	1.614	3.305	2.388	0.741	2.493
31	0.786	0.284	1.357	0.943	1.686	2.732	3.904	0.950	1.156	2.605	4.709	2.201	1.207	1.183	2.685	1.835	0.799	2.137
32	0.774	0.383	1.200	0.789	1.705	2.283	3.679	1.001	1.209	2.265	4.143	1.469	1.040	1.250	2.068	1.418	0.571	1.868
33	0.816	0.318	1.217	0.569	1.521	2.117	4.008	1.040	1.132	1.607	3.109	1.217	0.850	1.039	1.486	1.167	0.567	1.312
34	0.484	0.299	0.912	0.492	1.392	1.792	3.840	1.169	0.953	1.683	2.706	1.005	0.678	0.641	1.256	1.039	0.405	1.427
35	0.695	0.291	0.908	0.451	1.204	1.836	3.608	1.130	0.898	1.162	2.047	1.053	0.518	0.628	0.786	0.723	0.342	1.286
36	0.789	0.232	0.732	0.408	1.057	1.185	3.100	1.077	0.579	1.130	1.402	0.891	0.406	0.319	0.764	0.653	0.412	0.835
37	0.677	0.180	0.469	0.451	0.858	1.054	2.814	0.924	0.481	0.830	0.997	0.774	0.393	0.349	0.560	0.484	0.271	0.617
38	0.623	0.141	0.358	0.398	0.483	0.923	1.710	0.623	0.328	0.604	0.873	0.861	0.266	0.348	0.419	0.530	0.401	0.475
39	0.621	0.195	0.371	0.432	0.519	0.714	1.189	0.473	0.327	0.592	0.780	0.663	0.195	0.294	0.337	0.522	0.358	0.465
40	0.371	0.161	0.235	0.271	0.486	0.619	1.011	0.532	0.273	0.368	0.492	0.707	0.255	0.244	0.188	0.338	0.453	0.319
41	0.230	0.206	0.267	0.293	0.416	0.429	0.720	0.466	0.252	0.388	0.363	0.746	0.232	0.296	0.183	0.248	0.360	0.277
42	0.112	0.137	0.179	0.210	0.286	0.475	0.644	0.473	0.197	0.470	0.307	0.743	0.220	0.165	0.170	0.227	0.228	0.089
43	0.066	0.094	0.110	0.195	0.259	0.553	0.582	0.400	0.181	0.399	0.211	0.603	0.177	0.190	0.144	0.235	0.282	0.161
44	0.022	0.069	0.073	0.163	0.236	0.288	0.536	0.431	0.232	0.365	0.243	0.578	0.212	0.170	0.176	0.169	0.238	0.124
45	0.016	0.108	0.084	0.169	0.168	0.348	0.495	0.414	0.169	0.234	0.335	0.381	0.194	0.152	0.171	0.196	0.166	0.115
46	0.048	0.086	0.070	0.147	0.208	0.310	0.341	0.326	0.107	0.395	0.237	0.364	0.132	0.150	0.137	0.201	0.182	0.075
47	0.016	0.080	0.062	0.128	0.143	0.163	0.328	0.369	0.175	0.267	0.175	0.347	0.174	0.136	0.141	0.129	0.143	0.096
48	0.024	0.028	0.102	0.078	0.102	0.217	0.279	0.359	0.168	0.258	0.198	0.224	0.171	0.156	0.098	0.178	0.130	0.059
49	0.029	0.012	0.018	0.104	0.138	0.105	0.257	0.307	0.111	0.199	0.141	0.232	0.093	0.133	0.086	0.123	0.080	0.045
50	0.000	0.015	0.023	0.074	0.098	0.116	0.148	0.155	0.151	0.259	0.140	0.148	0.107	0.121	0.036	0.129	0.081	0.042
51	0.006	0.012	0.000	0.062	0.081	0.095	0.136	0.143	0.114	0.167	0.104	0.132	0.089	0.058	0.110	0.100	0.114	0.066
52	0.045	0.017	0.032	0.064	0.043	0.046	0.129	0.251	0.124	0.168	0.121	0.085	0.086	0.114	0.096	0.100	0.054	0.035
53	0.052	0.010	0.005	0.055	0.054	0.145	0.052	0.131	0.079	0.159	0.111	0.149	0.066	0.090	0.069	0.059	0.082	0.043
54	0.008	0.000	0.008	0.047	0.038	0.059	0.094	0.188	0.112	0.122	0.158	0.119	0.048	0.057	0.084	0.043	0.057	0.068
55	0.000	0.007	0.000	0.040	0.047	0.049	0.060	0.100	0.099	0.097	0.082	0.103	0.032	0.053	0.081	0.087	0.049	0.021
56	0.000	0.010	0.006	0.036	0.043	0.030	0.086	0.109	0.043	0.140	0.072	0.116	0.048	0.083	0.047	0.045	0.032	0.019
57	0.015	0.000	0.004	0.020	0.032	0.049	0.038	0.065	0.086	0.073	0.118	0.136	0.076	0.069	0.109	0.112	0.081	0.026
58	0.000	0.011	0.018	0.019	0.033	0.012	0.052	0.062	0.098	0.054	0.123	0.085	0.007	0.080	0.060	0.056	0.077	0.006
59	0.015	0.000	0.012	0.004	0.014	0.020	0.039	0.056	0.084	0.050	0.082	0.092	0.069	0.058	0.059	0.056	0.039	0.036
60	0.000	0.011	0.007	0.006	0.020	0.026	0.061	0.039	0.032	0.076	0.098	0.028	0.059	0.106	0.044	0.061	0.032	0.013
61	0.000	0.000	0.011	0.008	0.033	0.013	0.030	0.052	0.042	0.032	0.066	0.094	0.035	0.063	0.013	0.042	0.045	0.031
62	0.000	0.012	0.018	0.023	0.030	0.013	0.033	0.049	0.058	0.053	0.092	0.086	0.028	0.034	0.075	0.052	0.024	0.041
63	0.000	0.000	0.000	0.000	0.010	0.015	0.030	0.028	0.056	0.037	0.031	0.049	0.020	0.129	0.112	0.048	0.046	0.034
64	0.000	0.000	0.008	0.008	0.004	0.029	0.046	0.070	0.050	0.058	0.064	0.022	0.021	0.078	0.099	0.078	0.017	0.030
65	0.000	0.000	0.010	0.002	0.009	0.013	0.016	0.021	0.027	0.055	0.082	0.024	0.055	0.106	0.119	0.044	0.033	0.087
66	0.000	0.000	0.000	0.015	0.008	0.010	0.042	0.058	0.010	0.026	0.037	0.026	0.007	0.073	0.126	0.035	0.031	0.053
67	0.000	0.000	0.004	0.013	0.020	0.035	0.040	0.021	0.057	0.007	0.038	0.041	0.031	0.056	0.094	0.099	0.048	0.031
68	0.000	0.000	0.000	0.020	0.012	0.006	0.044	0.028	0.021	0.019	0.032	0.022	0.028	0.039	0.110	0.033	0.018	0.031
69	0.008	0.000	0.000	0.002	0.013	0.008	0.021	0.036	0.021	0.019	0.038	0.047	0.023	0.040	0.087	0.079	0.038	0.019
70	0.000	0.000	0.009	0.015	0.004	0.020	0.016	0.008	0.007	0.045	0.033	0.030	0.027	0.064	0.074	0.049	0.053	0.038
71	0.000	0.000	0.004	0.003	0.002	0.007	0.011	0.010	0.013	0.037	0.029	0.016	0.032	0.046	0.108	0.079	0.015	0.032
72	0.000	0.000	0.000	0.000	0.011	0.000	0.008	0.010	0.027	0.063	0.042	0.023	0.015	0.046	0.036	0.041	0.063	0.018
73	0.009	0.009	0.000	0.007	0.006	0.004	0.000	0.005	0.007	0.031	0.027	0.018	0.028	0.054	0.056	0.036	0.031	0.025
74	0.000	0.009	0.012	0.009	0.006	0.000	0.021	0.010	0.037	0.037	0.027	0.016	0.006	0.023	0.019	0.061	0.035	0.033
75	0.000	0.008	0.000	0.008	0.000	0.000	0.006	0.005	0.006	0.037	0.024	0.017	0.000	0.022	0.012	0.054	0.025	0.052

76	0.000	0.011	0.003	0.000	0.000	0.000	0.005	0.011	0.018	0.038	0.006	0.005	0.000	0.018	0.036	0.035	0.034	0.025
77	0.000	0.000	0.000	0.006	0.000	0.000	0.003	0.005	0.011	0.005	0.017	0.028	0.021	0.011	0.018	0.045	0.022	0.018
78	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.009	0.012	0.004	0.025	0.012	0.013	0.023	0.006	0.025	0.016	0.012
79	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.011	0.003	0.018	0.006	0.023	0.021	0.017	0.000	0.034	0.031	0.019
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.029	0.012	0.007	0.012	0.013	0.041	0.012	0.007
81	0.000	0.000	0.000	0.008	0.006	0.000	0.007	0.006	0.010	0.013	0.024	0.005	0.000	0.027	0.012	0.038	0.012	0.007
82	0.000	0.000	0.000	0.007	0.000	0.000	0.003	0.011	0.000	0.006	0.035	0.007	0.000	0.005	0.019	0.007	0.020	0.006
83	0.000	0.000	0.000	0.000	0.008	0.004	0.008	0.000	0.005	0.000	0.018	0.005	0.000	0.000	0.000	0.013	0.008	0.006
84	0.000	0.000	0.000	0.000	0.003	0.000	0.008	0.006	0.000	0.018	0.011	0.026	0.000	0.006	0.012	0.035	0.020	0.019
85	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.006	0.000	0.011	0.005	0.011	0.014	0.012	0.000	0.021	0.000	0.000
86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.015	0.007	0.012
87	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.016	0.017	0.027
88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.006	0.013
89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.012	0.020	0.011	0.000	0.006	0.010	0.010
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.007	0.012	0.006	0.007	0.000	0.016
91	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.012	0.000	0.011	0.006
92	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.006	0.000
93	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.005	0.000	0.007	0.006	0.000	0.000	0.000	0.000
94	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.029	0.000	0.009	0.025	0.000
95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.011	0.000
96	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.007	0.006	0.000	0.000	0.000	0.007
97	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.004	0.000	0.012
98	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
99	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
101	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.006	0.000
103	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
106	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
107	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.006	0.000
109	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
130	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WORKING DOCUMENT 09

Maturity ogive for the southern hake stock

Cousido-Rocha, M., Izquierdo, F., Martinez-Minaya, J., Mendes, H., Silva, C., Silva, A.V., Sainza, M., Cerviño, S.

2022-03-09

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Below the objective and a theoretical explanation of the model are reported. However the details of both can be find through the document tabs which explain the analysis step by step.

Objective: A combined maturity ogive (maturity proportions-at-length) for the southern hake stock estimated through the data derived from both institutes (laboratories), IPMA (Instituto Português do Mar e da Atmosfera) and IEO (Instituto Español de Oceanografía).

Model (theoretical explanation)

Maturity proportions-at-length have been estimated by bayesian regression models using the integrated nested Laplace approximation (INLA) (Rue et al., 2009) approach in the R-INLA software (https://www.r-inla.org/).

For estimating a combined maturity ogive for both laboratories a bivariate model has been required (Zuur and Ieno, 2018, additional details in Paradinas et al., 2017 and Izquierdo et al., 2021). The bivariate response variable is defined as follows.

$y_i^{IEO} \sim Bernoulli(\pi_i^{IEO})$, $i = 1, \ldots, N^{IEO}$; being N^{IEO} the number of individuals measured by IEO. $y_j^{IPMA} \sim Bernoulli(\pi_j^{IPMA})$, $j = 1, \ldots, N^{IPMA}$; being N^{IPMA} the number of individuals measured by IPMA.

The covariables (explanatory variables) are the length and the year. The length variable is introduced linear. On the other hand, the year covariable is introduced differently depending on the aim: a standard year combined maturity ogive (Approach 1) or a combined maturity ogive by year (Approach 2).

Approach 1

The year variability is taken into account through the random effect $a_i, a_j \sim N(0, \sigma^2_{year})$, $i = 1, \ldots, N^{IEO}$, $j = 1, \ldots, N^{IPMA}$. Note that σ^2_{year} parameter is common for IEO and IPMA response variables.

$$Logit(\pi_i^{IEO}) = \ln(\pi_i^{IEO}/(1-\pi_i^{IEO})) = \beta_0 + \beta_1 \times (l^{IEO}(i)) + a_i + \epsilon_i$$

$$Logit(\pi_j^{IPMA}) = \ln(\pi_j^{IPMA}/(1-\pi_j^{IPMA})) = \beta_0 + \beta_1 \times (l^{IPMA}(j)) + a_j + \epsilon_i$$

$l^{IEO}(i)$ assigns to each individual of IEO its corresponding length. The same for $l^{IPMA}(j)$. $\epsilon_i, \epsilon_j \sim N(0, \sigma_\epsilon^2)$; $a_i, a_j \sim N(0, \sigma_{year}^2)$.

Approach 2

The year is included in the model as a factor covariable.

$$Logit(\pi_i^{IEO}) = \ln(\pi_i^{IEO}/(1-\pi_i^{IEO})) = \beta_0 + \beta_1 \times (l^{IEO}(i)) + year_i + \epsilon_i$$
$$Logit(\pi_j^{IPMA}) = \ln(\pi_j^{IPMA}/(1-\pi_j^{IPMA})) = \beta_0 + \beta_1 \times (l^{IPMA}(j)) + year_j + \epsilon_i$$

$l^{IEO}(i)$ assigns to each individual of IEO its corresponding length. The same for $l^{IPMA}(j)$. $year_i$, $year_j$ is a categorical covariate allowing for a different mean value per year. $\epsilon_i, \epsilon_j \sim N(0, \sigma_\epsilon^2)$.

References

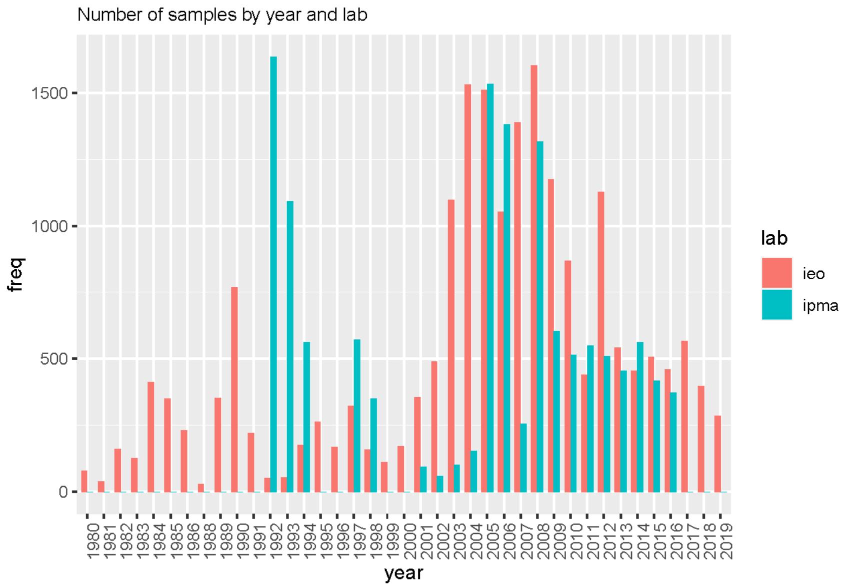
- Izquierdo, F., Paradinas, I., Cerviño, S., Conesa, D., Alonso-Fernández, A., Velasco, F., … & Pennino, M. G. (2021). Spatio-temporal assessment of the European hake (Merluccius merluccius) recruits in the northern Iberian Peninsula. Frontiers in Marine Science, 8, 1.
- Paradinas, I., Conesa, D., Lopez-Quilez, A., & Bellido, J. M. (2017). Spatio-temporal model structures with shared components for semi-continuous species distribution modelling. Spatial Statistics, 22, 434-450.
- Rue, H., Martino, S., and Chopin, N. (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. J. R. Stat. Soc. B. 71, 319–392. doi: 10.1111/j.1467-9868.2008.00700.x
- Wood, S.N. (2017) Generalized Additive Models: An Introduction with R (2nd edition). Chapman and Hall/CRC
- Zuur, A. F., Ieno, E. I. (2018). Beginner s Guide to Spatial, Temporal and Spatial-Temporal Ecological Data Analysis with R-INLA Volume II: GAM and zero-inflated models Published by Highland Statistics Ltd. Highland Statistics Ltd. Newburgh United Kingdom

Exploratory

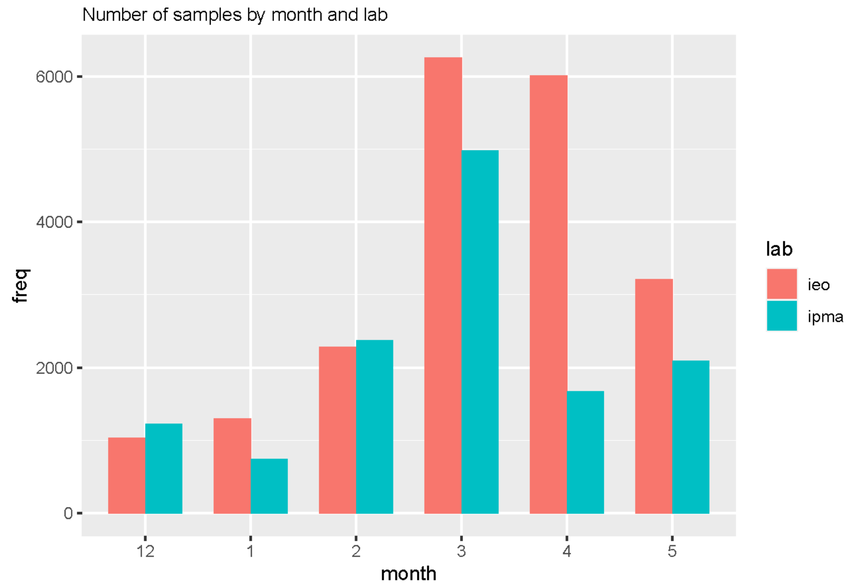
The data set contains the year of maturity, the month, the length (lt), the sex, the year of sample and the laboratory (institute) as you can see below. Note that for this study we have considered a subset of the data considering only females (sex=2).

```
##   year_mat month lt sex mat year_sample lab
## 1     1980     5 56   2   1        1980 ieo
## 2     1980     5 51   2   1        1980 ieo
## 3     1980     5 53   2   0        1980 ieo
## 4     1980     5 51   2   0        1980 ieo
## 5     1980     5 49   2   0        1980 ieo
## 6     1980     5 55   2   0        1980 ieo
```

The following plot report the number of samples for each year and institute. IPMA has no maturity data for the following years: 1980-1991, 1995, 1996, 1999, 2000, 2017-2019. IEO data is provided for the completed time period 1980-2019. Note that 2020 maturity data was provided only in May by the IEO. Since the information for this year is incomplete and may cause bias in the estimation of the ogive it has been decided to eliminate it.

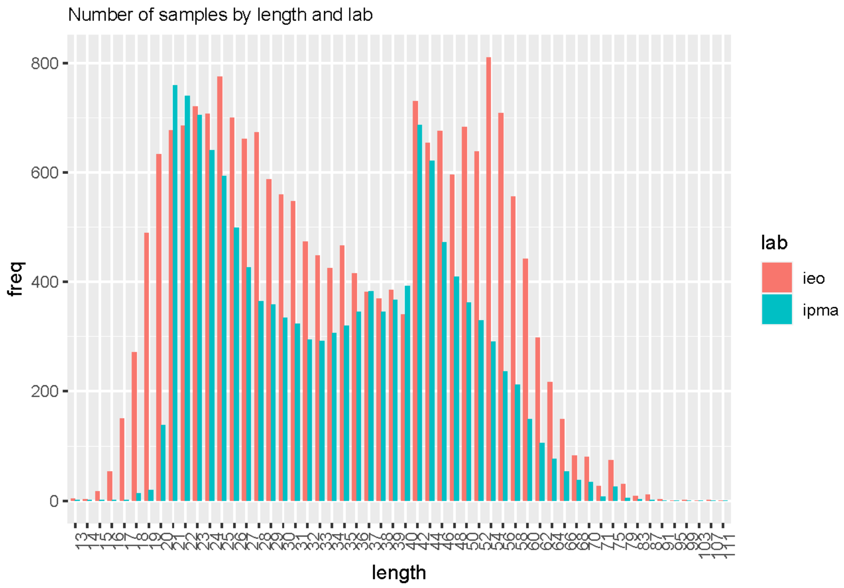


Next plot reports the number of samples by month and institute. Maturity data was compiled from the IEO and IPMA samples only for the spawning season, December to May. Note that, samples collected in December were allocated to the following year. Larger IPMA sampling corresponds to February and March, whereas for the IEO the larger sampling corresponds to March and April.



Next plot reports the number of samples by length and institute (laboratory). Overall good sampling of relevant length classes (from 20cm to 70cm).

```
##
##         13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30
##   ieo    4   3  17  54 150 271 489 633 677 686 721 708 775 700 661 674 587 560
##   ipma   1   1   1   1   1  14  20 138 760 740 705 641 594 499 427 365 359 335
##
##         31  32  33  34  35  36  37  38  39  40  42  44  46  48  50  52  54  56
##   ieo  548 474 448 425 467 415 382 369 385 341 731 654 676 596 683 639 811 709
##   ipma 323 294 292 307 320 345 383 345 367 392 687 621 473 409 362 330 291 236
##
##         58  60  62  64  66  68  70  71  75  79  83  87  91  95  99 103 107 111
##   ieo  556 442 298 217 149  83  80  27  74  31   9  11   3   0   2   0   1   0
##   ipma 212 149 105  76  53  38  34   8  26   5   3   2   0   0   0   0   0   0
```

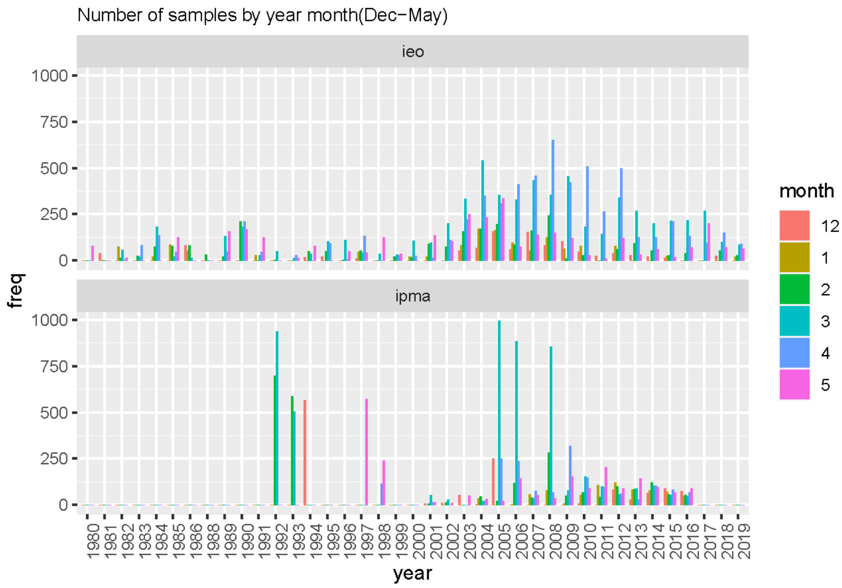


Following 2010 benchmark it was decided to cut the ogive assigning zero to lengths below 21 cm because they are not mature.

```
## [1] 15

##         lt mat
## 4336  17.5   1
## 8529  20.5   1
## 21020 18.7   1
## 21021 19.2   1
## 21024 19.6   1
## 21026 19.9   1
## 21027 20.7   1
## 21029 20.5   1
## 28788 19.6   1
## 28789 20.2   1
## 30068 19.1   1
## 34919 15.6   1
## 45245 17.7   1
## 51715 20.3   1
## 51873 18.2   1
```

Next plot reports the number of samples by year, month and institute. The plot shows that previously to 2001 IPMA information is missing except for 1992, 1993, 1994, 1997 and 1998. Furthermore, IEO sample size before 2001 is low and for some years not all months of the spawning season has been sampled. According to that years 1980-2000 are grouped for the modeling. On the other hand, for years 2017-2019 there are not IPMA information and the IEO samples sizes are again low. Hence, such years are also grouped in the modeling.

Hence, our year covariable is not the year specific level factor is a year specific category factor with the following categories: 1980-2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017-2019.



Motivation

The maturity data is provided by two countries, Portugal and Spain, and a combined maturity ogive is required. Previous analysis provides evidences that in Portugal the maturity occurs at lower lengths than in Spain. In fact the regression logistic model (generalized linear model) below explains the maturity (binary response, immature/mature) using the length and the country factor leading to two statistical different ogives for each country.

The maturity data covers from 1980 to 2019, however, while the Spanish data cover the entire period, we have missing Portugal data for some years, and furthermore the samples sizes by year for each country are not balanced. For that reason the unification of the maturity data on an unique sample ignoring the country for further modeling, using for example glm, is not a suitable option. Other option can be a weighted average of the country ogives, but for that it is necessary to decide which weights must be used. After some research, we have found a possible solution using a Bayesian approach.

Our proposal is a bivariate bayesian regression model using the integrated nested Laplace approximation (INLA) (Rue et al., 2009) approach in the R-INLA software (https://www.r-inla.org/).

```r
df2 <- data
mod.lab2 <- glm(mat ~ lt*lab, family = binomial(logit), data = df2)
summary(mod.lab2)
```

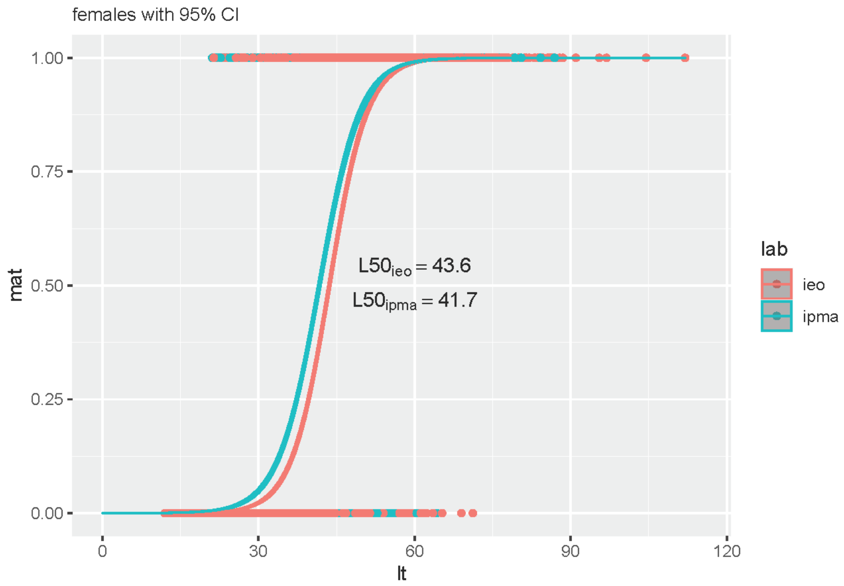
```
##
## Call:
## glm(formula = mat ~ lt * lab, family = binomial(logit), data = df2)
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -3.9076  -0.2908  -0.1078   0.1922   3.5054
##
## Coefficients:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept) -12.061738   0.179328 -67.261  < 2e-16 ***
## lt            0.276627   0.004146  66.714  < 2e-16 ***
## labipma       1.482101   0.260561   5.688 1.28e-08 ***
## lt:labipma   -0.022793   0.006250  -3.647 0.000266 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 41136  on 33197  degrees of freedom
## Residual deviance: 15888  on 33194  degrees of freedom
## AIC: 15896
##
## Number of Fisher Scoring iterations: 7
```

```r
#L50 Females IEO
-(coef(mod.lab2)[1]/coef(mod.lab2)[2])
```

```
## (Intercept)
##    43.60289
```

```r
#L50 Females IPMA
-(coef(mod.lab2)[1]+coef(mod.lab2)[3])/(coef(mod.lab2)[2]+coef(mod.lab2)[4])
```

```
## (Intercept)
##    41.67934
```



Prepare data

The bivariate model response considers separetely two maturity variables one for each country. The two response variables are explained using length and year covariables. The model formulation in terms of covariables depends on the aim: - (i) a standard year combined maturity ogive or - (ii) a combined maturity ogive by year.

On (i) the common predictor for the two responses is equal to an intercept plus a linear effect of the length plus a year random effect. The year random effect is changed by a year factor for (ii) approach. The model carried out a combined estimation of all the parameters of the common predictor providing a combined maturity to introduce in the stock assessment model.

NOTE: as mentioned previously year covariable has the following categories: 1980-2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017-2019.

```
# Prepare data -----------------------------------------------------------------


NLbins<-c(seq(from=20, to=40, by=1),seq(from=42, to=70, by=2)) # Desired bins (SS model) 67
l_b=length(NLbins)

len=data$lt
l_len=length(len);aux=rep(0,l_len)

years<-(min(as.numeric(as.character(data$year_mat))):max(as.numeric(as.character(data$year_mat))))
```

```
# Response ----------------------------------------------------------------------

data_ieo=subset(data,data$lab=="ieo")
data_ipma=subset(data,data$lab=="ipma")
data=rbind(data_ieo,data_ipma)

ind_ieo=which(data$lab=="ieo")
ind_ipma=which(data$lab=="ipma")
len=length(data$lab)

len_ieo=length(ind_ieo)
len_ipma=length(ind_ipma)

YCombined <- matrix(NA, nrow = len, ncol = 2)
YCombined[1:len_ieo, 1]      <- (data$mat[ind_ieo])
YCombined[(len_ieo+1):(len_ipma+len_ieo), 2] <- (data$mat[ind_ipma])

# Grouped years -----------------------------------------------------------------

# Years previous to 2001 into a group -------------------------------------------

data$Gyear_mat=as.character(data$year_mat)
ind=which(as.numeric(as.character(data$year_mat))<2001)
data$Gyear_mat[ind]="1980_2000"

# Years 2017,2018 and 2019 into a group ----------------------------------------
ind=which(as.numeric(as.character(data$year_mat))>2016)
data$Gyear_mat[ind]="2017-2019"

data$Gyear_mat=as.factor(data$Gyear_mat)
```

Model total

Standard ogive: a single ogive for both institutes and years.

Code

```
# Model 1 -----------------------------------------------------------------------

f3 <-  YCombined ~ 1 + lt +
                            f(Gyear_mat, model = "iid")

I3 <- inla(f3,
           control.compute = list(config=TRUE,
                                  dic = TRUE,
                                  cpo=TRUE),
           family = c("binomial","binomial"),
           data = data,
           control.inla = list(strategy = 'adaptive'),
           verbose=TRUE, num.threads = 1)
```

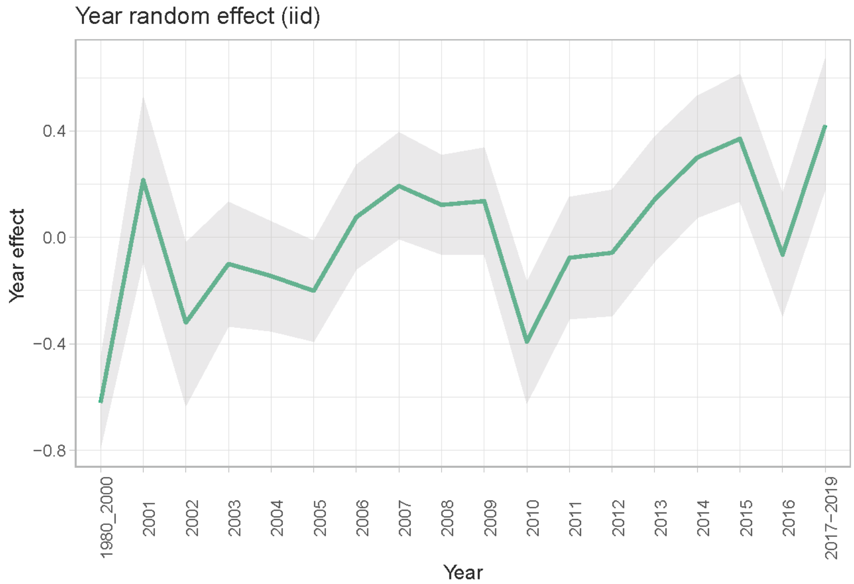
```
summary(I3)
```

```
##
## Call:
##    c("inla(formula = f3, family = c(\"binomial\", \"binomial\"), data =
##    data, ", " verbose = TRUE, control.compute = list(config = TRUE, dic =
##    TRUE, ", " cpo = TRUE), control.inla = list(strategy = \"adaptive\"),
##    ", " num.threads = 1)")
## Time used:
##     Pre = 0.73, Running = 55.9, Post = 2.4, Total = 59.1
## Fixed effects:
##                mean    sd 0.025quant 0.5quant 0.975quant    mode kld
## (Intercept) -11.242 0.147    -11.534  -11.241    -10.955 -11.239   0
## lt            0.265 0.003      0.259    0.265      0.271   0.265   0
##
## Random effects:
##   Name     Model
##     Gyear_mat IID model
##
## Model hyperparameters:
##                           mean   sd 0.025quant 0.5quant 0.975quant  mode
## Precision for Gyear_mat 13.66 5.08       5.90    12.93      25.61 11.54
##
## Expected number of effective parameters(stdev): 16.94(0.656)
## Number of equivalent replicates : 1959.42
##
## Deviance Information Criterion (DIC) ...............: 15834.58
## Deviance Information Criterion (DIC, saturated) ....: 15834.57
## Effective number of parameters .....................: 17.20
##
## Marginal log-Likelihood:  -7947.11
## CPO and PIT are computed
##
## Posterior marginals for the linear predictor and
##  the fitted values are computed
```

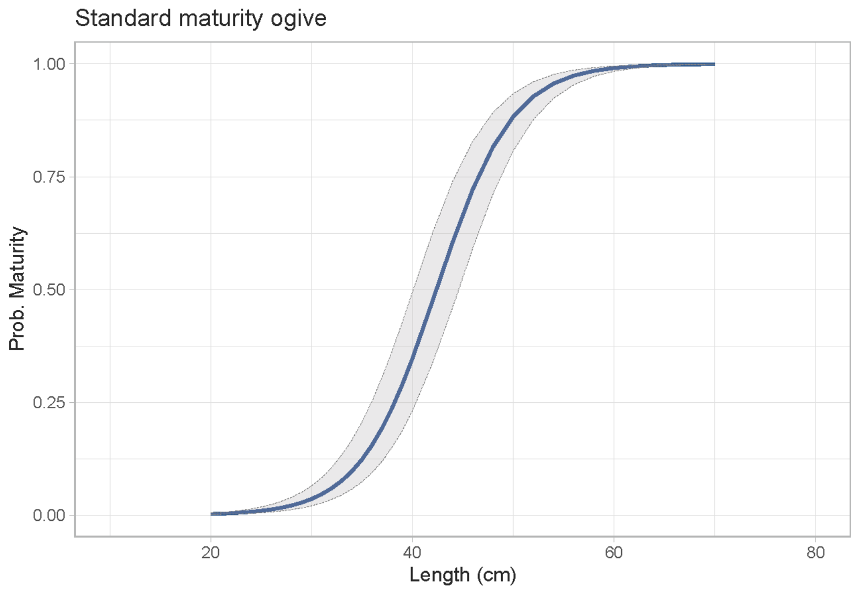
```
#INLAutils::plot_fixed_marginals(I3)
#INLAutils::plot_hyper_marginals(I3)
#INLAutils::plot_random_effects(I3)

# Prediction IPS ---------------------------------------------------------------
I1=I3
r=I3
r.samples = inla.posterior.sample(1000, r)
psam <- sapply(r.samples, function(x) {

   lt_effect <- x$latent %>% rownames(.) %>% stringr::str_detect("^lt") %>% x$latent[.,]
   intercept <- x$latent %>% rownames(.) %>% stringr::str_detect("^\\(Intercept\\)") %>% x$latent[.,]
   year_effect <- rnorm(length(lt_effect), sd = 1/sqrt(x$hyperpar[1]))
   predictor <- intercept + year_effect + lt_effect*NLbins
   exp(predictor)/(1 + exp(predictor))
})
```

```
q.sam_al_a <- apply(psam, 1, quantile,
                    c(.025, 0.05, 0.5, 0.95, .975), na.rm =TRUE)
```

Plot



Year random effect (iid)
Year effect
0.4
0.0
−0.4
−0.8
1980_2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017−2019
Year



Standard maturity ogive
Prob. Maturity
1.00
0.75
0.50
0.25
0.00
20
40
60
80
Length (cm)

L_{50} values

Length at 50% maturity.

```
##        L50    lower    upper
## 1 42.36566 40.35277 44.47734
```

Model by year

Yearly ogive: a specific ogive for year category.

Code

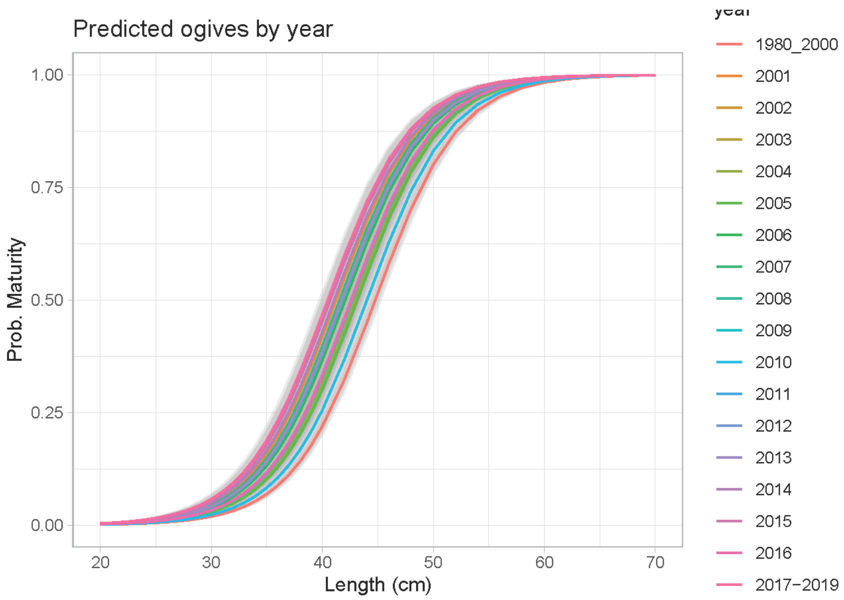
```
# Model 2 ----------------------------------------------------------------------

f3 <-  YCombined ~ 1 + lt +  Gyear_mat

I3 <- inla(f3,
           control.compute = list(config=TRUE,
                                  dic = TRUE,
                                  cpo=TRUE),
           family = c("binomial","binomial"),
           data = data,
           control.inla = list(strategy = 'adaptive'),
           verbose=TRUE, num.threads = 1)
summary(I3)
```

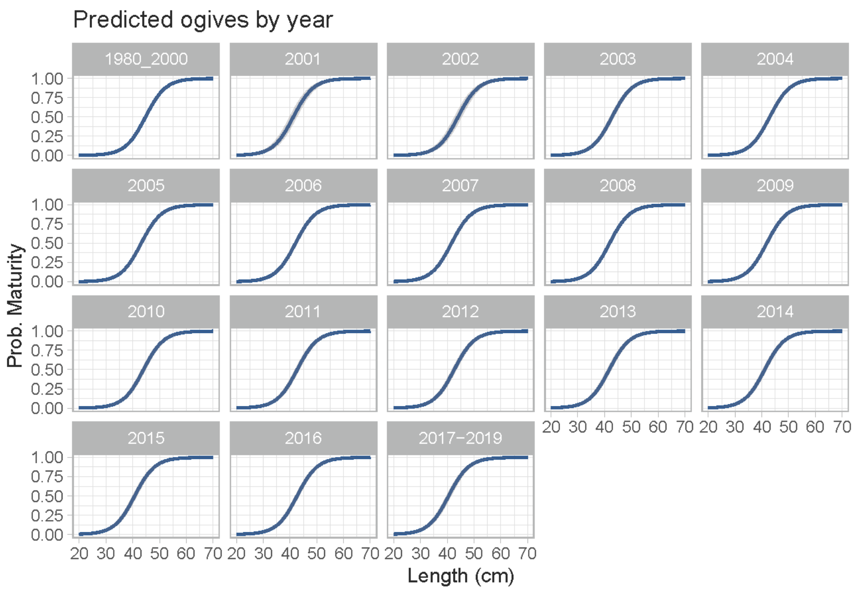
```
##
## Call:
##    c("inla(formula = f3, family = c(\"binomial\", \"binomial\"), data =
##    data, ", " verbose = TRUE, control.compute = list(config = TRUE, dic =
##    TRUE, ", " cpo = TRUE), control.inla = list(strategy = \"adaptive\"),
##    ", " num.threads = 1)")
## Time used:
##     Pre = 0.373, Running = 18.1, Post = 2.91, Total = 21.4
## Fixed effects:
##                     mean    sd 0.025quant 0.5quant 0.975quant    mode kld
## (Intercept)      -11.912 0.142    -12.193  -11.911    -11.636 -11.909   0
## lt                 0.266 0.003      0.260    0.266      0.272   0.266   0
## Gyear_mat2001      0.938 0.177      0.590    0.938      1.287   0.938   0
## Gyear_mat2002      0.203 0.172     -0.133    0.203      0.541   0.202   0
## Gyear_mat2003      0.523 0.117      0.295    0.523      0.752   0.522   0
## Gyear_mat2004      0.480 0.096      0.292    0.480      0.668   0.480   0
## Gyear_mat2005      0.427 0.083      0.263    0.427      0.590   0.427   0
## Gyear_mat2006      0.724 0.089      0.549    0.724      0.898   0.724   0
## Gyear_mat2007      0.850 0.092      0.670    0.850      1.030   0.850   0
## Gyear_mat2008      0.771 0.082      0.611    0.771      0.932   0.771   0
## Gyear_mat2009      0.789 0.092      0.608    0.789      0.969   0.789   0
## Gyear_mat2010      0.196 0.111     -0.022    0.196      0.412   0.196   0
## Gyear_mat2011      0.553 0.114      0.329    0.553      0.776   0.554   0
## Gyear_mat2012      0.574 0.120      0.338    0.574      0.809   0.574   0
```

```
## Gyear_mat2013        0.806 0.118      0.575    0.806      1.036   0.806   0
## Gyear_mat2014        0.985 0.113      0.763    0.985      1.205   0.985   0
## Gyear_mat2015        1.073 0.120      0.837    1.073      1.307   1.073   0
## Gyear_mat2016        0.567 0.114      0.342    0.568      0.791   0.568   0
## Gyear_mat2017-2019   1.137 0.124      0.893    1.137      1.380   1.137   0
##
## Expected number of effective parameters(stdev): 19.02(0.00)
## Number of equivalent replicates : 1745.93
##
## Deviance Information Criterion (DIC) ...............: 15835.94
## Deviance Information Criterion (DIC, saturated) ....: 15835.93
## Effective number of parameters .....................: 19.02
##
## Marginal log-Likelihood:  -8008.40
## CPO and PIT are computed
##
## Posterior marginals for the linear predictor and
##  the fitted values are computed
```

```
# Prediction IPS ---------------------------------------------------------------
I2=I3
r=I3
r.samples = inla.posterior.sample(1000, r)
psam <- sapply(r.samples, function(x) {

   lt_effect <- x$latent %>% rownames(.) %>% stringr::str_detect("^lt") %>% x$latent[.,]
   intercept <- x$latent %>% rownames(.) %>% stringr::str_detect("^\\(Intercept\\)") %>% x$latent[.,]
   beta_y <- x$latent %>% rownames(. ) %>% stringr::str_detect("^Gyear_mat") %>% x$latent[.,]



   predictor1990 <- intercept + lt_effect*NLbins

   pre=list();l=length(beta_y)
   for (i in 1:l){
      pre[[i]]=intercept + beta_y[i] + lt_effect*NLbins
   }

   predictor=predictor1990

   for (i in 1:l){
      predictor <- c(predictor, pre[[i]])
   }

   exp(predictor)/(1 + exp(predictor))
})


q.sam_al_a <- apply(psam, 1, quantile,
                    c(.025, 0.05, 0.5, 0.95, .975), na.rm =TRUE)
```

Plot


Predicted ogives by year
Prob. Maturity
1.00
0.75
0.50
0.25
0.00
20
30
40
50
60
70
Length (cm)
1980_2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017−2019

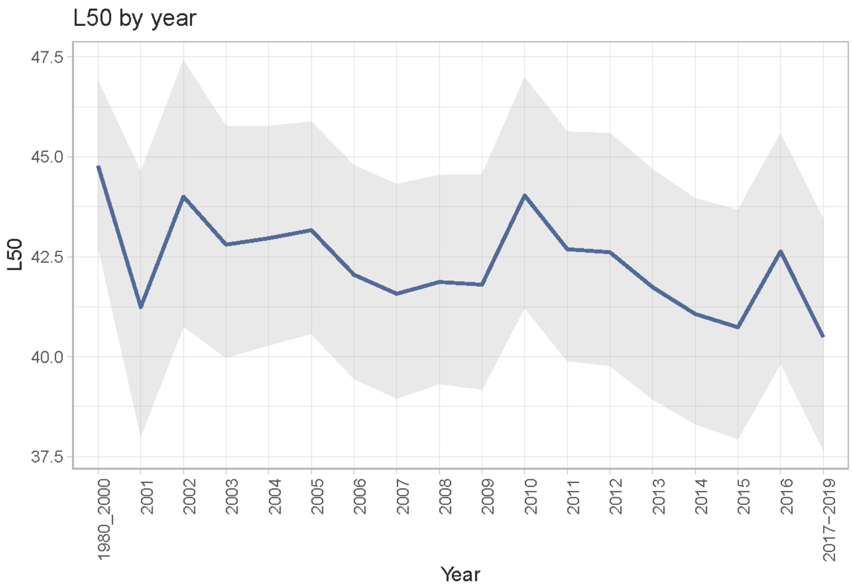

Predicted ogives by year
1980_2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017−2019
Prob. Maturity
1.00
0.75
0.50
0.25
0.00
20 30 40 50 60 70
Length (cm)

15

L_{50}

L_{50} (length at 50% maturity) times series. Since the analysis of the series shows clear variability among year categories, the time specific model is proposed to be used instead to the standard year combined maturity ogive.

```
##          L50    lower    upper      year
## 1  44.76778 42.74336 46.88983 1980_2000
## 2  41.24082 38.01732 44.62072      2001
## 3  44.00448 40.75780 47.40163      2002
## 4  42.80211 39.98009 45.75557      2003
## 5  42.96373 40.28891 45.76701      2004
## 6  43.16444 40.57634 45.87834      2005
## 7  42.04829 39.44575 44.77822      2006
## 8  41.57379 38.95971 44.31419      2007
## 9  41.86873 39.32035 44.54118      2008
## 10 41.80167 39.18236 44.54971      2009
## 11 44.03250 41.22972 46.97485      2010
## 12 42.68880 39.89288 45.62410      2011
## 13 42.61215 39.77339 45.59071      2012
## 14 41.73883 38.93614 44.67973      2013
## 15 41.06759 38.31661 43.95626      2014
## 16 40.73617 37.94327 43.66906      2015
## 17 42.63505 39.83871 45.57335      2016
## 18 40.49509 37.67432 43.45491 2017-2019
```



Supplementary material

Structural changes

A structural change analysis has been applied over the year time series of L_{50} (derived from the model using year factor covariable with a specific level for each year instead of the year categories). As you can see this analysis also reports 2000 as a break point of the time series in accordance with our conclusion after the exploratory analysis.

```
library(strucchange)


load("50.RData")

maturity<-dL50

# Input NA's (if is required)

interpFun <- function(dat) {
for (i in 1:length(dat)){
  if (is.na(dat[i]))
    if(i == 1) {
      dat[i] <- rnorm(1,mean(dat, na.rm=T),
                      sd(dat, na.rm=T))
    } else {
      dat[i] <- rnorm(1,mean(dat[c(i-1, i+1)],na.rm=T),
                         sd(dat[c(i-1, i+1)],na.rm=T))
    }
}
return(dat)
}

# Define time series -----------------------------------------------------------
mInterp <- interpFun(maturity$L50)
mInterp <- ts(mInterp,
                  start=min(maturity$year),
                  frequency = 1)

# Detect break and test-------------------------------------------------------
ocusm <- efp(mInterp~1, type="OLS-CUSUM")
#ocusm <- efp(mInterp~1, type="Rec-CUSUM")
#ocusm <- efp(mInterp~1, type="Rec-MOSUM")
#ocusm <- efp(mInterp~1, type="OLS-MOSUM")
bpm <- breakpoints(mInterp~1)
maturity$year[bpm$breakpoints]
```

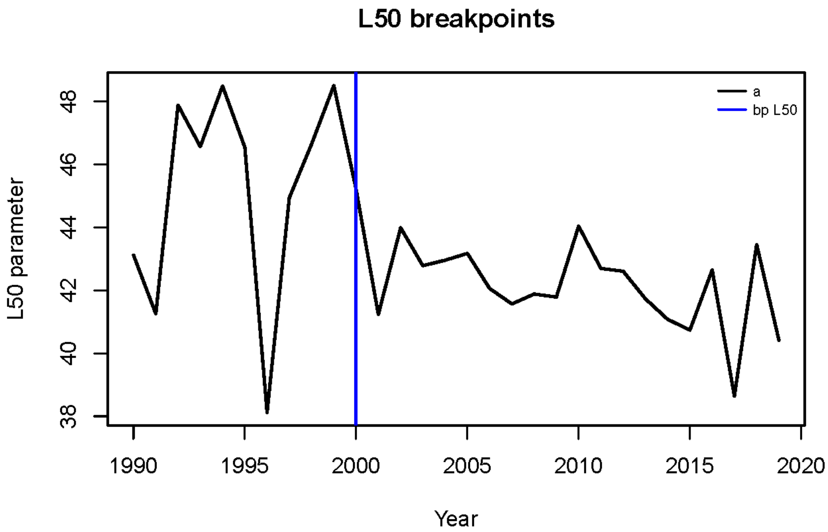
```
## [1] 2000
```

```
sctest(ocusm)
```

```
##
##  OLS-based CUSUM test
##
```

```
## data:  ocusm
## S0 = 1.4989, p-value = 0.02237
```

```
# Plot series + break point ---------------------------------------------------


plot(mInterp,
     xlab= "Year",
     ylab= "L50 parameter",
     lty=1,
     lwd=2,
     main = "L50 breakpoints")
lines(mInterp,
      lty = 1,
      lwd = 2)
abline(v=maturity$year[bpm$breakpoints],
       lwd= 2,
       lty = 1,
       col="blue")
legend("topright",
       legend = c("a", "bp L50"),
       lty = c(1,1),
       col = c("black", "blue"), bty="n", x.intersp=0.5, horiz= F, cex=0.70)
```



WORKING DOCUMENT 10

Length-weight analysis for southern hake stock

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2022-03-09

Contents

Nowaday, the length-weight relationship carried out in 1999 is used. This relationship provides global (not year specific) estimates of the a and b parameters ($W_i = aL_i^b$, $i = 1, \ldots, N$, being N the total sample size). More precisely, the actual values are $a = 0.00659$ and $b = 3.01721$. Hence, in the current study a review of length-weight relationship is done addressing the following tasks:

- Estimation of global (not year specific) a and b using the updated length-weight data base.
- Estimation of year specific b (and common a).
- Estimation of global a and b by sex.
- Analysis of previous results and derived proposal.

Models: The typical length-weight model is $W_i = aL_i^b$, where a and b are parameters to be estimated. If we take logarithms (with base 10) in both sides, we obtain $\log_{10}(W_i) = \log_{10}(a) + b\log_{10}(L_i)$. This model can be fitted in R using the common functions for linear models:

$\log_{10}(W_i) = \log_{10}(a) + b\log_{10}(L_i) + \epsilon_i$,

where ϵ_i normally distributed with mean 0 and variance σ^2.

Prepare data

We read the data files: Portugal and Spain data. We have then three data sets, **dataS** corresponds to the Spain data, **dataP** corresponds to Portugal data, and finally **data** contains both data sets.

```
##   year month   tl  tw gw sex source       area prof M    Y     logL     logW
## 1 2009     7 36.7 385 NA   F market 9a-S_cadiz   NA 7 2009 1.564666 2.585461
## 2 2009     7 29.0 210 NA   F market 9a-S_cadiz   NA 7 2009 1.462398 2.322219
## 3 2009     7 36.0 330 NA   F market 9a-S_cadiz   NA 7 2009 1.556303 2.518514
## 4 2009     7 35.2 414 NA   F market 9a-S_cadiz   NA 7 2009 1.546543 2.617000
## 5 2009     7 30.9 245 NA   F market 9a-S_cadiz   NA 7 2009 1.489958 2.389166
## 6 2009     7 35.6 345 NA   F market 9a-S_cadiz   NA 7 2009 1.551450 2.537819
```

We unify the *area* variable defining the categories northwestern Cantabrian fishing grounds (Spain data, termed "CNO") and Portugal.

```
##
##      CNO Portugal
##    41276    48331
```

The time series is reduced starting in 1982. Note that data for 2020 is not considered since not enough sampling has been carried out in such year.

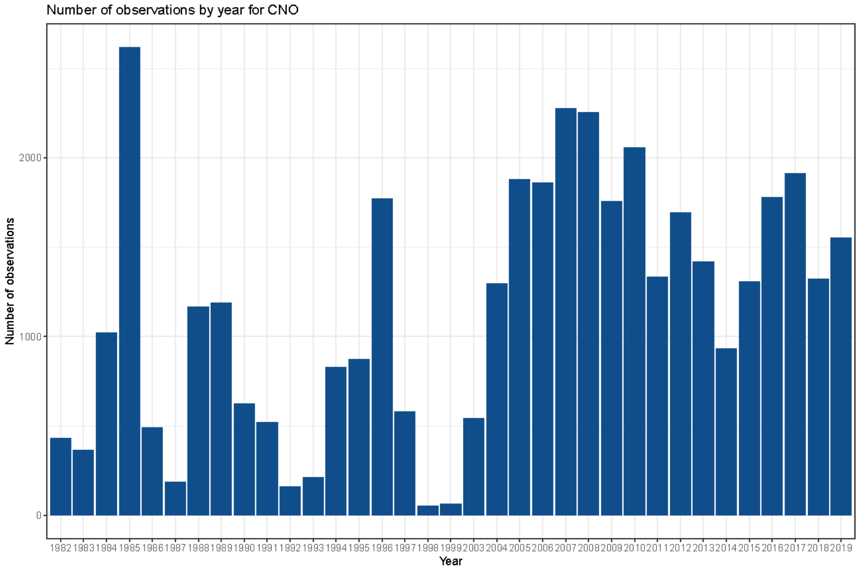
```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1982    2004    2009    2007    2013    2019
```

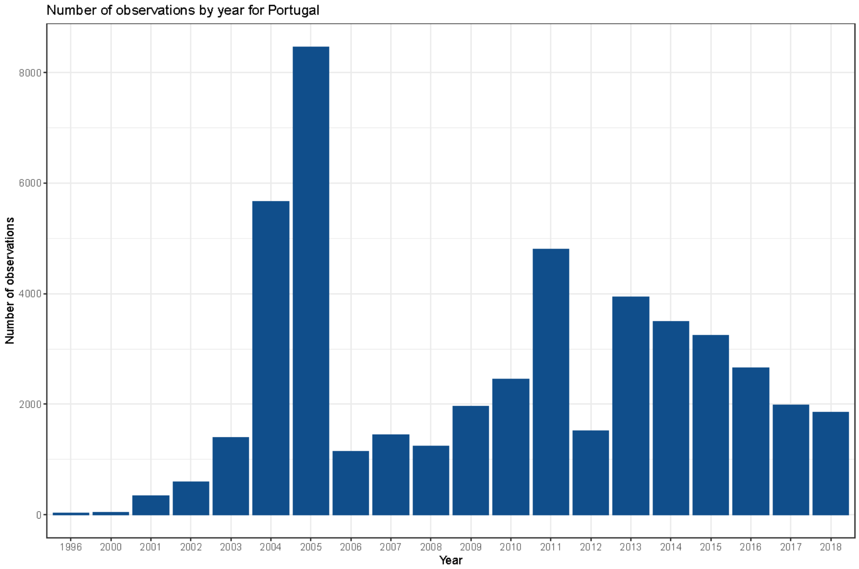
Exploratory

General

We check the number of individuals by area. Portugal data cover from 1996 to 2018, whereas Spain data cover from 1982 to 2019. Note that in 2000, 2001, 2002 there are not individuals in CNO (Cantabrian fishing grounds), also no data is available for Portugal for 1997-1999 and 2019.

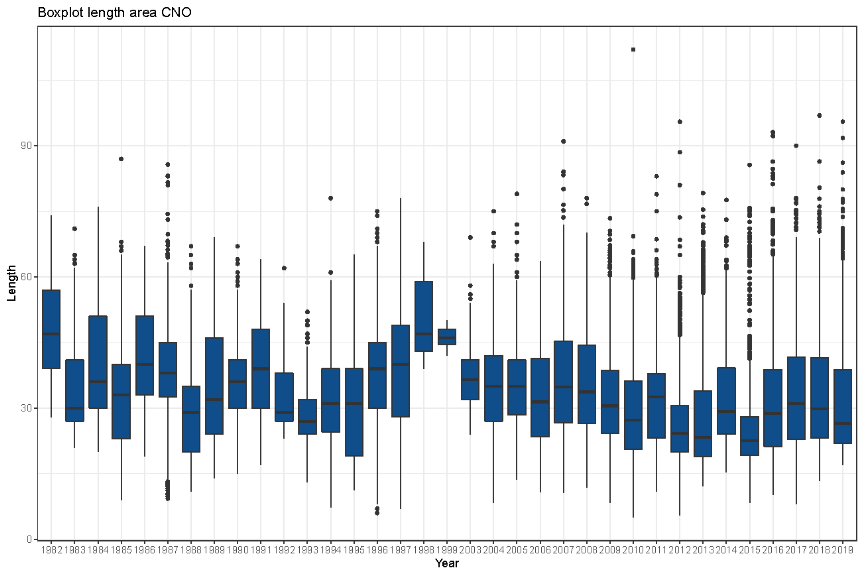
```
##
##         CNO Portugal
##   1982  431        0
##   1983  364        0
##   1984 1023        0
##   1985 2619        0
##   1986  490        0
##   1987  187        0
##   1988 1165        0
##   1989 1187        0
##   1990  623        0
##   1991  519        0
##   1992  160        0
##   1993  214        0
##   1994  827        0
##   1995  874        0
##   1996 1773       35
##   1997  581        0
##   1998   53        0
##   1999   63        0
##   2000    0       47
##   2001    0      350
##   2002    0      596
##   2003  542     1401
##   2004 1295     5670
##   2005 1880     8464
##   2006 1862     1150
##   2007 2275     1443
##   2008 2254     1243
##   2009 1757     1963
##   2010 2058     2455
##   2011 1333     4807
##   2012 1693     1516
##   2013 1418     3947
##   2014  934     3495
##   2015 1306     3243
##   2016 1777     2658
##   2017 1914     1991
##   2018 1323     1857
##   2019 1552        0
```

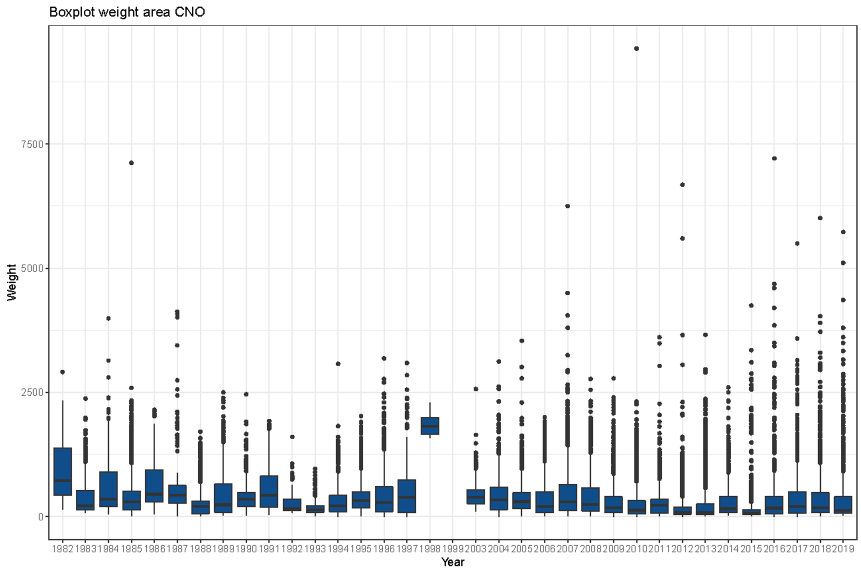




We look at length and weight along time (by grouped area). Two outliers in weight have been detected in

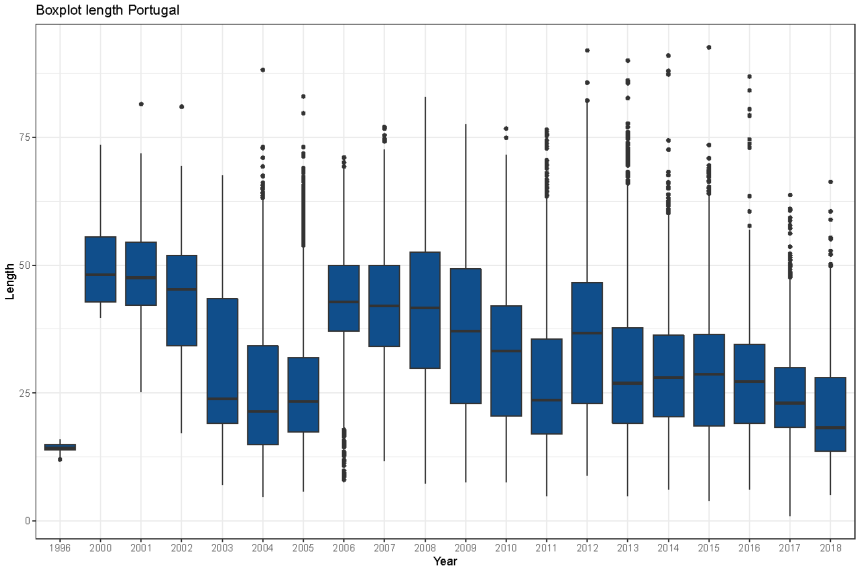
2010 (CNO area), and hence they have been removed (their values were 110211, 116611).

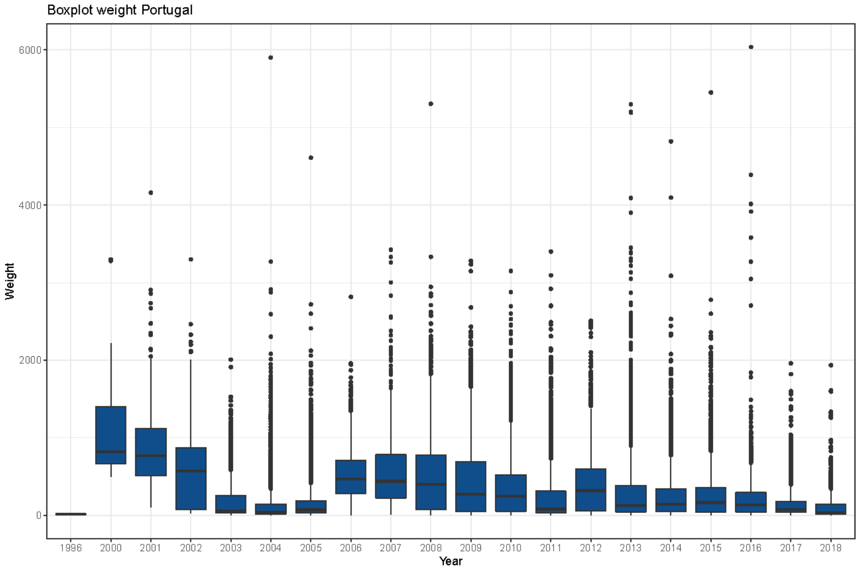




Year 1999 does not contains the weights for the corresponding lengths. Hence, 1999 for CNO is removed from the data base. Year 1998 has a particular behaviour and a small sample size (53 individuals).

```
##       year month tl tw  gw sex source area prof M    Y     logL logW areaU
## 14363 1999     2 48 NA 648   I market   8c   NA 2 1999 1.681241   NA   CNO
## 14364 1999     2 49 NA 714   I market   8c   NA 2 1999 1.690196   NA   CNO
## 14365 1999     2 48 NA 686   I market   8c   NA 2 1999 1.681241   NA   CNO
## 14366 1999     2 50 NA 750   I market   8c   NA 2 1999 1.698970   NA   CNO
## 14367 1999     2 47 NA 693   I market   8c   NA 2 1999 1.672098   NA   CNO
## 14368 1999     2 46 NA 605   F market   8c   NA 2 1999 1.662758   NA   CNO
```

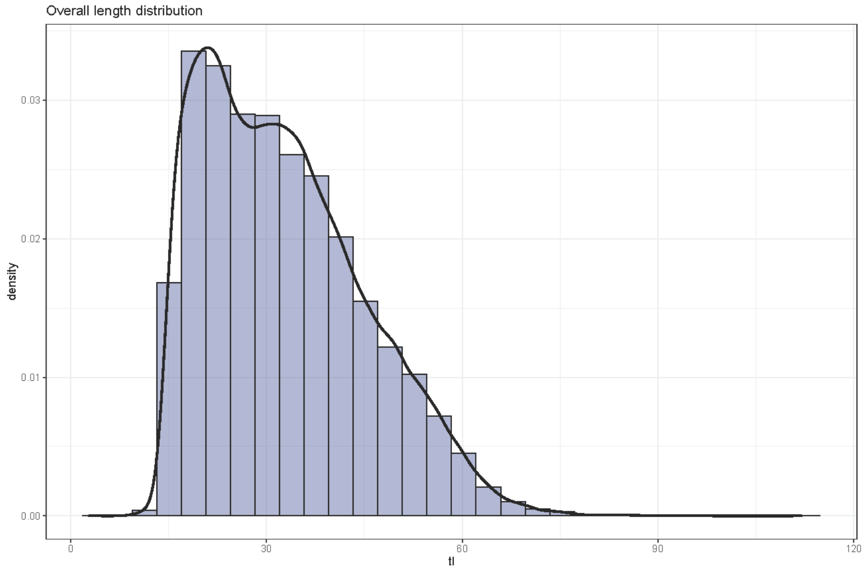


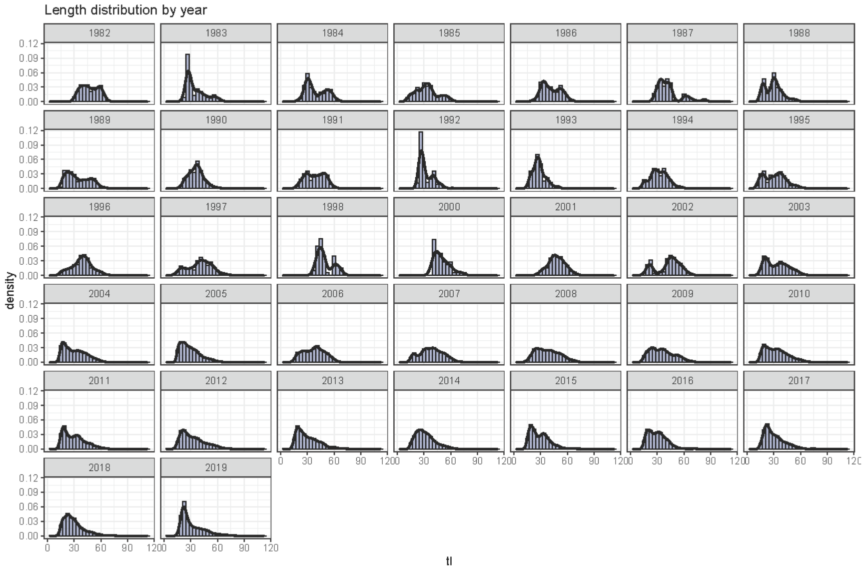


Year 1996 has a clear strange behaviour, then we eliminate the data of this year whose sample size is 35 (too small).

Finally, we decide to eliminate all individuals whose weight is less or equal than 18 gr since the measures for weights smaller than these ones are not trustworthy.

Length distributions





Length-weight model

Global model

Estimation of global (not year specific) a and b using the updated length-weight data base.

```
fit.0 <- lm(logW ~ logL, data = data)
summary(fit.0)
```

```
##
## Call:
## lm(formula = logW ~ logL, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.90013 -0.03208 -0.00432  0.02778  2.99730
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.398095   0.001881   -1275   <2e-16 ***
## logL         3.153611   0.001268    2488   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.05646 on 76590 degrees of freedom
##   (4983 observations deleted due to missingness)
## Multiple R-squared:  0.9878, Adjusted R-squared:  0.9878
## F-statistic: 6.188e+06 on 1 and 76590 DF,  p-value: < 2.2e-16
```

The diagnosis plots can be improved eliminating the values whose cook's distance is above its 0.99775 percentile.

The model is adjusted again.

```
fit.0 <- lm(logW ~ logL, data = data)
summary(fit.0)
```

```
##
## Call:
## lm(formula = logW ~ logL, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.34822 -0.03128 -0.00371  0.02813  0.35800
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.414365   0.001580   -1528   <2e-16 ***
## logL         3.164206   0.001065    2972   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04723 on 76417 degrees of freedom
##   (4983 observations deleted due to missingness)
## Multiple R-squared:  0.9914, Adjusted R-squared:  0.9914
## F-statistic: 8.834e+06 on 1 and 76417 DF,  p-value: < 2.2e-16
```

Model by year (common intercept, year specific slope)

Estimation of year specific b (and common a). Below the summaries report the model results using two different parametrizations of the same model.

```
fit.YY <- lm(logW ~ logL:Y +logL, data = data)
summary(fit.YY)
```

```
##
## Call:
## lm(formula = logW ~ logL:Y + logL, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.34050 -0.03008 -0.00318  0.02734  0.35558
##
## Coefficients:
##               Estimate Std. Error   t value Pr(>|t|)
## (Intercept) -2.4146726  0.0016067 -1502.863  < 2e-16 ***
## logL         3.1672825  0.0010830  2924.651  < 2e-16 ***
## logL:Y.L    -0.0323537  0.0010835   -29.859  < 2e-16 ***
## logL:Y.Q    -0.0051941  0.0017287    -3.005 0.002660 **
## logL:Y.C     0.0103104  0.0012312     8.374  < 2e-16 ***
## logL:Y^4    -0.0075119  0.0016830    -4.463 8.08e-06 ***
## logL:Y^5     0.0029580  0.0012980     2.279 0.022679 *
## logL:Y^6    -0.0152811  0.0015889    -9.618  < 2e-16 ***
## logL:Y^7    -0.0037772  0.0013198    -2.862 0.004212 **
## logL:Y^8     0.0111245  0.0015192     7.323 2.46e-13 ***
```

```
## logL:Y^9     0.0009670  0.0016171     0.598 0.549845
## logL:Y^10   -0.0012902  0.0013215    -0.976 0.328906
## logL:Y^11    0.0026899  0.0016729     1.608 0.107865
## logL:Y^12   -0.0044380  0.0012643    -3.510 0.000448 ***
## logL:Y^13    0.0050320  0.0017317     2.906 0.003663 **
## logL:Y^14    0.0062401  0.0012337     5.058 4.24e-07 ***
## logL:Y^15   -0.0106238  0.0016891    -6.290 3.20e-10 ***
## logL:Y^16    0.0004268  0.0011648     0.366 0.714058
## logL:Y^17    0.0023624  0.0017300     1.366 0.172081
## logL:Y^18   -0.0119752  0.0012886    -9.293  < 2e-16 ***
## logL:Y^19    0.0103504  0.0015851     6.530 6.62e-11 ***
## logL:Y^20    0.0035704  0.0014325     2.493 0.012686 *
## logL:Y^21   -0.0037021  0.0015072    -2.456 0.014039 *
## logL:Y^22   -0.0048811  0.0016558    -2.948 0.003201 **
## logL:Y^23    0.0096612  0.0015244     6.338 2.34e-10 ***
## logL:Y^24    0.0035673  0.0017844     1.999 0.045598 *
## logL:Y^25   -0.0150287  0.0014054   -10.694  < 2e-16 ***
## logL:Y^26    0.0088529  0.0017529     5.051 4.42e-07 ***
## logL:Y^27   -0.0002690  0.0013994    -0.192 0.847542
## logL:Y^28    0.0090714  0.0020866     4.348 1.38e-05 ***
## logL:Y^29    0.0098937  0.0018067     5.476 4.36e-08 ***
## logL:Y^30    0.0017274  0.0020300     0.851 0.394808
## logL:Y^31   -0.0083472  0.0014994    -5.567 2.60e-08 ***
## logL:Y^32    0.0064917  0.0017542     3.701 0.000215 ***
## logL:Y^33   -0.0053534  0.0020271    -2.641 0.008271 **
## logL:Y^34    0.0066544  0.0030359     2.192 0.028390 *
## logL:Y^35   -0.0033692  0.0027129    -1.242 0.214275
## logL:Y^36   -0.0022713  0.0006514    -3.487 0.000489 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04599 on 76381 degrees of freedom
##   (4983 observations deleted due to missingness)
## Multiple R-squared:  0.9919, Adjusted R-squared:  0.9919
## F-statistic: 2.519e+05 on 37 and 76381 DF,  p-value: < 2.2e-16
```

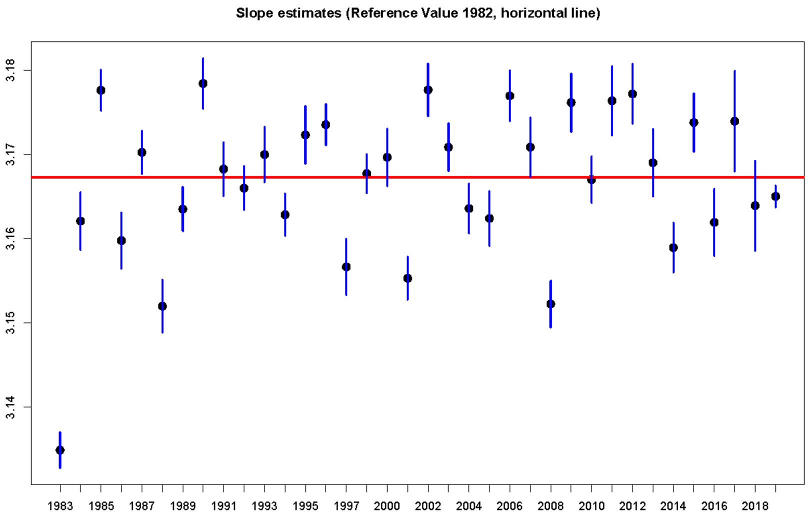
```
# alternative parameterization
fit.YY.bis <- lm(logW ~ logL:Y, data = data)
summary(fit.YY.bis)
```

```
##
## Call:
## lm(formula = logW ~ logL:Y, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.34050 -0.03008 -0.00318  0.02734  0.35558
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.414673   0.001607 -1502.9   <2e-16 ***
## logL:Y1982   3.164556   0.001637  1932.9   <2e-16 ***
## logL:Y1983   3.170155   0.001926  1645.6   <2e-16 ***
## logL:Y1984   3.171420   0.001356  2339.2   <2e-16 ***
## logL:Y1985   3.179782   0.001216  2615.3   <2e-16 ***
```

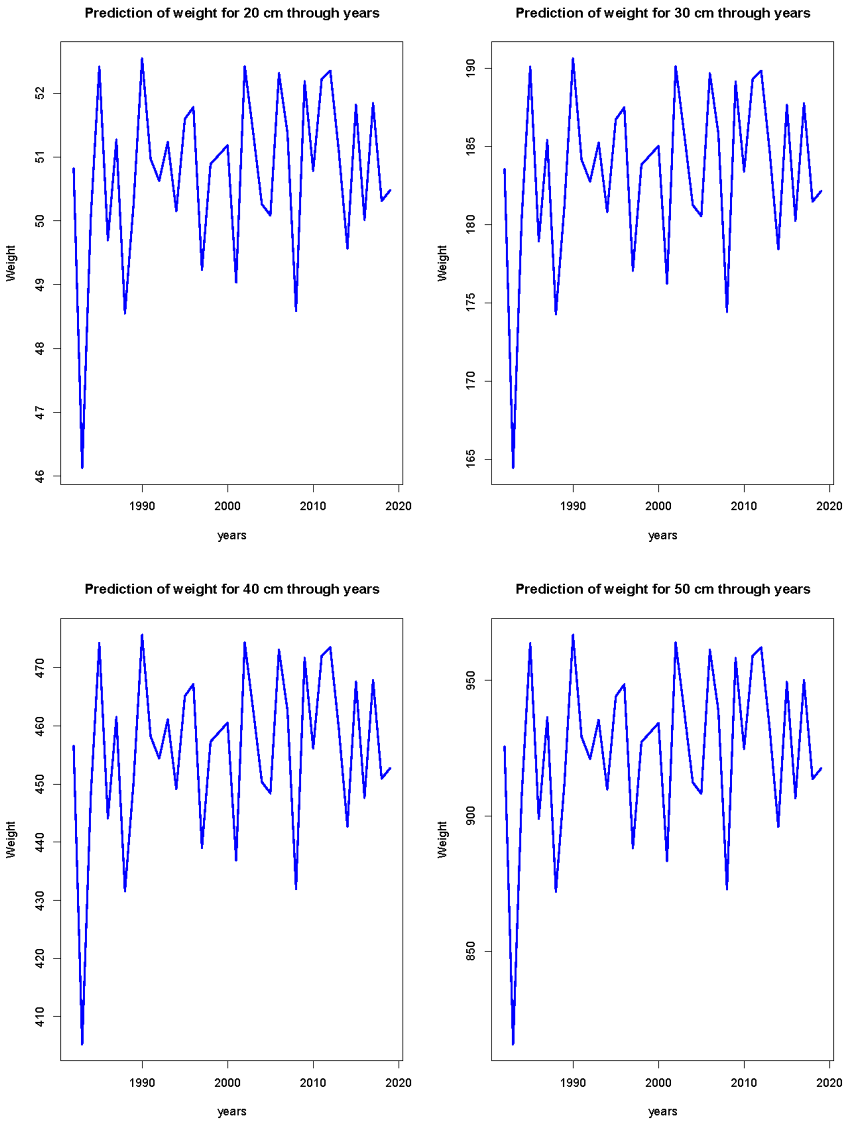
```
## logL:Y1986   3.173834   0.001631  1945.4   <2e-16 ***
## logL:Y1987   3.172121   0.002379  1333.1   <2e-16 ***
## logL:Y1988   3.195030   0.001454  2196.7   <2e-16 ***
## logL:Y1989   3.174024   0.001374  2309.6   <2e-16 ***
## logL:Y1990   3.178302   0.001579  2013.4   <2e-16 ***
## logL:Y1991   3.168156   0.001634  1939.2   <2e-16 ***
## logL:Y1992   3.157475   0.002647  1192.6   <2e-16 ***
## logL:Y1993   3.168621   0.002456  1290.1   <2e-16 ***
## logL:Y1994   3.175160   0.001532  2072.9   <2e-16 ***
## logL:Y1995   3.176700   0.001633  1945.2   <2e-16 ***
## logL:Y1996   3.171229   0.001387  2286.6   <2e-16 ***
## logL:Y1997   3.160179   0.001728  1828.8   <2e-16 ***
## logL:Y1998   3.161178   0.006667   474.2   <2e-16 ***
## logL:Y2000   3.187652   0.004069   783.3   <2e-16 ***
## logL:Y2001   3.170237   0.001847  1716.6   <2e-16 ***
## logL:Y2002   3.163135   0.001715  1843.9   <2e-16 ***
## logL:Y2003   3.169709   0.001350  2347.2   <2e-16 ***
## logL:Y2004   3.174690   0.001206  2632.7   <2e-16 ***
## logL:Y2005   3.165045   0.001168  2709.8   <2e-16 ***
## logL:Y2006   3.161249   0.001201  2632.0   <2e-16 ***
## logL:Y2007   3.161313   0.001151  2747.8   <2e-16 ***
## logL:Y2008   3.153412   0.001166  2704.9   <2e-16 ***
## logL:Y2009   3.158032   0.001185  2664.4   <2e-16 ***
## logL:Y2010   3.159046   0.001174  2691.2   <2e-16 ***
## logL:Y2011   3.161997   0.001180  2679.9   <2e-16 ***
## logL:Y2012   3.161874   0.001235  2560.2   <2e-16 ***
## logL:Y2013   3.159695   0.001182  2672.9   <2e-16 ***
## logL:Y2014   3.161606   0.001186  2665.1   <2e-16 ***
## logL:Y2015   3.166102   0.001211  2614.3   <2e-16 ***
## logL:Y2016   3.164287   0.001199  2638.4   <2e-16 ***
## logL:Y2017   3.159834   0.001214  2603.3   <2e-16 ***
## logL:Y2018   3.157208   0.001267  2490.9   <2e-16 ***
## logL:Y2019   3.155406   0.001340  2354.3   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04599 on 76381 degrees of freedom
##   (4983 observations deleted due to missingness)
## Multiple R-squared:  0.9919, Adjusted R-squared:  0.9919
## F-statistic: 2.519e+05 on 37 and 76381 DF,  p-value: < 2.2e-16
```

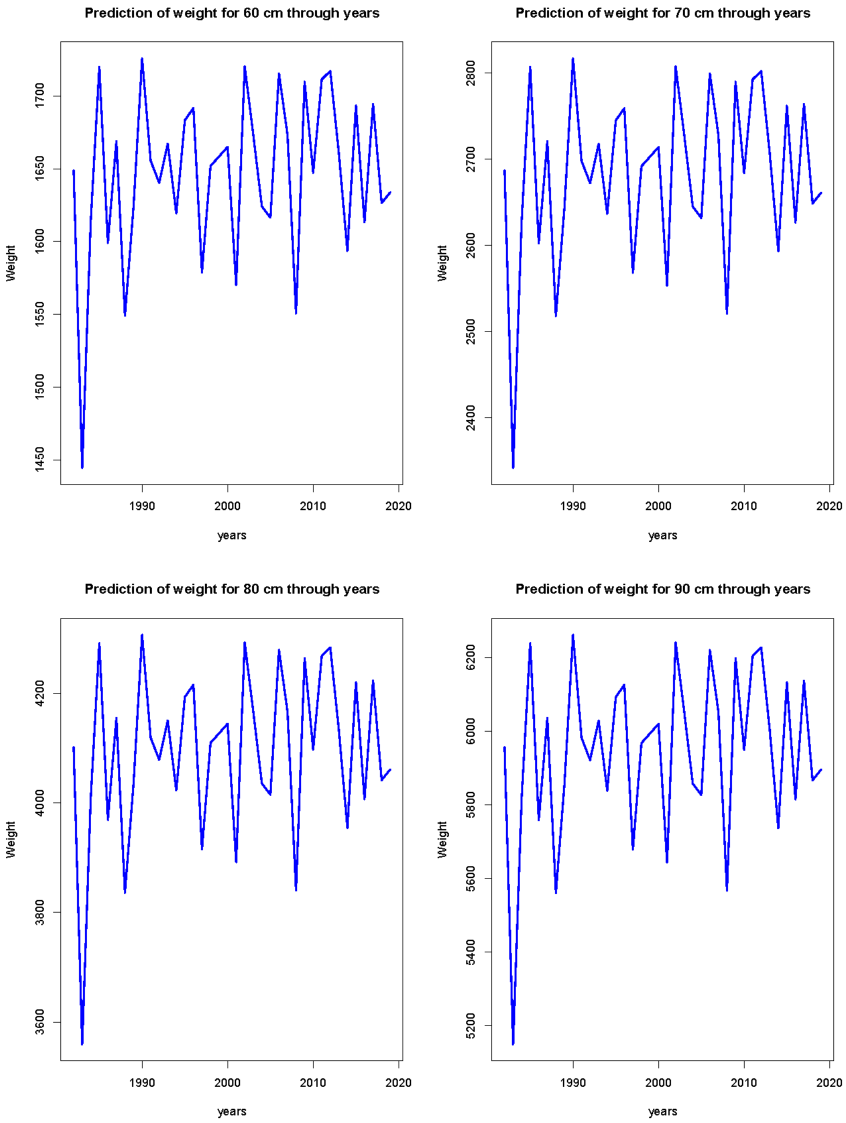
Plots (model by year)

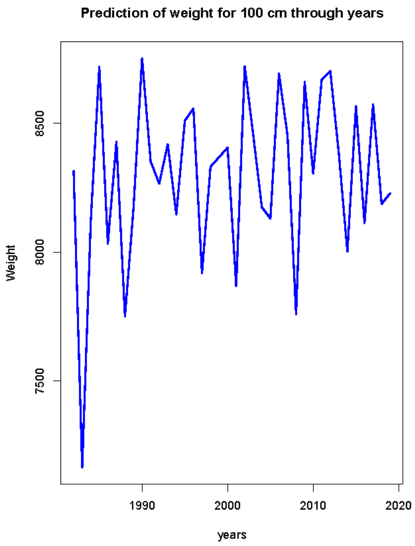
Comparison of the b year specific estimates (black point) respect to the b estimate at the first year of our time series (1982, red horizontal line). The 95% confidence intervals are plotted using a vertical line.



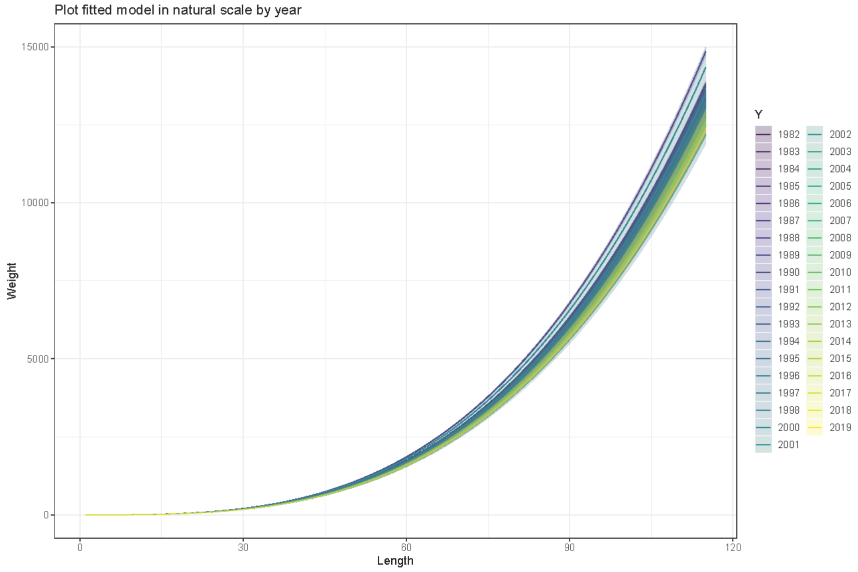
Predicted weights along the years for the length values of the sequence 20, 30, ..., 100 cm. The plots show that the predicted weight series are more or less stable for the last years (and for all the lengths). Then, it seems that year specific b estimates are not required.


Prediction of weight for 20 cm through years
Weight
46
47
48
49
50
51
52
1990
2000
2010
2020
years
Prediction of weight for 30 cm through years
Weight
165
170
175
180
185
190
1990
2000
2010
2020
years
Prediction of weight for 40 cm through years
Weight
410
420
430
440
450
460
470
1990
2000
2010
2020
years
Prediction of weight for 50 cm through years
Weight
850
900
950
1990
2000
2010
2020
years


Prediction of weight for 60 cm through years
Prediction of weight for 70 cm through years
Prediction of weight for 80 cm through years
Prediction of weight for 90 cm through years
Weight
years
1990
2000
2010
2020
1450
1500
1550
1600
1650
1700
2400
2500
2600
2700
2800
3600
3800
4000
4200
5200
5400
5600
5800
6000
6200



Additionally to previous plots, the next plot show the weight-length relation curves for each year.



Model by sex

Estimation of global a and b by sex. Below the summaries report the model results using two different parametrizations of the same model.

```
fit.SSS <- lm(logW ~ logL*sex, data = data)
summary(fit.SSS)
```

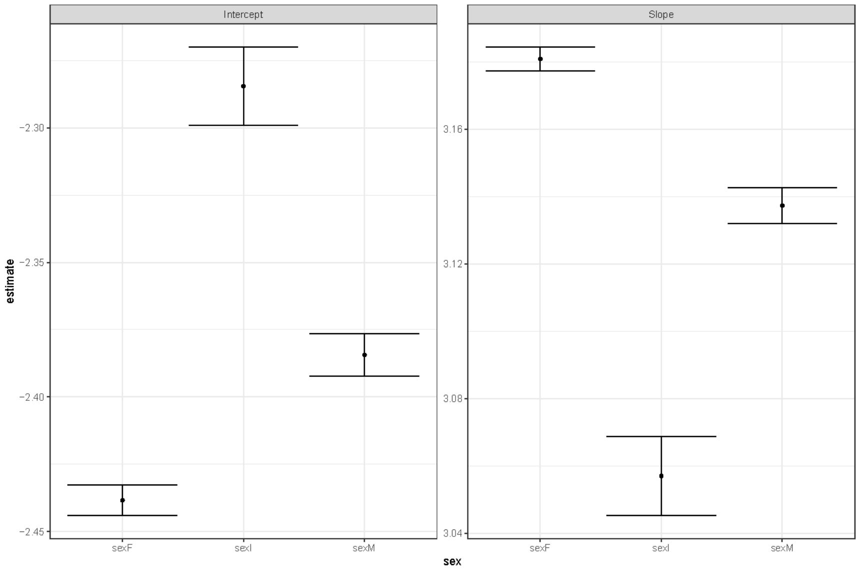
```
##
## Call:
## lm(formula = logW ~ logL * sex, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.33954 -0.02925 -0.00326  0.02611  0.35808
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.438396   0.002847 -856.60   <2e-16 ***
## logL         3.180831   0.001844 1725.16   <2e-16 ***
## sexI         0.153870   0.007972   19.30   <2e-16 ***
## sexM         0.054033   0.004892   11.04   <2e-16 ***
## logL:sexI   -0.123814   0.006235  -19.86   <2e-16 ***
## logL:sexM   -0.043534   0.003263  -13.34   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0452 on 62656 degrees of freedom
```

```
##   (3153 observations deleted due to missingness)
## Multiple R-squared:  0.9921, Adjusted R-squared:  0.9921
## F-statistic: 1.577e+06 on 5 and 62656 DF,  p-value: < 2.2e-16
```

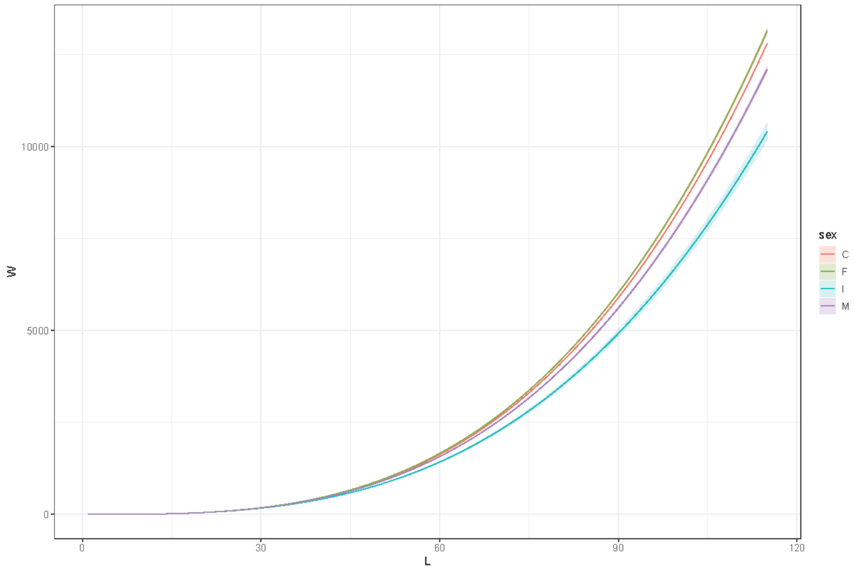
```
fit.SSS.bis <- lm(logW ~ logL*sex -1 -logL, data = data)
summary(fit.SSS.bis)
```

```
##
## Call:
## lm(formula = logW ~ logL * sex - 1 - logL, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.33954 -0.02925 -0.00326  0.02611  0.35808
##
## Coefficients:
##            Estimate Std. Error t value Pr(>|t|)
## sexF      -2.438396   0.002847  -856.6   <2e-16 ***
## sexI      -2.284526   0.007446  -306.8   <2e-16 ***
## sexM      -2.384363   0.003979  -599.3   <2e-16 ***
## logL:sexF  3.180831   0.001844  1725.2   <2e-16 ***
## logL:sexI  3.057018   0.005956   513.3   <2e-16 ***
## logL:sexM  3.137297   0.002693  1165.1   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0452 on 62656 degrees of freedom
##   (3153 observations deleted due to missingness)
## Multiple R-squared:  0.9996, Adjusted R-squared:  0.9996
## F-statistic: 2.634e+07 on 6 and 62656 DF,  p-value: < 2.2e-16
```

Plot of the a and b estimates for each sex (F=females, M=males, I=inmatures) with the corresponding confidence interval.



Plot of the sex specific length-weight curves (C means global model, that is, no sex differences). The results show that the females and males curves are almost the same for the range of lengths for which data of both sexes is available, hence it lead to conclude that the sex differences are not relevant enough to propose sex-specific estimates.



Final proposal

We propose to update the *a* and *b* values using the estimates derived from the global model using data from 2003 to 2019. The selection of years has been carried out focusing on the sampling sizes of both countries.

1999 estimates:

a = 0.00659 b = 3.01721

Updated:

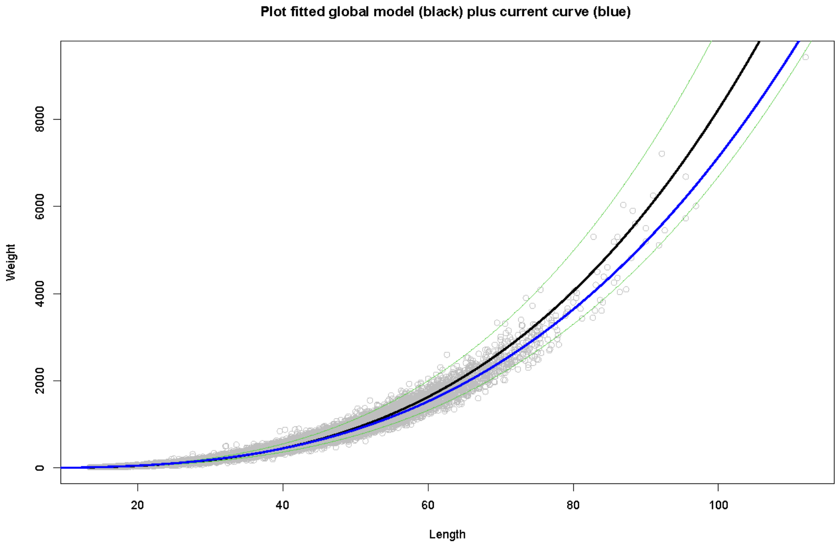
a=0.00377 b=3.16826

```
data=subset(data,data$year>2002)
fit.0 <- lm(logW ~ logL, data = data)
summary(fit.0)
```

```
##
## Call:
## lm(formula = logW ~ logL, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.34459 -0.02976 -0.00350  0.02659  0.36163
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.423832   0.001678   -1445   <2e-16 ***
## logL         3.168263   0.001140    2780   <2e-16 ***
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04565 on 62660 degrees of freedom
##   (3153 observations deleted due to missingness)
## Multiple R-squared:  0.992,  Adjusted R-squared:  0.992
## F-statistic: 7.727e+06 on 1 and 62660 DF,  p-value: < 2.2e-16
```

Comparison of the updated weight-length curve with the 1999 curve. The confidence interval is plotted in green. The grey points correspond to the observed data. The curves differs for large length values for which almost no data is available.



WORKING DOCUMENT 11

Gear groupings for mon.27.78abde and ank.27.78abde

Working document to WKAngler 2022 – Hans Gerritsen – Marine Institute – Version 2 10/12/2021

Summary

Data extraction

The WKAngler (2018) benchmark workshop compiled the historic landings data (tonnage and length distributions) for the period 1986-2012. Additionally, a data call was issued to upload all data from 2003 into intercatch. In order to make the two datasets compatible the fleet aggregations used in the historic data was mapped to metier level 4 (Table 1.)

Table 1. The historic data (1986-2012) were grouped by into the fleets below. These were mapped to metier level 4 for compatability with the data available in intercatch (2003-present).

Fleet	Fleet description	Area	Country	MetierLvl4
FU3	Gillnets	7	UK,FR	GNS_DEF
FU4	Non-Nephrops trawling in medium to deep water	7	UK,FR,IE,SP	OTB_DEF
FU5	Non-Nephrops trawling in shallow water	7	UK,FR,IE	OTB_DEF
FU6	Beam trawling in shallow water	7	BE,UK	TBB_DEF
FU8	Nephrops trawling in medium to deep water	7	FR	OTB_CRU
FU9	Nephrops trawling in shallow to medium water	8	FR	OTB_CRU
FU10	Trawling in shallow to medium water	8	FR	OTB_DEF
FU13	Gillnets in shallow to medium water	8	FR	GNS_DEF
FU14	Trawling in medium to deep water	8	FR,SP	OTB_DEF
IRL_VIIb-k, IRL_VIIbgj		7	IE	OTB_DEF
Other		7,8	UK,FR,IE,SP	MIS_MIS

The historic data were available in separate spreadsheets for each year (and stock). WKAngler extracted the annual landings and length distributions, applied an SOP correction (sum of products of the numbers-at-length and the mean length-at-age) to account for missing length data (e.g. fleets that were not sampled in one or more quarter) as well as to account for updated length-weight parameters. However, the WKAngler data was only available for all fleets combined. Therefore, the data were re-extracted by fleet. The re-extracted historical data conformed quite closely to the WKAngler dataset when aggregated annually (Figures 1a and 1b).

There is a period of overlap between the historic dataset (1986-2012) and the data available in intercatch (2002 onwards). WKAngler considered that the intercatch data was likely to be more complete than the historic data and therefore the historic data were used only for the period 1986-2002 and intercatch data thereafter. WKAngHake will take the same approach.

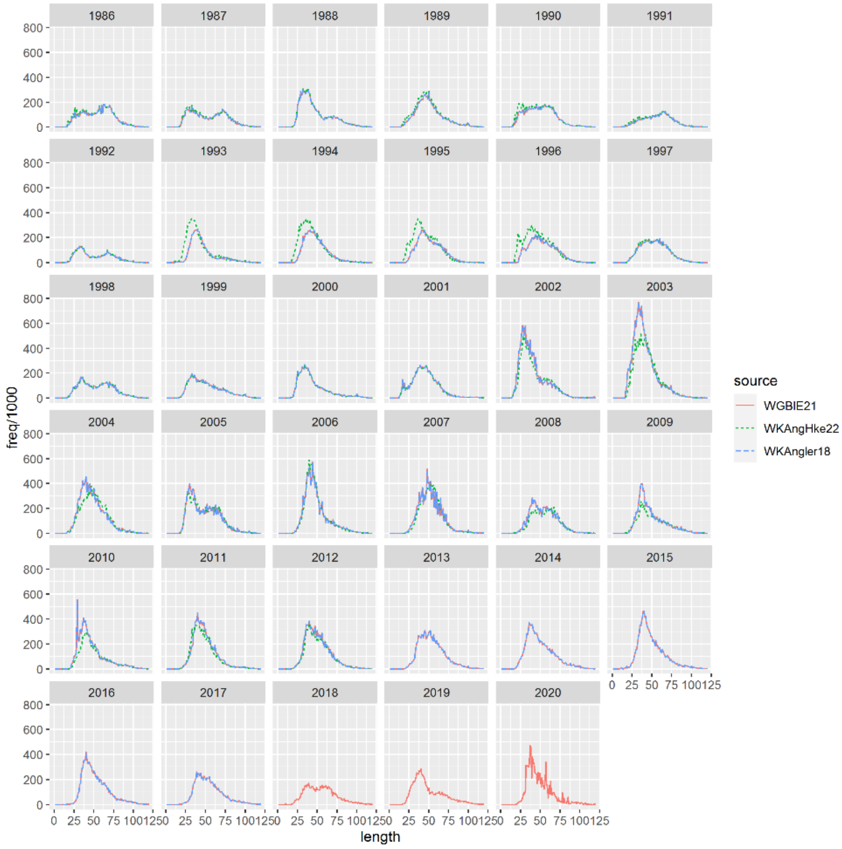


Figure 1a. Annual length frequency distributions of white anglerfish (all fleets and areas combined). WGBIE21 is the data used by the most recent working group; WKAngler18 is the data compiled at the 2018 benchmark (this is identical to WGBIE21 but with a shorter time series) and WKAngHke22 is the re-extracted historical data (1986-212). There were some small differences between WKAngler18 and the present analysis (WKAngHke22) in some years during the period before 2003. This is due to slight differences in the weighting of the individual fleets and filling-in of unsampled fleets.

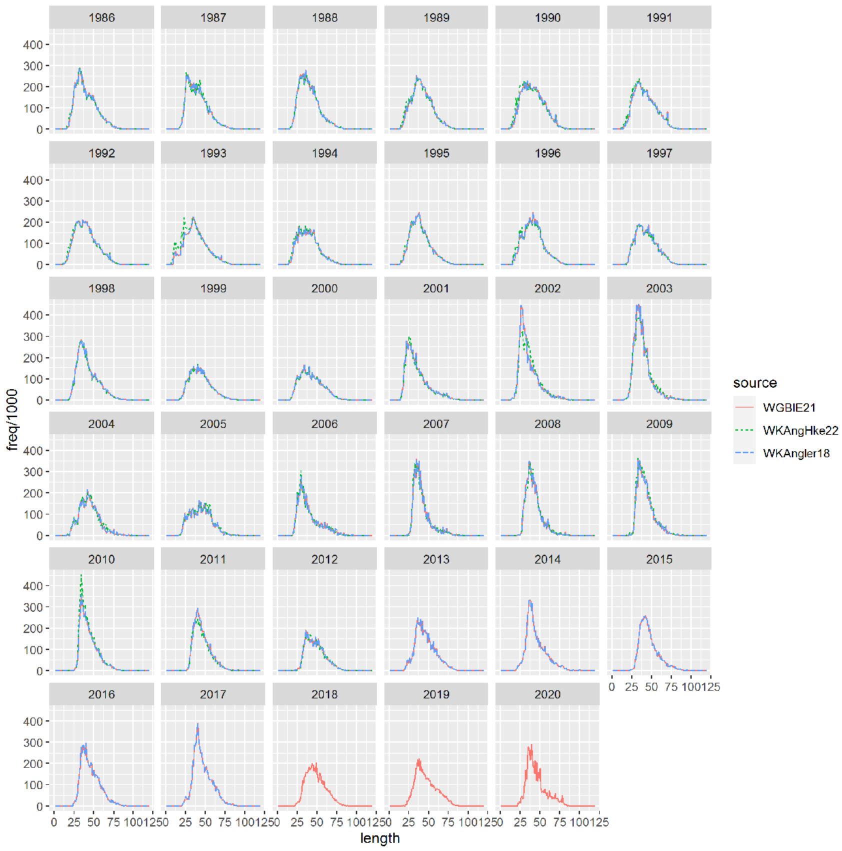


Figure 1b. Annual length frequency distributions of black anglerfish (all fleets and areas combined). WGBIE21 is the data used by the most recent working group; WKAngler18 is the data compiled at the 2018 benchmark (this is identical to WGBIE21 but with a shorter time series) and WKAngHke22 is the re-extracted historical data (1986-212). Differences between WKAngler18 and the present analysis (WKAngHke22) are almost imperceptible.

Fleet groupings

Otter trawlers targeting demersal species (OTB_DEF) are the dominant gear type for landings of both stocks (Figure 2a); Spain and France are the dominant countries involved in the fishery (Figure 2b), although since 2000 the proportion of landings of white anglerfish of Spanish fleet has decreased to similar levels of UK and Irish fleets nowadays

An initial fleet grouping was made by separating the Spanish and French OTB_DEF landings by country and sub-area (27.7 and 27.8). For the remainder of the landings, the flag countries and areas were combined but the metiers were considered as separate fleets. This resulted in the following gear groupings: GNS_DEF (gillnets; all countries, all areas); MIS_MIS (unknown gears; all countries, all areas); OTB_CRU (nephrops trawls; all countries, all areas); OTB_DEF France 27.7; OTB_DEF

France 27.8; OTB_DEF Spain 27.7; OTB_DEF Spain 27.8, OTB_DEF (remaining countries and areas combined) and TBB_DEF (beam trawls; all countries, all areas). Figure 2c shows that each of these initial fleet groups contributed between 5% and 40% to the total landings.

Figure 2a. Proportion of the landings by gear type over time.

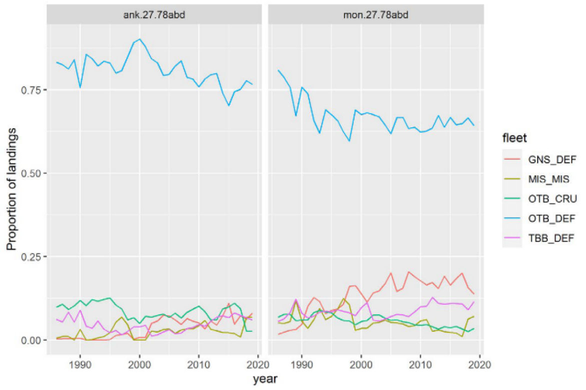


Figure 2b. Proportion of the landings by vessel flag country over time.

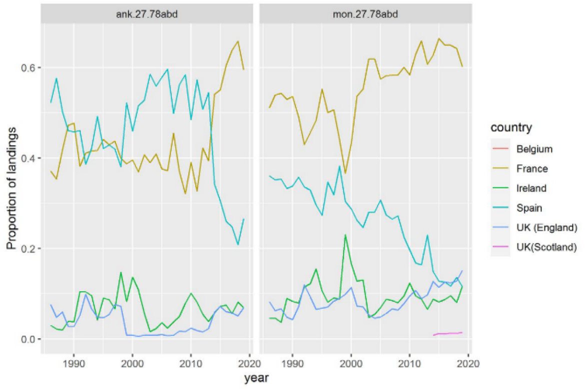
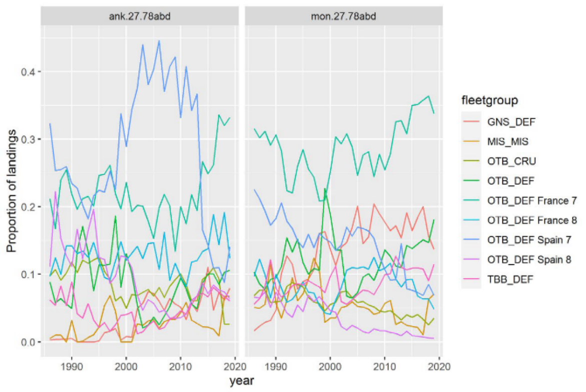


Figure 2c. Proportion of the landings by initial fleet groupings.



The length distributions of the initial fleet groups are shown in Figure 3. It is clear that gillnets have a different selection pattern from the other gears and that the length distributions have changed over time (generally more large fish at the start of the time series).

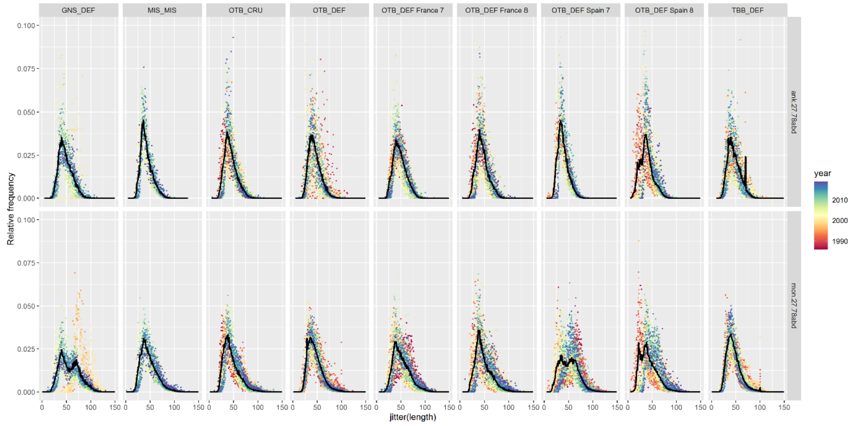


Figure 3. Relative length frequency distributions (standardised by fleet and year) for black anglerfish (top) and white anglerfish (bottom). Colours represent individual years and the black line is the average over all years.

Figure 4 shows the deviation from the overall length frequency distribution of the landings. A fleet with mainly horizontal lines would indicate that this fleet has an average length distribution. This is only the case for the white anglerfish landings from the MIS_MIS (miscellaneous) fleet. The GNS_DEF fleet catches relatively more large and fewer small fish. GNS_DEF length distributions in the early years of the time series are very different from later years.

For black anglerfish the fleets OTB_CRU, OTB_DEF, OTB_DEF France 7; OTB_DEF France 8 and TBB_DEF are quite similar with slightly more large (>40cm) fish than the overall length distribution while the OTB_DEF Spain 7 and OTB_DEF Spain 8 are consistently responsible for landing relatively more small (<40cm) fish. For white anglerfish (mon.27.78abd; bottom row), the OTB_CRU, OTB_DEF and TBB_DEF fleets are similar; the two French fleets are also similar, as are the two Spanish fleets. For both stocks the GNS_DEF landings are quite variable and distinct from the other fleets. So while the French OTB fleets do not look very different from the other OTB fleets for black anglerfish, they are quite different for white anglerfish. In order to keep the fleet groupings consistent for the two stocks, the following fleet grouping is proposed:

Init fleet groups	**Description**	**Final fleet groups**	**Description**
GNS_DEF	Gillnets all countries	Gillnets	Gillnets all countries
MIS_MIS	Other gears, fleets etc.	Trawls-others	Demersal otter and beam trawls UK, IE, BEL, NL and Nephrops trawls all countries
OTB_CRU	Nephrops fleets, all countries	Trawls-others	
OTB_DEF	Demersal fleets, UK, IE ,Others	Trawls-others	
TBB_DEF	Beam traws, all countries	Trawls-others	
OTB_DEF Fra 7	Demersal fleets, France Area 7	Trawls-France	Demersal otter trawls France
OTB_DEF Fra 8	Demersal fleets, France Area 8	Trawls-France	
OTB_DEF Esp 7	Demersal fleets, Spain Area 7	Trawls-Spain	Demersal otter trawls Spain
OTB_DEF Esp 8	Demersal fleets, Spain Area8	Trawls-Spain	

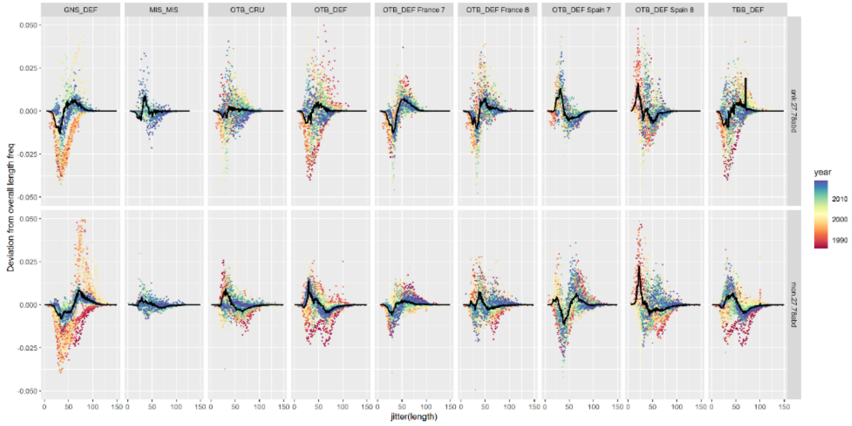


Figure 4. The plots show the deviation from the overall length frequency distribution of the landings from each fleet. For black anglerfish (ank.27.78abd; top row), the fleets OTB_CRU, OTB_DEF, OTB_DEF France 7; OTB_DEF France 8 and TBB_DEF are quite similar overall while the OTB_DEF Spain 7 and OTB_DEF Spain 8 are consistently responsible for landing relatively more small (<40cm) fish. For white anglerfish (mon.27.78abd; bottom row), the OTB_CRU, OTB_DEF and TBB_DEF fleets are similar; the two French fleets are also similar, as are the two Spanish fleets. For both stocks the GNS_DEF landings are quite variable and distinct from the other fleets. Gillnet length distributions in the early years of the time series are very different from later years.

WORKING DOCUMENT 12

ICES *Benchmark Workshop on anglerfish (Lophius budegassa, Lophius piscatorius) and hake (Merluccius merluccius), online meeting, 14 – 18 February 2021*

Standardization of the Portuguese trawl fleet LPUE for Iberian hake

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Summary

This study develops a standardized LPUE for hake with a Tweedie Generalized Linear Model to handle the null observations and improve the abundance index of the Portuguese trawl commercial catch-effort data. This LPUE was compared with a prior LPUE standardization model, that only considered the positive catches of hake with a Gamma generalized linear model, and the CPUE from the Portuguese Autumn groundfish surveys (IBTS). The results showed that the new LPUE and the IBTS indices are reflecting the same abundance trend. The estimates are assumed to be proportional to abundance and therefore proposed to be included in the Iberian hake stock assessment.

Introduction

Indices of abundance derived from fishery-dependent time series of landing or catch per unit effort (LPUE/CPUE) are usually assumed proportional to abundance and therefore are an integral part of the stock assessment process. Nominal CPUE values are often not proportional to the abundance of the stock being assessed and abundance indices are commonly standardized removing the impact of other factors that influence catch rates but are not related to the resource abundance (Maunder and Punt, 2004).

At previous benchmark workshop (WKROUND, 2010), Cardador and Jardim (2010) presented a standardization LPUE model for hake (*Merluccius merluccius*) only considering the positive catches of hake with a Gamma generalized linear model (with log link). The explanatory variables were: year (as factor), area (north, southwest, south and no specified area), engine power (nine levels of engine power in 100 kW class intervals, ranging from 100-1000 kW), trawl duration (5 levels, in 4-hour class intervals equivalent to 1 to 5 hauls in average per day), log total catch classes (cat_catch, 6 levels), proportion of hake in the total catch (cat_phke, 3 levels), métier (assigned to each record based on the predominance of some species, HOM – horse mackerel, CEF – cephalopods, WHB – blue whiting and MIX – other), according to the cluster analysis presented in Silva et. al 2009).

The Portuguese LPUE used in the assessment model was predicted considering one reference level of each factor according to the equation:

$$ln\ (LPUE) \sim year\ +\ zone\ (north) + EnginePower\ (]500, 600])\ +\ metier\ (MIX)\ +\ cat\_phke\ (10-25\%)\ +\ cat\_catch\ (]400{,}1000kg])$$

In this work, we develop an alternative approach to model landings per unit of effort data in order to provide a series of standardized LPUE estimates along with their confidence intervals fitting a Generalized Linear Model with Tweedie distributed errors to handle null observations (Shono, 2008). The *year* effect of the two LPUE standardization models and the CPUE from the Portuguese Autumn groundfish surveys (IBTS) are compared.

Data and methods

Data

Data from the Portuguese trawl logbooks were provided by the Portuguese fisheries administration (Directorate-General for Natural Resources, Safety and Maritime Services – DGRM) for the period 1988-2020, including two slightly different sources: paper logbooks (1988-2011) with records by day and ICES rectangle, and electronic logbooks (2012-2020) where the information was recorded by haul. To use the full period, data were grouped by day and ICES rectangle and include the vessel identification code, the number of hauls and fishing hours per day and rectangle and the corresponding catch in weight by species. Additionally, the main characteristics of each vessel are also available from EU Fleet Register: engine power (kW), gross registered tonnage (t), length-over-all (m) (Table 1). Vessel characteristics related variables were found highly correlated among them (83% to 88%) and only the engine power was kept for the analysis.

After a first exploratory data analysis, records with duration greater than 21hours, hake catches above 60 kg/h and area outside ICES Portugal mainland EEZ were removed from the data set. The final dataset included about 65% of zero hake catches. Based on ICES rectangles and in the topographic and oceanographic characteristics of the fishing grounds (Fiúza, 1983), three main zones (NW, SW and S) were considered. The final set was composed by 384,953 records.

The data employed in the CPUE standardization from 1988 to 2020 are summarised in Table 1. All columns refer to the data obtained from the Portuguese trawl fishery logbooks with number of vessels and total number of fishing days recorded, annual average trawling hours and vessel engine power. The mean hake and total catches per fishing day and the annual proportion of zeros observed are also shown.

Table 1 - Summary of the data obtained from Portuguese trawl logbooks for standardization of Hake LPUE.

Year	Number of vessels	Number of records (days)	Total trawl hours	Average engine power (kW)	Average Total Catch	Average hake catch (kg)	Percentage of zeros
1988	33	3520	47399	529.1	1330.7	31.8	72.8
1989	18	1543	21341	551.9	1440.8	39.0	70.4
1990	52	5841	74351	542.7	1651.2	16.0	83.2
1991	54	4416	55321	546.3	1603.0	6.2	92.1
1992	47	6964	85599	530.9	1086.7	5.2	94.7
1993	67	11904	144019	517.5	975.8	2.2	96.7
1994	73	11489	136724	525.8	809.0	2.3	96.1
1995	73	11563	143604	525.4	822.4	4.8	95.7
1996	76	11449	143111	524.2	759.7	3.6	95.5
1997	77	13945	178204	518.2	725.7	4.3	95.2
1998	79	13804	179703	529.5	862.7	7.2	87.4
1999	87	11976	150254	517.9	816.5	14.8	82.5
2000	69	12893	167195	519.5	1019.9	9.4	85.5
2001	35	6042	79216	545.1	1154.2	16.4	85.8
2002	61	7161	83105	561.0	1094.9	22.7	77.8
2003	84	14063	178945	490.8	835.9	10.7	80.6
2004	65	12355	151940	511.9	874.3	14.6	84.4
2005	85	8866	110014	495.4	948.1	24.9	69.7
2006	87	8274	106635	461.9	733.0	32.1	54.4
2007	88	16995	211480	474.1	846.6	35.2	52.6
2008	94	15985	207072	468.7	1036.7	44.2	49.2
2009	90	15414	200015	450.8	879.5	46.6	46.8
2010	76	14250	185267	437.4	917.1	42.8	46.7
2011	79	13615	180240	440.7	927.7	30.0	55.6
2012	75	13760	163261	455.0	911.1	44.5	47.3
2013	80	13697	155765	445.2	1138.3	49.5	46.2
2014	79	13484	152063	432.0	1134.6	43.2	45.7
2015	80	14445	160468	431.8	1151.9	48.6	45.4
2016	79	15010	165687	430.2	1393.3	48.7	44.8
2017	78	14905	167260	418.6	1395.4	38.7	49.6
2018	82	15480	176907	423.9	1053.4	43.2	48.9
2019	81	15013	171038	420.4	1128.9	53.9	41.3
2020	82	14832	166095	407.7	1098.0	48.5	42.2

The haul duration in hours per day and zone was used as a measure of effort to calculate the LPUE. The characterization of the effort in 1988-2020 using hours and kW*hours as a measure of effort is shown in Figure 1.

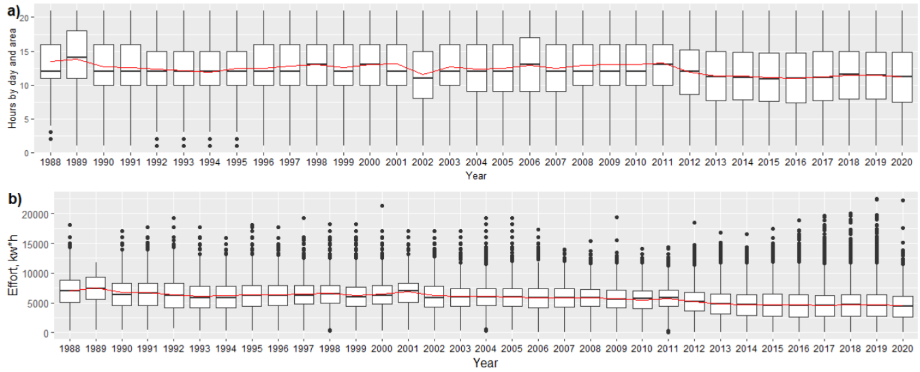

Figure 1 – Fishing effort in (a) hours and (b) kW*hour per day and area through the time series. The red line indicates the mean.

The density distribution and the time series of the positive values of LPUE (total kg/h) and log LPUE of hake are presented in Figure 2. The LPUE data shows an asymmetrical and skewed distribution to the left, but after a log transformation the data becomes less skewed and more symmetrical, therefore using a log link seems to be a reasonable procedure for modelling purposes.

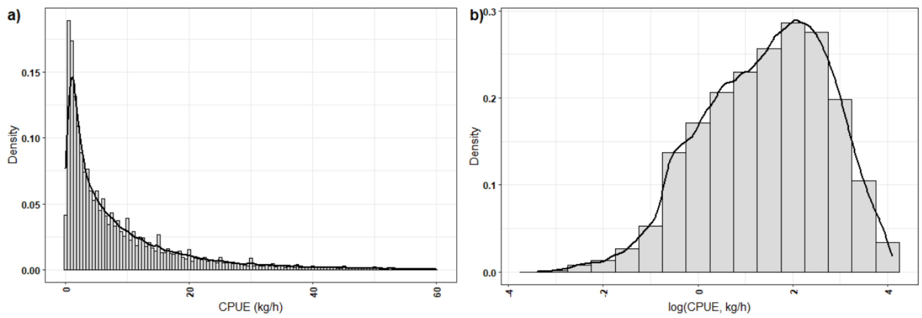

Figure 2 – Shape of the distribution of the hake positive LPUE data before (a) and after log-transformation (b)

Methods

Generalized linear models were fitted to the data, considering the hake LPUE as the response variable. Hake is caught in a mixed trawl fishery, it is not the main target of this fishery and, consequently its LPUE is a continuous variable with a discrete mass of zeros. These zeros can cause mathematical problems for fitting the models, therefore a Tweedie distribution with a log link was assumed. This distribution is part of the exponential family of distributions and is defined by a mean (μ) and a variance ($\varphi\mu^p$), where ϕ is the dispersion parameter and p is the power parameter (Dunn and Smyth, 2005). Here, we considered Tweedie distributions for the case $1<p<2$, which represents the class of Poisson mixtures of gamma distributions (Dunn and Smyth, 2005). In this case, the distribution is continuous for values greater than zero, with a positive mass at 0.

All explanatory variables were tested either as continuous variables or as factors.

All significant variables ($p<0.05$) were retained, and the deviance explained by each covariate was also analyzed. The best model was selected based on the explained deviance, the Akaike Information Criterion (AIC) and residual diagnostics. The *year* mean estimates of the standardized LPUE of hake from each model were obtained with least-squares means.

The variables considered in the analysis are shown in Table 2. Potential collinearity between the independent variables was analyzed and where appropriate, interdependence between the response and the predictor variables (e.g. proportion of hake in catch) was also explored.

As data from logbooks include the ICES rectangles, the coordinates of each rectangle centroid were used for the period 1988-2011 (paper logbooks) and the haul coordinates for the period 2012-2020 (electronic logbooks) to explore spatial covariates. No depth information was available and the ICES rectangles were too large to infer on the depth. The results of these explorations were not successful and the rectangles were aggregated in three main zones: Northwest, Southwest and South.

Table 2 - Variables tested in the LPUE standardization of Portuguese *Merluccius merluccius* (CAT – Categorical; CON – Continuous)

VARIABLE	TYPE	SUMMARY
year	CAT	1988 – 2020
zone	CAT	3 levels: n - Nortwestern area; sw- Southwestern area; s - Southern area
date of capture	CAT	1988-01-02 – 2020-12-30
LOA	CON	Vessel size: 9 – 35 m
Gross Tonnage	CON	7.9gt - 366
Engine Power	CON	44.7 – 1070 kW
	CAT	Vessel power, 3 levels:]0, 400kW];]400, 800 kW];]800, 3000kW]
Hours	CON	Records ≤ 21h
	CAT	Fishing time per day and zone, 6 levels:]0, 4h];]4, 8h];]8,12h];]12, 16h];]16, 20h];]20, 21h]
Catch	CON	0.2 – 167,277 Kg
	CAT	Total daily catch, 6 levels [log total catch classes]:]0, 5]: 0 - 150 Kg;]5, 6]: 150 - 400 Kg;]6, 7]:400 - 1000 Kg;]7, 8]: 1000 - 3000 Kg;]8, 9]: 3000 - 8000 Kg;]9, 12]: >8000 Kg
Proportion of hake in catch	CON	0 – 1
	CAT	3 levels: [0, 10%];]10, 25%];]25, 100%]
Metier	CAT	MIX - mixed species, WHB – targeting blue whiting, HOM – targeting horse mackerel, CEF – targeting cephalopods. Each métier record was assigned according to the predominance of some species.
Month of capture	CAT	Jan – Dec
cpue_kh	CON	0 – 60 kg/h

Results

For Tweedie Generalized Linear Modelling the *p-index* was estimated by maximizing the profile log-likelihood across the grid values of p in the range of $1 < p < 2$. The estimated value was $p = 1.173469$ and produced the distribution that is indicated in Figure 3a. This distribution could account for 36.1% of zeros (Figure. 3b).

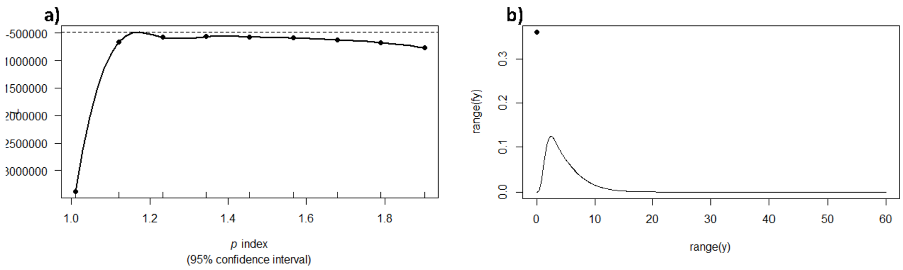

Figure 3 – (a) Value of log-likelihood function (*L*) changing the power-parameter p of the Tweedie model for LPUE standardization of hake in the Portuguese trawl fleet; (b) The point represents the mass of zeros (36.1%) explained by the Tweedie distribution and the line represents the continuous distribution for the positive values.

A summary of the tested models with total explained deviance, Akaike Information Criteria (AIC), and model formulation are shown in Table 2. The use of proportion of hake (cat_phke) as a proxy for fishing ground and target species was tested in models 1 to 3, using different combinations of month and vessel power variables. These models showed the lowest AIC value and higher explained deviance than all other models. Although the use of the proportion of hake in the catch as a discrete independent variable have reduced its dependency on the response variable, the residuals pattern indicate that the assumption of the model might not be completely met (see Annex – Figure 1). In a tradeoff between model assumptions and variability explained, models 4 and 5 with total catch and the engine power as categorical or continuous, respectively, were selected. Model 6 formulation is the same as the latter but using kW*hour as effort in the LPUE response variable (Table 3).

Table 3 - Total Explained Deviance and Akaike Information Criteria (AIC) for the proposed suite of models. Details in text.

MODEL GROUPS	MODEL NAME	MODEL FORMULA	AIC	EXP. DEV.
Models with cat_hake	Model 1	glm (cpue_kh ~ year + zone + metier + cat_phke + cat_pow, family = tweedie (var.power = p, link.power = 0))	1333825	47.8
	Model 2	update (Model 1 + month)	1329128	48.3
	Model 3	update (Model 1, cat_power replaced by power)	1311755	50.2
Models with cat_catch	Model 4	glm(cpue_kh ~ year + zone + metier + cat_catch+ cat_pow+ month, family = tweedie (var.power = p, link.power = 0))	1415069	38.8
	Model 5	update (Model 4 cat_power replaced by power)	1412174	39.1
Model with Effort kW*hour	Model 6	glm(cpue_kW*h ~ year + zone + metier + month + cat_catch, family = tweedie(var.power = p, link.power = 0))	-237845	31.4

Explained deviance for each variable, total explained deviance and Akaike Information Criteria (AIC) for the final suite of models 4, 5, 6 are presented in Table 3 and the trends of their predicted year effects (scaled for each model) are very similar, as shown on Figure 5. The proposed model 5 was chosen based on the simplicity of the model with continuous engine power variable, the lowest AIC and better residuals pattern (see Annex – Table 1).

Table 3 – Explained deviance (ED) for each variable and total Explained Deviance and Akaike Number Criteria (AIC) for the final suite of models (NC – Not Comparable)

EXPLANATORY VARIABLES	MODEL4	MODEL5	MODEL6
year	16.71	16.71	19.42
zone	3.89	3.89	2.65
metier	2.54	2.54	1.57
catch categories	14.06	14.06	7.41
month	0.27	0.28	0.32
power categories	1.29		
power		1.62	
ED	**38.8**	**39.1**	**31.4**
AIC	**1415069**	**1412174**	**-237845 (NC)**

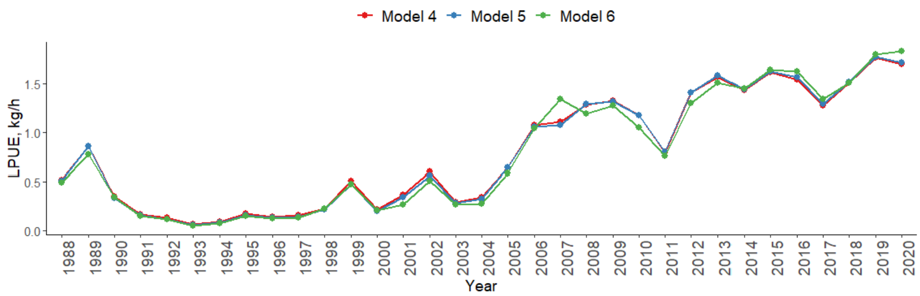

Figure 5 – Time series of Hake standardized LPUE indices from models 4, 5, and 6. For comparison purposes, each series was scaled relative to its mean.

The selected model included *year*, *zone*, *metier*, *cat_catch* and *power*, with the form:

$$GLM(LPUE_{HKE} \sim year + zone + metier + cat\ catch + power, family = tweedie(var.power = p, link.power = 0))$$

where $link.power = 0$ means a log link function. The residuals of the selected model are presented in Figure 6.

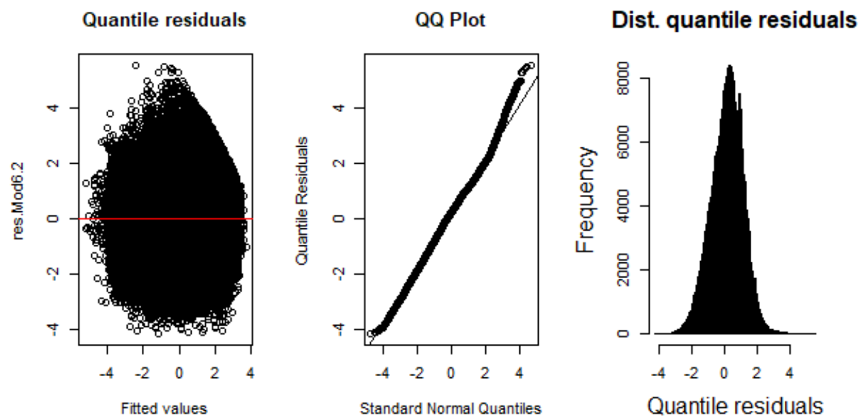

Figure 6 - Residuals of model 5 for the hake LPUE. Left: fitted vs residuals; middle: QQ plot; right: Residuals distribution plot.

For comparison purposes we show in Figure 7 the results of the two LPUE standardization models: the one agreed at WKROUND (ICES, 2010) using the predictions from a reference fleet and the least-squares means (or predicted marginal means) from model 5 and also the CPUE series from the Portuguese IBTS survey estimated with a stratified mean (Cochran, 1977) according to the survey design. The model 5 LPUE and the IBTS CPUE trends are similar and show higher correlation (Table 4).

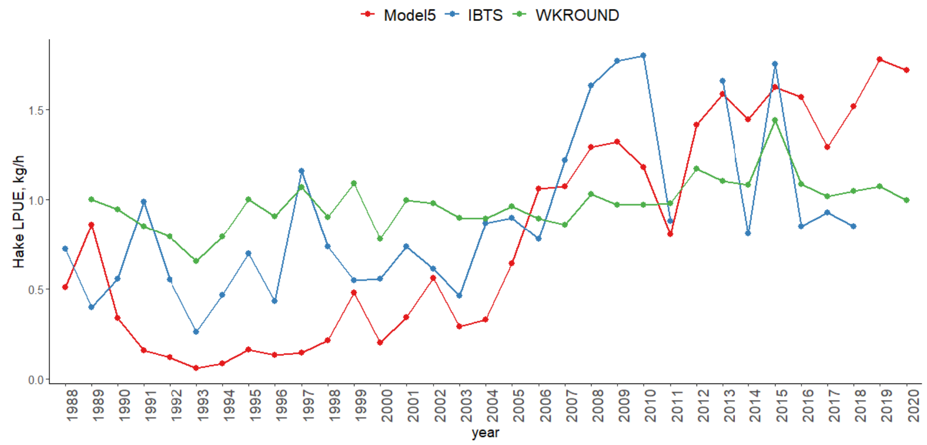

Figure 7 – LPUE standardization using the predictions from the Tweedie Generalized Linear model 5 and the model agreed in WKROUND (ICES, 2010) and the CPUE from the Portuguese IBTS survey. For comparison purposes, each series was scaled relative to its mean.

Table 4 – Correlation matrix between the predictions from the Tweedie Generalized Linear model 5, the model agreed in WKROUND (ICES, 2010) and the CPUE from the Portuguese IBTS survey. * significant at the 0.05 level.**

Discussion

This study developed a standardized hake LPUE model for the Portuguese trawl fleet using data from 1988 to 2020. The applied method for predicting the LPUE uses a discrete mass of zeros as well as continuous values for the non-zero positive component of the data, which is a common feature of commercial-catch logbook data. Data from the Portuguese trawl logbooks for the analyzed period included two different sources: paper logbooks (1988-2011) and electronic logbooks (2012-2020). Because of the different reporting format of the two sources, a revision of the data was performed and a final dataset was made available with homogeneous grouping and assemblage of both continuous and categorical variables for the full time series.

Some variables were categorized according to the previous work done by Cardador and Jardim (2010), namely the total catch, the proportion of hake in the catch, number of trawled hours per day and vessel power. This was also done in this study to investigate potential nonlinear relationships and reduce problems with large numbers of zero observations that are very common in logbook data. The use of the percentage of hake in the catch, a proxy for fishing ground and hake targeting, as a discrete rather than a continuous explanatory variable may also reduce its dependency on the response variable. Although the models using this variable showed the lowest AIC value and higher explained deviance than the final selected model (Table 2), the residuals pattern give some indications that the assumptions of the model might not be completely met.

In a tradeoff between model assumptions and explained variability, a final suite of models with métier, total catch, fishing zone and vessel power as explanatory variables were explored and showed very similar trends (Figure 7). The proposed model was chosen based on the parsimony of the model, the lowest AIC and better residuals pattern.

The correlation between the predicted LPUE year estimates using the proposed Tweedie Generalized Linear Model and the Portuguese IBTS survey CPUE showed that the models are correlated (65%, see Table 4) and both indices reflect the same abundance trend. The proposed standardized hake LPUE, respective confidence intervals and coefficient of variation (CV) of the predicted mean are presented in Table 4. The narrow confidence intervals and the small CVs reflect the very large sample size used in this study.

These estimates are considered appropriate and assumed to be proportional to abundance and therefore proposed to be included in the Iberian hake stock assessment, updating the model agreed at WKROUND (ICES, 2010) to produce a relative index of abundance based on the commercial trawl fleet operating in the Portuguese stock area.

Table 4 - Standardized hake LPUE index (Kg/h), Confidence intervals (LCL – Lower Confidence limit; UCL – Upper Confidence Limit) and Coefficient of Variation of the mean.

YEAR	LPUE	LCL	UCL	CV(%)
1988	0.73	0.67	0.79	4.10
1989	1.24	1.11	1.38	5.51
1990	0.49	0.45	0.52	3.79
1991	0.23	0.20	0.26	6.28
1992	0.17	0.16	0.20	5.87
1993	0.09	0.08	0.10	6.19
1994	0.12	0.11	0.14	5.79
1995	0.24	0.22	0.26	4.54
1996	0.19	0.17	0.21	4.98
1997	0.21	0.19	0.23	4.35
1998	0.31	0.29	0.33	3.57
1999	0.69	0.65	0.73	2.90
2000	0.29	0.27	0.31	3.46
2001	0.49	0.46	0.53	3.84
2002	0.80	0.76	0.85	3.07
2003	0.42	0.39	0.44	3.09
2004	0.48	0.45	0.51	3.02
2005	0.92	0.88	0.98	2.80
2006	1.53	1.45	1.61	2.66
2007	1.55	1.49	1.61	1.99
2008	1.86	1.79	1.93	1.90
2009	1.90	1.83	1.98	1.96
2010	1.70	1.64	1.77	2.04
2011	1.16	1.11	1.21	2.30
2012	2.04	1.96	2.12	1.97
2013	2.28	2.20	2.37	1.91
2014	2.08	2.00	2.16	1.98
2015	2.34	2.26	2.43	1.90
2016	2.26	2.18	2.34	1.87
2017	1.86	1.79	1.94	1.97
2018	2.19	2.11	2.27	1.92
2019	2.57	2.47	2.66	1.85
2020	2.48	2.39	2.57	1.89

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ANNEX

Table 1 – Model 5: Parameters estimated from Tweedie Generalized Linear Model

PARAMETER	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)
(Intercept)	-3.35E+00	5.70E-02	-58.759	<2.00E-16***
year1989	5.29E-01	6.65E-02	7.964	1.67E-15***
year1990	-4.06E-01	5.26E-02	-7.722	1.15E-14***
year1991	-1.17E+00	7.28E-02	-16.085	<2.00E-16***
year1992	-1.43E+00	6.92E-02	-20.697	<2.00E-16***
year1993	-2.11E+00	7.19E-02	-29.362	<2.00E-16***
year1994	-1.79E+00	6.85E-02	-26.178	<2.00E-16***
year1995	-1.13E+00	5.83E-02	-19.354	<2.00E-16***
year1996	-1.34E+00	6.19E-02	-21.644	<2.00E-16***
year1997	-1.24E+00	5.69E-02	-21.839	<2.00E-16***
year1998	-8.56E-01	5.11E-02	-16.74	<2.00E-16***
year1999	-6.11E-02	4.66E-02	-1.312	0.189658
year2000	-9.19E-01	5.03E-02	-18.288	<2.00E-16***
year2001	-3.94E-01	5.28E-02	-7.453	9.12E-14***
year2002	9.60E-02	4.76E-02	2.015	0.043939*
year2003	-5.63E-01	4.79E-02	-11.77	<2.00E-16***
year2004	-4.27E-01	4.73E-02	-9.039	<2.00E-16***
year2005	2.35E-01	4.61E-02	5.103	3.35E-7***
year2006	7.39E-01	4.54E-02	16.284	<2.00E-16***
year2007	7.51E-01	4.18E-02	17.983	<2.00E-16***
year2008	9.34E-01	4.15E-02	22.516	<2.00E-16***
year2009	9.57E-01	4.15E-02	23.066	<2.00E-16***
year2010	8.45E-01	4.20E-02	20.14	<2.00E-16***
year2011	4.59E-01	4.32E-02	10.62	<2.00E-16***
year2012	1.03E+00	4.17E-02	24.621	<2.00E-16***
year2013	1.14E+00	4.14E-02	27.493	<2.00E-16***
year2014	1.05E+00	4.18E-02	25.061	<2.00E-16***
year2015	1.17E+00	4.14E-02	28.165	<2.00E-16***
year2016	1.13E+00	4.13E-02	27.322	<2.00E-16***
year2017	9.35E-01	4.18E-02	22.344	<2.00E-16***
year2018	1.10E+00	4.15E-02	26.468	<2.00E-16***
year2019	1.26E+00	4.12E-02	30.501	<2.00E-16***
year2020	1.22E+00	4.13E-02	29.525	<2.00E-16***
zones	1.38E-02	1.05E-02	1.314	0.188982
zonesw	4.11E-01	8.49E-03	48.362	<2.00E-16***
metierhom	1.14E+00	3.52E-02	32.368	<2.00E-16***
metiermix	1.34E+00	3.46E-02	38.746	<2.00E-16***
metierwhb	-1.94E-01	4.62E-02	-4.208	0.0000257***
cat_catch(5,6]	7.86E-01	1.97E-02	39.829	<2.00E-16***
cat_catch(6,7]	1.62E+00	1.90E-02	85.422	<2.00E-16***
cat_catch(7,8]	2.21E+00	1.90E-02	116.315	<2.00E-16***
cat_catch(8,9]	2.31E+00	2.10E-02	110.149	<2.00E-16***
cat_catch(9,12]	2.02E+00	4.15E-02	48.819	<2.00E-16***

PARAMETER	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)
power_main	1.65E-03	2.36E-05	69.933	<2.00E-16***
monthFeb	-1.35E-02	1.88E-02	-0.72	0.471536
monthMar	7.82E-03	1.83E-02	0.427	0.669699
monthApr	7.58E-02	1.80E-02	4.208	2.58E-5***
monthMay	1.46E-01	1.76E-02	8.319	<2.00E-16***
monthJun	6.36E-02	1.80E-02	3.535	0.000408***
monthJul	6.72E-02	1.78E-02	3.782	0.000155***
monthAug	1.09E-01	1.78E-02	6.119	9.4E-10***
monthSep	2.04E-01	1.79E-02	11.427	<2.00E-16***
monthOct	1.58E-01	1.82E-02	8.684	<2.00E-16***
monthNov	-4.33E-03	1.87E-02	-0.232	0.816774
monthDec	-2.50E-01	2.08E-02	-12.029	<2.00E-16***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for Tweedie family taken to be 10.48749)
Null deviance: 3060711 on 384952 degrees of freedom
Residual deviance: 1863918 on 384898 degrees of freedom

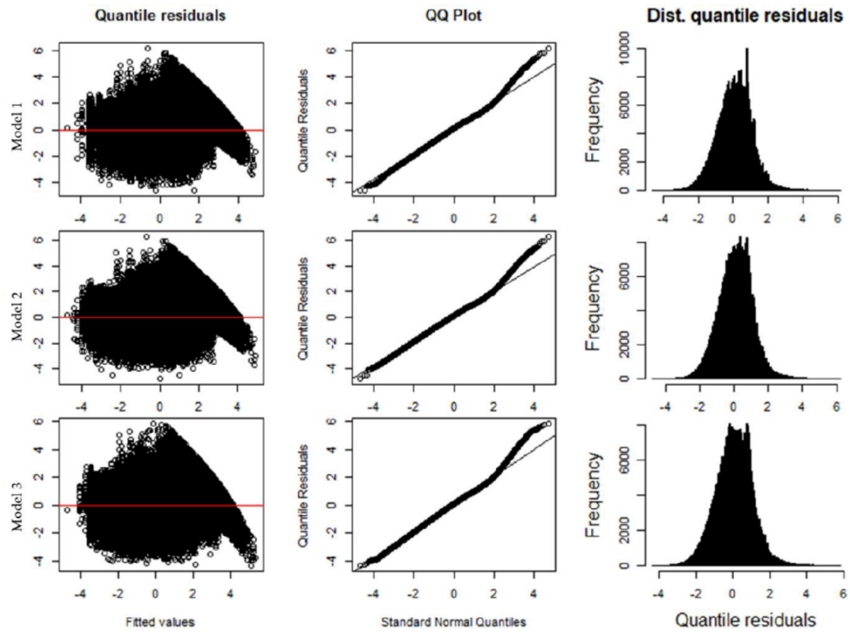

Figure 1 - Model residuals for the standardized CPUE index (kg/h) for the Portuguese trawl fishery. Left: fitted vs residuals; middle: QQ plot; right: residuals distribution plot. Top: model 1; middle: model 2; bottom: model 3.

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WD13

SPANISH CATCH AND EFFORT DATA STANDARDIZATION OF SOUTHERN EUROPEAN HAKE (*MERLUCCIUS MERLUCCIUS*)

Working Document for the benchmark

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Abstract

The southern stock of European hake (*Merluccius merluccius*) constitutes an important resource for the Spanish and Portuguese fishing fleets. The Spanish fleet fishes this species using various types of trawling techniques, gillnets, and bottom-set lines which target different components of the population. Current stock assessment includes abundance indices from surveys and from commercial trawlers for model calibration purposes. However, this commercial catch and effort data did not account for the entire diverse nature of the fleet in terms of fishing techniques potentially providing a biased index. Here, we standardize hake catch-effort data from the Spanish fleet operating in Iberian waters (8.c and 9.a) using two fishery-dependent sources: observers information for trawlers and gillnets from 2003 to 2020, and logbook data for the hook and line métier from 2009 to 2020. The standardization process was based on fitting mixed-effects models to each métier data independently assuming a Gamma distribution with a log link using the INLA approach. Results provided evidences of the importance of vessel size and haul duration for obtaining higher catches whereas fishing in deeper waters was only beneficial for the gillnets. Seasonality and spatial variability varied depending on the studied métier, and the temporal trends were roughly stable over the study period with the exception of the otter trawls that showed a slight increase. The standardized indices were combined into 2 new indices that were later used for the new stock assessment of the species.

Keywords: Catch-effort standardization, multi-gear, INLA, European hake, Northwest Iberian waters

INTRODUCTION

The southern stock of European hake (*Merluccius merluccius*) constitutes an important resource for the Spanish and Portuguese fishing fleets (Murua, 2010). The Spanish fleet targeting this species is characterized for being a multi-gear fleet operating in multiple fishing grounds along the Northwest Iberian Peninsula and the Cantabric Sea from coastal waters to deeper areas up to ~800 m. The fleet includes vessels using various types of trawling techniques, gillnets, and bottom-set lines which target different components of the population, from smaller individuals by the trawlers to larger specimens by the gillnets and hooks.

The stock assessment was carried out using GADGET until 2020, and included abundance indices from the Portuguese and Spanish surveys performed in autumn as part of the IBTS system (e.g. Izquierdo et al., 2021). Moreover, Spanish sales notes and owners associations data from trawlers compiled by IEO were further used up until 2012 for model calibration purposes (ICES 2020).

However, this commercial catch and effort data did not account for the entire diverse nature of the fleet in terms of fishing techniques potentially providing a biased index. Hence, the objective of the current analysis was to standardize hake catch-effort data from the Spanish fleet operating in Iberian waters (8.c and 9.a) using two fishery-dependent sources of data covering the whole range of gears targeting hake all along the year and spatial domain.

MATERIAL AND METHODS

Data were obtained from i) onboard observers for 3 trawl métiers (“baka”: OTB_DEF_>=55, “jurelera”: OTB_MPD_>=55, and “pareja”: PTB_MPD_>=55) and 1 gillnet métier (“volanta”: GNS_DEF_80_99) from 2003 to 2020, and from ii) logbooks for bottom-set longlines (“palangre”: LLS_DEF) from 2009 to 2020. The hook and lines included two IEO sub-métiers, the proper bottom-set longlines (LLS11) and smaller lines (PAL11), that were pooler together for the modeling purposes. These two fishery-dependent types of data are routinely compiled by the IEO as part of its mandate under the European Data Collection Framework. Depending on the source, the data for each haul or fishing trip *i* included: the catch, fishing operation information such as haul duration (HD) and depth (DE) for the observers' data and fishing time (FT) for the logbook data, the vessel characteristics such as the length overall (LOA), the date of the catch, and spatial information including coordinates for the observers' data and ICES rectangle for the logbook data. A summary of the available data is presented in Table 1.

The standardization process was based on fitting mixed-effects models to each métier data independently assuming a Gamma distribution with a log link using the INLA approach (Bakka et al., 2018).

For the observers' data the model was of the following form:

$$C_i = \alpha + Year_i + Quarter_i + LOA_i + HD_i + DE_i + u_i \quad [1]$$

Where u_i is a spatial correlated random effect which is a Gaussian Markovian Random Field (GMRF) with mean 0 and covariance matrix Σ (Bakka et al., 2018). The Matérn correlation function was used to parametrize the covariance matrix, and parameters were approximated by the stochastic partial differential equation (SPDE) method (Krainski et al., 2019) over an irregular mesh of a different number of vertices depending on the available data for each métier (Table 1). For the model depicted in equation 1, we assigned vague priors (the default in R-INLA) for all the fixed parameters due to a lack of prior information. However, for the hyperparameters defining the SPDE, that is, the range (r) and the standard deviation (σ) of the spatial random field, we used penalized complexity priors as described by Fuglstad et al. (2019), assuming that the probability of r (the distance at which spatial autocorrelation is small) was < 50 km $= 0.01$, and the probability of σ was $> 2 = 0.01$. All predictors were standardized to mean 0 and standard deviation 1.

For the logbook data the model was of the following form:

$$C_i = \alpha + Year_i + Quarter_i + LOA_i + FT_i + a_r + \epsilon_i \quad [2]$$

Where a_r is a random intercept at the ICES rectangle level assumed to follow a normal distribution with mean 0 and variance σ_a^2, and ϵ is and error term assumed to follow a normal distribution with mean 0 and variance σ^2. All predictors were standardized to mean 0 and standard deviation 1.

The resultant standardized indices were combined in one index weighting each series by the inverse of their variance after scaling the indices dividing by their mean.

All data treatment and analyses were performed with the software R (version 4.1.2, R Core Team 2021) and using the package 'R-INLA 21.11.22' (Lindegren and Rue 2015).

RESULTS

Data summary

A summary of the data available for each source and métier combination is shown in Table 1. Within the observers data, the otter trawl was the métier that counted the largest number of observed hauls whereas the gillnetters counted the smallest number of observations. For the logbook data, the hook and line métier, had considerably many more available observations. For all métiers, the percentage of zeros was very small and those cases were kept in the modeling procedure by adding a constant value equal to one. The spatial distribution for observers and logbook data is shown in Figure 1 and 2, respectively.

Observers models

Models for the trawling métiers revealed similarities and differences (Fig. 3–5). In particular, an increase in haul duration was related to larger catches, and hauls in deeper waters resulted in less yield (Fig. 3A, 4A and 5A). On the other hand, larger otter trawls and midwater trawls caught more hake, whereas larger pair trawls did not necessarily resulted in more catch (Fig. 3A, 4A and 5A). Regarding season, otter trawls had more catches in winter while that season was less important for the other two trawling métiers (Fig. 3A, 4A and 5A). The time trends did not show highly remarkable patterns with the exception of bottom trawlers for which catches slightly increased over the study period (Fig. 3B, 4B and 5B). Once accounted for the fixed effects, the random spatial fields showed overall differences with "hotspots" for the otter trawl and the midwater trawl located in the Galician coast, while larger catches for the pair trawls occurred to the east of the Cantabric Sea (Fig. 3C, 4C and 5C).

The model for the gillnets showed that hake catch increased with vessel length and haul depth; however, longer hauls did not result in a higher yield (Fig. 6A). Catches for this métier decreased from winter to autumn (Fig. 6A), were roughly stable since 2009 (Fig. 6B), and the random spatial field showed larger catches in the northern part of the Galician coast (Fig. 6C). Nonetheless, all results for this métier should be treated with caution given the small number of observations and particularly in the Galician Atlantic coast.

Logbook models

The model for the hook and line métiers showed that hake catch increased with vessel length and duration of the fishing operations (Fig. 7C). Catches for this métier were larger in spring and significantly lower in summer and autumn (Fig. 7C), and were roughly stable during the study period (Fig. 7B). The random intercept showed that larger catches for this métier occurred in more oceanic waters to the east of the Cantabric Sea and off the Finisterre zone, whereas minimal catch were located to the south of the Galician coast and in shallower waters to the east of the Cantabric Sea (Fig. 7A).

Combination of indices

The combined indices resulted in two trends, presented in Fig 8.

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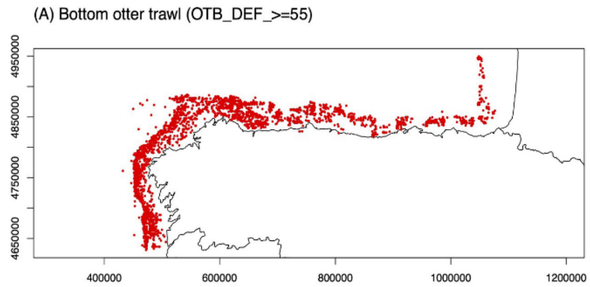
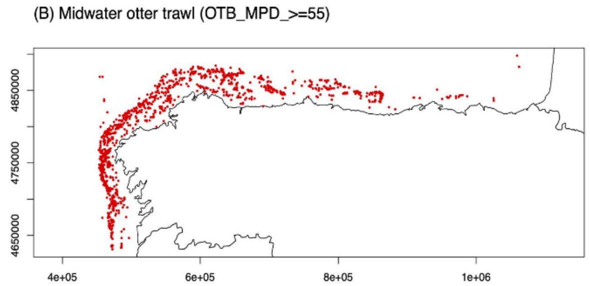
TABLES

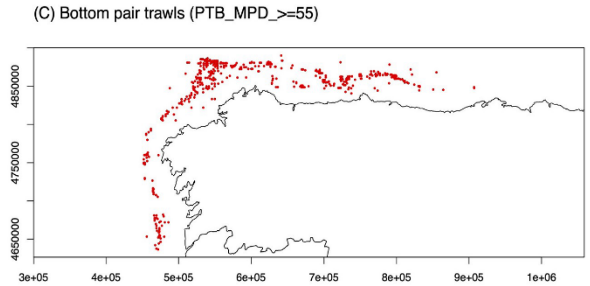
Table 1. Summary of available data for each data type and métier combination.

Source	Métier	Years	Hauls/trips/ operations	Unique vessels	Unique days	Zeros (%)	Mesh vertices
Observers	OTB_DEF	2003–2020	3109	69	975	4.78	1049
Observers	OTB_MPD	2003–2020	1173	50	496	6.90	977
Observers	PTB_MPD	2003–2020	513	43	455	3.51	595
Observers	GNS_DEF	2008–2020	352	20	134	1.40	601
Logbooks	LLS_DEF	2009–2020	43594	363	3499	1.74	NA

FIGURES


(A) Bottom otter trawl (OTB_DEF_>=55)
4950000
4850000
4750000
4650000
400000
600000
800000
1000000
1200000


(B) Midwater otter trawl (OTB_MPD_>=55)
4850000
4750000
4650000
4e+05
6e+05
8e+05
1e+06


(C) Bottom pair trawls (PTB_MPD_>=55)
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3e+05
4e+05
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7e+05
8e+05
9e+05
1e+06

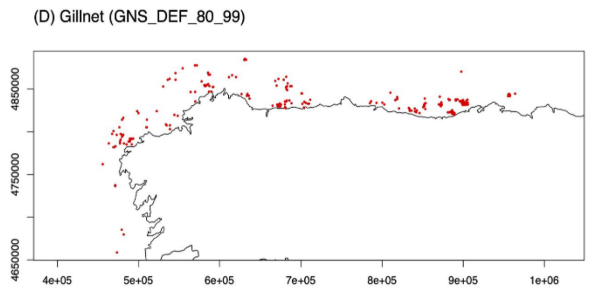

Figure 1. Location of observers' data for the three trawling métiers (A−C) and the gillnet (D).

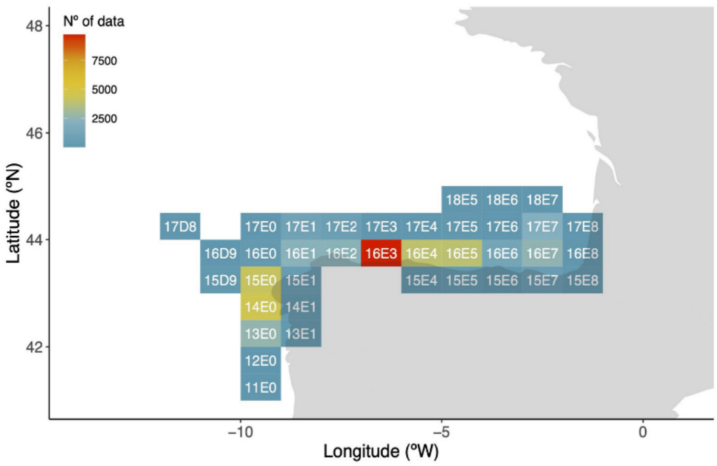

Figure 2. Distribution of logbook data in each ICES rectangle for the hook and line métier (LLS_DEF). The alphanumerical code of each ICES rectangle is indicated in white color.

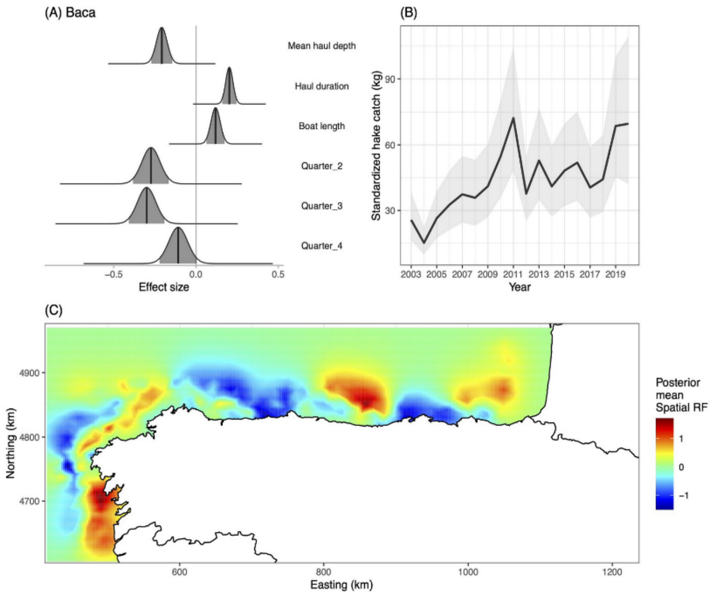

Figure 3. Results of the model fitted to the bottom otter trawl (OTB_DEF_>=55) observers data. (A) Posterior distribution of the fixed effects, (B) temporal trend in standardized catches, and (C) posterior distribution of the mean spatial random field. Note that predictions for the trend were computed for Quarter 1 and mean values for the continuous predictors.

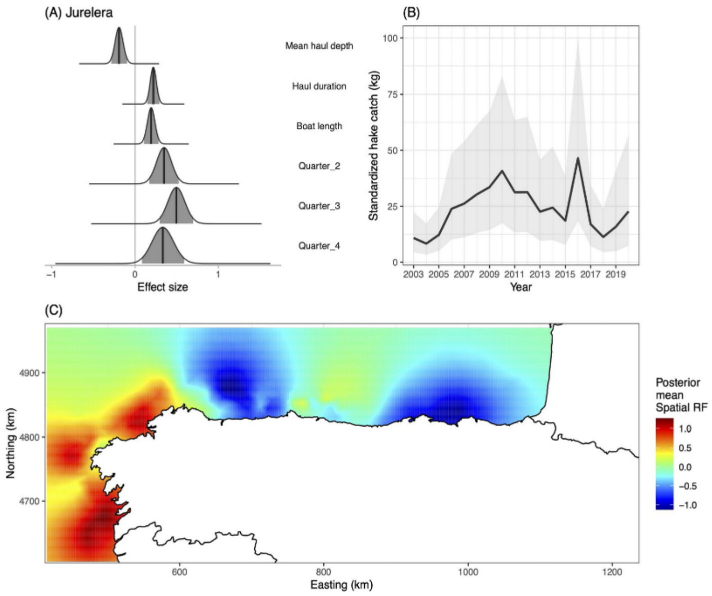

Figure 4. Results of the model fitted to the midwater otter trawl (OTB_MPD_>=55) observers data. (A) Posterior distribution of the fixed effects, (B) temporal trend in standardized catches, and (C) posterior distribution of the mean spatial random field. Note that predictions for the trend were computed for Quarter 1 and mean values for the continuous predictors.

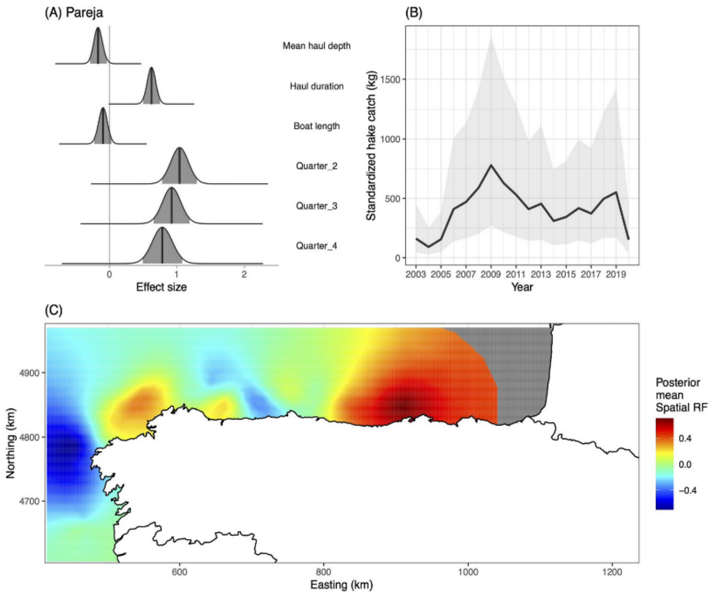

Figure 5. Results of the model fitted to the bottom pair trawls (PTB_MPD_>=55) observers data. (A) Posterior distribution of the fixed effects, (B) temporal trend in standardized catches, and (C) posterior distribution of the mean spatial random field. Note that predictions for the trend were computed for Quarter 1 and mean values for the continuous predictors.

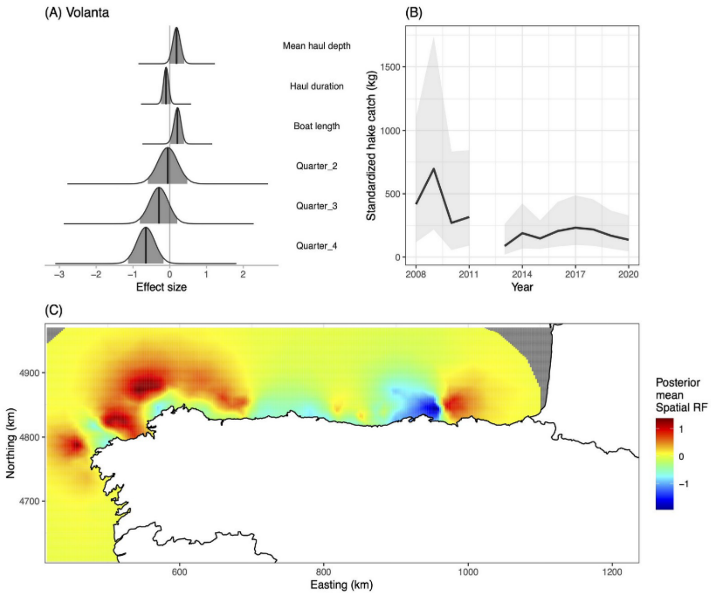

Figure 6. Results of the model fitted to the gillnetters (GNS_DEF_80_99) observers data. (A) Posterior distribution of the fixed effects, (B) temporal trend in standardized catches, and (C) posterior distribution of the mean spatial random field. Note that predictions for the trend were computed for Quarter 1 and mean values for the continuous predictors.

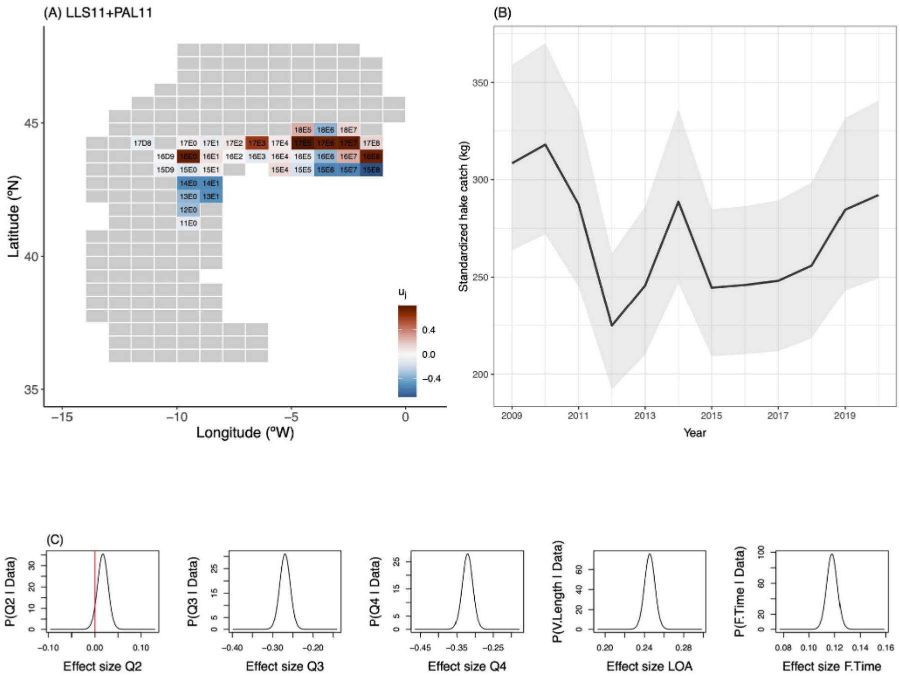

Figure 7. Results of the model fitted to the bottom-set longlines logbook data. (A) Spatial distribution of the ICES rectangle-level random effect, (B) temporal trend in standardized catches, and (C) posterior distribution of the fixed effects. The alphanumerical code of each ICES rectangle is indicated in black color. Note that predictions for the trend were computed for Quarter 1 and mean values for the continuous predictors.

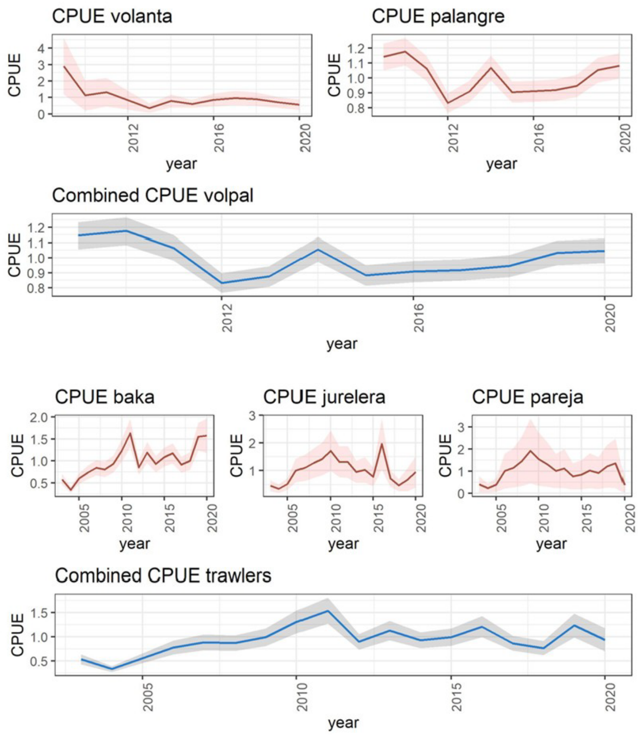

Figure 8. Combined indices for Volanta (gillneter) and Palangre (Longliners) and 3 different trawlers in one.

Annex 4: Updated stock annexes

ICES. 2022. Stock Annex: Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay). ICES Stock Annexes. 37 pp. https://doi.org/10.17895/ices.pub.21623226

NEW EDITION OF: https://doi.org/10.17895/ices.pub.18622544

ICES. 2022. Stock Annex: Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters). ICES Stock Annexes. 13 pp. https://doi.org/10.17895/ices.pub.21623340

NEW EDITION OF: https://doi.org/10.17895/ices.pub.18622547

ICES. 2022. Stock Annex: Black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay). ICES Stock Annexes. 13 pp. https://doi.org/10.17895/ices.pub.21623154

NEW EDITION OF: https://doi.org/10.17895/ices.pub.18622010

ICES. 2022. Stock Annex: White anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay). ICES Stock Annexes. 17 pp. https://doi.org/10.17895/ices.pub.21623349

NEW EDITION OF: https://doi.org/10.17895/ices.pub.18621971

Stock Annex: Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Northern stock of hake (hke.27.3a46-8abd)
Working Group	Working Group for the Bay of Biscay and the Iberic waters Ecoregion (WGBIE)
Last updated	May 2022
Revised by	WKANGHAKE (2022); Dorleta Garcia and Sonia Sanchez-Maroño

A. General

A.1. Stock definition

European hake (*Merluccius merluccius*) is widely distributed over the Northeast Atlantic shelf, from Norway to Mauritania, with a larger density from the British Islands to the south of Spain (Casey and Pereiro, 1995) and in the Mediterranean and Black sea. In the last decade the population has expanded into the North Sea (Staby *et al.*, 2018), it is not clear, however, if the expansion has been motivated by environmental change (i.e. climate change or a decrease in the abundance of gadoids) or by the huge increase in the biomass of the population (Staby *et al.*, 2018; Gullestad *et al.*, 2020). Although, previous genetic studies (Plá and Roldán, 1994; Roldán *et al.*, 1998), show no evidence of multiple populations in the Northeast Atlantic, a most recent study (Leone *et al.*, 2019) indicates that the population in the Norwegian sea is genetically different from that in the Bay of Biscay. However, ICES assumes since the end of the 1970s two different stock units: the so-called Northern stock, in Division 3.a, subareas 4, 6 and 7 and divisions 8.a, 8.b, and 8.d and the Southern stock in divisions 8.c and 9.a, along the Spanish and Portuguese coasts. The main argument for this choice was that the Cap Breton canyon (close to the border between the Southern part of Division 8.b and the more Eastern part of Division 8.c, i.e. approximately between the French and Spanish borders) could be considered as a geographical boundary limiting exchanges between the two populations.

Hake spawn from February through to July along the shelf edge, the main areas extending from the north of the Bay of Biscay to the south and west of Ireland (Figure 1). The main spawning season in the North Sea is shorter and happens later in the year, from July and September (Staby *et al.*, 2018). After a pelagic life, 0-group hakes reach the bottom in depths of more than 200 m, then move to shallower water with a muddy seabed (75–120 m) by September. There are two major nursery areas: in the Bay of Biscay and off the coast of southern Ireland.

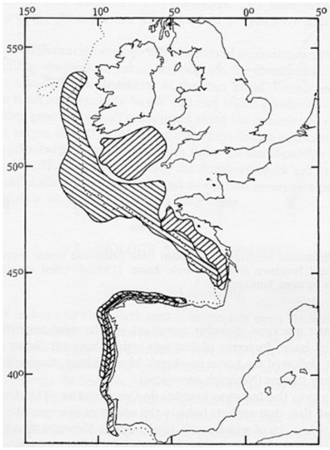

Figure 1. Main spawning and nursery areas. Spawning areas sloping downwards from left to right; Nursery areas sloping downwards from right to left. (from Casey and Pereiro, 1995).

A.2. Fishery

A set of different Fishery Units (FU) has been defined by the ICES Working Group on Fisheries Units in subareas 7 and 8 in 1985, in order to study the fishing activity related to demersal species (ICES, 1991a). To take into account the hake catches from other areas, a new Fishery Unit was introduced at the beginning of the nineties (FU 16: Outsiders). This Fishery Unit was created on the basis of a combination between mixed areas and mixed gears (trawl, seine, longline, and gillnet). The current FUs are defined as follows:

Fishery Unit	Description	Subarea
FU1	Longline in medium to deep water	7
FU2	Longline in shallow water	7
FU3	Gillnets	7
FU4	Non-*Nephrops* trawling in medium to deep water	7
FU5	Non-*Nephrops* trawling in shallow water	7
FU6	Beam trawling in shallow water	7
FU8	*Nephrops* trawling in medium to deep water	7
FU9	*Nephrops* trawling in shallow to medium water	8
FU10	Trawling in shallow to medium water	8
FU12	Longline in medium to deep water	8
FU13	Gillnets in shallow to medium water	8
FU14	Trawling in medium to deep water	8
FU15	Miscellaneous	7 and 8
FU16	Outsiders	3a, 4, 5 and 6

Fishery Unit	Description	Subarea
FU00	French unknown	

The main part of the fishery is currently conducted in six Fishery Units, three of them from Subarea 7: FU 4, FU 1 and FU 3, two from Subarea 8: FU 13 and FU 14 and one in subareas 3.a, 4, 5 and 6: FU16.

From the information reported to the Working Group, France accounted in recent years for the main part of the landings (around 42%) followed by Spain (around 30%), before the proportions were just the opposite. The rest of the catch is divided as follows: UK (14%), Ireland (5%), Denmark (4%), Norway (4%), and Germany, Netherlands, Belgium, and Sweden contributing with less than 1% to the total catch in average.

The minimum landing size for fish caught in subareas 4, 6, 7 and 8 is set at 27 cm total length (30 cm in Division 3.a).

From 14 June 2001, an Emergency Plan was implemented by the Commission for the recovery of the Northern hake stock (Council Regulations N°1162/2001, 2602/2001 and 494/2002). In addition to a TAC reduction, 2 technical measures were implemented:

- A 100 mm minimum mesh size has been implemented for otter trawlers when hake comprises more than 20% of the total weight of marine organisms retained on board. This measure did not apply to vessels less than 12 m in length and which return to port within 24 hours of their most recent departure.
- Two areas have been defined, one in Subarea 7 and the other in Subarea 8, where a 100 mm minimum mesh size is required for all otter trawlers, whatever the amount of hake caught.

Council Regulation (EC) No. 1954/2003 established measures for the management of fishing effort in a biologically sensitive area in subareas 7.b, 7.j, 7.g, and 7.h. Effort exerted within the biologically sensitive area by the vessels of each EU Member State may not exceed their average annual effort (calculated over the period 1998–2002).

There are explicit management objectives for this stock under the EC Reg. No 811/2004 implementing measures for the recovery of the northern hake stock. It is aiming at increasing the quantities of mature biomass to values equal to or greater than 140 000 t. This is to be achieved by limiting fishing mortality to 0.25 and by allowing a maximum change in TAC between years of 15%.

According to ICES in 2007, the northern hake stock met the SSB target in the recovery plan of 140 000 t for two consecutive years (2006 and 2007). Article 3 of the recovery plan indicates that, in such a situation, a management plan should be implemented.

An annual one-month fishing activity stop has been implemented by the Spanish administration since 2004. In 2008, a specific national regulation established a 90-days stop to be distributed from August 2008 to December 2009.

In Subarea 8, for 2006, 2007 and 2008, otter trawlers using a square mesh panel are allowed to use 70 mm mesh size in the area, mentioned above, where 100 mm minimum mesh size is required for all otter trawlers. (EC Reg. No. 51/2006; EC Reg. 41/2007).

Furthermore, there was a ban on gillnets in divisions 6.a, 6.b and 7.b, 7.c,7.j, 7.k fishing at more than 200 m of depth (EC Reg. No 51/2006) during the first semester of 2006.

Since 2019, there is an agreed multi-annual management plan for mixed fisheries implemented in EU waters (Regulation (EU) 2019/472). Hake is included in this plan which, among other things, it establishes an upper and lower limit to fishing mortality around the fishing mortality at maximum sustainable yield target (F_{MSY}). The upper and lower limits (F_{upp} and F_{low}) are defined in such a way that the catch produced in the long term is not lower than 95% of maximum sustainable yield catch.

A.3. Ecosystem aspects

Although a comprehensive study on the role of hake in its ecosystem has not yet been carried out, some partial studies are available. Hake belongs to a very extended and diverse community of commercial species including megrim, anglerfish, *Nephrops*, sole, sea bass, ling, blue ling, greater forkbeard, tusk, whiting, blue whiting, *Trachurus* spp, conger, pout, cephalopods (octopus, *Loligidae*, *Ommastrephidae* and cuttlefish), and rays. The relative importance of these species in the hake fishery varies largely in relation to the different gears, sea areas, and countries involved.

Hake is preyed upon by sharks and other fish. Cannibalism on juveniles by adults is also quoted. Adults feed on fish (mainly on blue whiting and other gadoids, sardine, anchovy, and other small pelagic fish); juvenile hake prey mainly upon planktonic crustaceans (above all euphausids, copepods, and amphipods).

Ecological factors or environmental conditions impacting hake population dynamics are not taken into account at present in the assessment or the management. However, synchronous changes have been observed in hake recruitment success and several global, regional and local parameters, which suggest that environmental conditions may be influential for hake (Goikoetxea and Irigoien, 2013). An ecological regime shift occurred in the Northeast Atlantic shelf system in 1988/89, which was detected at a global scale (NAO, Gulf Stream and northern hemisphere temperature anomaly), as well as regionally (climatology of the Northeast Atlantic and copepod variability in the Celtic Sea). The region went from a period of cool temperatures and relatively weak winds (1978–1989) to a period of warmer temperatures and stronger westerly winds (1990–2006). Given the synchronous stepwise increase in hake recruitment success, it was concluded that the environment shifted to a regime that was favourable for northern hake. Early life stages of hake were found to benefit from a warming trend (either through the widening of the optimal environmental window or/and higher growth rates). In addition, coastward transport avoided vulnerable stages from their dispersion to oceanic areas and helped in their transport from spawning areas to nursery grounds (Goikoetxea, 2011). Other previous studies also highlighted the influence of environmental parameters such as water temperature and wind-driven transport on northern hake stock (Fernandes *et al.*, 2010; Álvarez *et al.*, 2001).

B. Data

In 2013, a data call was run by ICES in order to obtain more precise data on discards since 2003. Discard and landing data were uploaded into Intercatch by most of the countries that exploit the stock. The dissagregation level varied by country and year, from season, métier and length dissagregation level to total landings or discards by year.

B.1. Commercial catch

B.1.1. Landings

Until 2010, the Spanish landings data were based on sales notes and Owners Associations records compiled by the National laboratories (IEO and AZTI). From 2011, the Spanish data are derived from official statistics provided by the Spanish Fishery Administration derived from logbook and sale notes. French landings data are based on logbook and auction hall sales.

From 1978 to 1989, landings in weight are available by year, gear (trawl, gillnets and longline), country (UK, France and Spain) and ICES divisions (Division 4.a, Subarea 6, Division 7, and divisions 8.a and 8.b). From 1990 to the present, for most of the years, landings in weight by FUs and countries are available on a quarterly basis. In 1992, only data from Spain is available by FU and on a quarterly basis (Table 1).

Table 1. Landings-in-weight (and their level of aggregation) available to the Working Group.

	1978 to 1989	1990–1991	1992	1993 to Present
By Gear, Country and ICES divisions	X			
By FU		X	X	X
By year	X		X	
By quarter		X	X*	X

*** For Spain only**

From 1978 to 1989, length–frequency distributions are available by year, gear, country and ICES divisions. From 1990 to the present, length compositions of the landings are not available for all Fishery Units, quarters and countries. Only the main FUs/Countries are sampled. Table 2 presents, as an example, the length distributions available for 2019.

Table 2. Length–frequency distributions provided to the Working Group in 2019.

FU	France	Ireland	Spain	UK(EW)	Scotland	Denmark
01			Quarterly			
03	Quarterly		Quarterly	Quarterly		
04			Quarterly	Quarterly		
05	Quarterly			Quarterly		
06				Quarterly		
09	Quarterly					
10	Quarterly					
12	Quarterly		Quarterly			
13	Quarterly		Quarterly			

6

FU	France	Ireland	Spain	UK(EW)	Scotland	Denmark
14			Quarterly			
15		Quarterly				
16			Quarterly		Quarterly/ Yearly	Yearly

In 2014, the length frequency distribution, from 2003 to 2012, of the landings outside areas 6 and 7 (the landings of OTHERS fleet in Stock Synthesis) was recalculated using the data in Intercatch. The allocation schemes to disaggregate unsampled data (data without length information) in InterCatch were defined by year taking into account the area, season, and gear.

In Stock Synthesis (SS) it is not needed to allocate a length frequency distribution to all the landing and discard data. The model uses the available data in each fleet segment and assigns it to the whole landing and discard data automatically. In this case, as the fleets are disaggregated by gear and season the disaggregation level is considered detailed enough for all the fleets except the TRAWLOTH fleet. In this fleet, there are trawlers that target demersal species and trawlers that target crustaceans and both have different selection pattern. Hence, to weight the length frequencies coming from the two segments properly first the allocations are done for each of the segments and them the overall length frequency distribution is calculated as the sum of the length frequency distributions coming from the two segments.

B.1.2. Discards

Until 2002, the only discards series available and used by the WG were those of the French artisanal and coastal trawl fisheries in the Bay of Biscay, estimated on the basis of the length compositions obtained during FR-RESSGASC surveys. The RESSGASC survey used for their estimation ended in 2002.

EU countries are now required under the EU Data Collection regulation to collect data on discards.

A new sampling programme of discards in the French *Nephrops* trawlers fishery of the Bay of Biscay started in June 2002. Estimates obtained by this programme (see Table 3 below) were significantly different (by a factor 2 to 10) from previous estimates for that fishery (estimates are from 532 t in 2006 to 1597 t in 2005). Such discrepancies could be explained by changes in the sampling, changes in the discarding practices, variations in the abundance of small fish or by a combination of the three. The CVs associated with these estimates are around 20%. A huge number of discards (~1000 t) was estimated for French Gillnetters since 2012. The discards estimates on this fleet were negligible in previous years.

Discards are available for Danish trawlers, seiners and gillnetters fishing in Subarea 4 from 1995 to 2021 and for gillnetters in subareas 7 and 8 since 2012. Their values are quite variable from year to year from 100 to more than 1000 t.

Additional information on discards was available for the Irish otter trawlers fishery in subareas 6 and 7 from 1999 to 2001, for 2004 and 2005 and for 2009 to 2021 (values from 32 to 700 t, between 2006 and 2008 the discards were not raised because they were not available at the requested métier level). UK-EW discards were only available from 2000 to 2021 (raised only to the trip level).

7

Estimates of discards for the Spanish trawl fleets operating in the ICES Subarea 7 and divisions 8.a, 8.b, and 8.d are available for 1988, 1989, 1994, from 1999 to 2001 and from 2003 to 2021. In Subarea 7, a significant increase in the estimated discards rate was observed from 2010 to 2018 when compared with previous years. Discards were estimated to vary from very small amounts to more than 1000 t in 2003–2005 and over 5000 t since 2010. CVs were highly variable from 20% to more than 100%. Fixed gears were also sampled in order to design the Spanish Discards Sampling Programme, but no relevant discards were observed (Pérez *et al*., 1996).

During the 2003 assessment, the Working Group noted that, although some improvement in discard data availability had been observed (number of fleets sampled and area coverage), sampling does not cover all fleets contributing to hake catches and discard rates of several fleets are simply not known. Furthermore, when data are available, it was not possible to incorporate them into the assessment in a consistent way. As reconstructing a historical series was found problematic, discard estimates were removed from the full time-series of catch data. From 2003 to 2008, the assessment was thus conducted on landings only. After the 2008 Working Group assessment, discards estimates from several sampled fleets were used in the assessment. This includes the French *Nephrops* trawl in 8abd discards data from 2003 to present, the Spanish trawl in 7 in 1994, 1999, 2000, 2003 to present and the Spanish trawl in 8abd from 2005 to present. Since 2010 the stock is assessed using SS and discard data is partly included into the model.

During the last benchmark ICES (2022) the discards data since 2014 are raised externally before being introduced in SS. SS estimates discards, but as the observed discards are considered an overestimation of the real ones, the model estimates will be an overestimation. To correct this bias, to some extent, a procedure developed by Ireland scientist form Marine Institute (MI) was applied. This procedure identifies the strata without discard observations and assigns them a discard rate based on segments with available data considering the year, gear, country and season. The observed and estimated discards, the ratio between discards and catch and the raising multiplier since 2014 by fleet (as used in SS) are presented in Table 3.

Table 3. Summary of the discard data available since 2014.

SS Fleet	Indicador	2014	2015	2016	2017	2018	2019	2020	2021
FRNEP8	Observed	391	1134	2310	1819	889	816	1193	144
FRNEP8	Estimated	395	1194	2324	2200	995	1004	1440	662
FRNEP8	Ratio Disc/Catch	0.20	0.50	0.70	0.66	0.49	0.47	0.57	0.48
FRNEP8	Raising multiplier	1.01	1.05	1.01	1.21	1.12	1.23	1.21	4.58
GILLNET	Observed	55	857	1175	728	1014	333	444	626
GILLNET	Estimated	86	2780	1993	1320	1726	728	1028	1721
GILLNET	Ratio Disc/Catch	0.00	0.14	0.07	0.05	0.06	0.03	0.04	0.07
GILLNET	Raising multiplier	1.56	3.24	1.70	1.81	1.70	2.19	2.31	2.75
NS-TRAWL	Observed	4838	4158	4687	2680	1943	1817	948	1478
NS-TRAWL	Estimated	8375	7127	8057	4346	3677	2821	2143	2670
NS-TRAWL	Ratio Disc/Catch	0.24	0.23	0.20	0.12	0.13	0.11	0.10	0.15
NS-TRAWL	Raising multiplier	1.73	1.71	1.72	1.62	1.89	1.55	2.26	1.81
SPTRAWL7	Observed	1467	2064	616	651	903	318	157	87
SPTRAWL7	Estimated	1493	2065	1438	1316	1632	845	948	222
SPTRAWL7	Ratio Disc/Catch	0.43	0.51	0.41	0.43	0.47	0.31	0.29	0.11
SPTRAWL7	Raising multiplier	1.02	1.00	2.33	2.02	1.81	2.66	6.05	2.56
SPTRAWL8	Observed	183	589	656	906	347	586	310	153
SPTRAWL8	Estimated	230	611	656	910	416	586	350	155
SPTRAWL8	Ratio Disc/Catch	0.08	0.12	0.15	0.16	0.11	0.17	0.11	0.07
SPTRAWL8	Raising multiplier	1.26	1.04	1.00	1.00	1.20	1.00	1.13	1.02
TRAWLOTH	Observed	2591	1565	1669	1013	1937	1070	205	596
TRAWLOTH	Estimated	3301	2035	2220	1496	3196	1905	1230	2118
TRAWLOTH	Ratio Disc/Catch	0.28	0.17	0.16	0.12	0.30	0.24	0.20	0.29
TRAWLOTH	Raising multiplier	1.27	1.30	1.33	1.48	1.65	1.78	5.99	3.55
Total	Observed	9525	10367	11113	7797	7034	4940	3257	3084
Total	Estimated	13881	15812	16689	11588	11642	7889	7140	7548
Total	Ratio Disc/Catch	0.15	0.17	0.16	0.11	0.14	0.10	0.10	0.11
Total	Raising multiplier	1.46	1.53	1.50	1.49	1.65	1.60	2.19	2.45

B.2. Biological

Most of the biological parameters were borrowed from a Mediterranean hake stock and the southern stock. Initially, these values were used to focus on the structural part of the model, with the idea of updating later. However, the time available did not allow to update the biological component. It is expected to have an inter benchmark to update the biological component in the coming years. The values used are listed in Table 4.

Table 4. Biological parameters that are fixed in the fit of the assessment model.

Process	Parameter	Sex	Value	Source
Growth	Linf	F	120 cm	
	Linf	M	80 cm	
	k	F	0.165	
	k	M	0.23	
Maturity	a	F	42.85 cm	(ICES, 2010b WD8).
	b	F	-0.2	
Weight	a	F and M	3.77E-06	
	b	F and M	3.168	
Natural mortality	age 0	F	1.19	Adriatic and Sicilian European hake (FAO (2019a,b))
	age 0	M	1.19	
	age 1–4	F	0.64	
	age 1–4	M	0.64	
	age 5–14	F	0.34	
	age 5–14	M	0.415	
	age 15+	F	0.2	
	age 15+	M	0.279	

Conventional tagging of European hake (de Pontual *et al*., 2003) opened new avenues for a better understanding of the species biology and population dynamic which have remained controversial for decades (see e.g. Belloc, 1935; Hickling, 1933). The first tagging results provided evidence of substantial growth underestimation (by a factor ~2) due to age overestimation, (de Pontual *et al*., 2006), thus challenging the internationally agreed age estimation method. More tagging efforts, both off the Northwest Iberian Peninsula (Piñeiro *et al*., 2007) and the Mediterranean Sea (Mellon-Duval *et al*., 2010), proved that growth underestimation was not a regional issue. More recent recaptures of tagged fishes have confirmed the growth estimated previously (de Pontual *et al*., 2013). An ICES workshop (ICES, 2010a) confirmed that the previous internationally agreed ageing method is neither accurate nor precise and provides overestimation of age. A replacement ageing method with sufficient precision and accuracy is currently not available. Thus, in the benchmark assessment in 2010 (ICES, 2010b) the working group started to evaluate the stock using a length based assessment model.

B.3. Surveys

Several research-vessel surveys cover part of the geographical distribution of the Northern hake stock (Figure 2).

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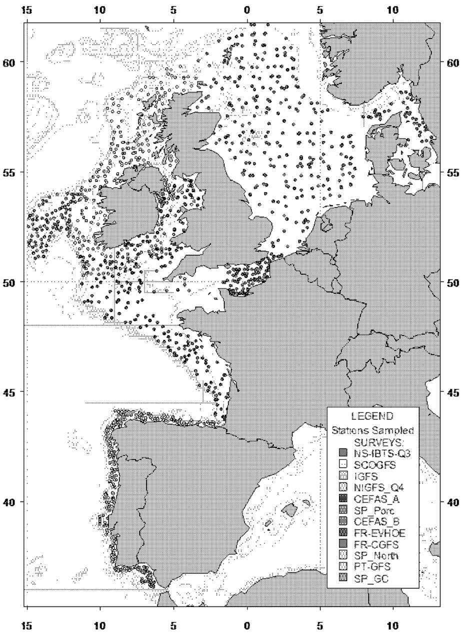

Figure 2. Map of East Atlantic groundfish surveys: stratification and trawling positions. FR-EVHOE correspond to EVHOE-WIBTS-Q4, SP Porc corresponds to SPPGFS-WIBTS-Q4 and IGFS corresponds to IGFS-WIBTS-Q4.

Abundance indices used in the SS assessment:

French Evhoe groundfish survey (EVHOE-WIBTS-Q4): years 1997–2016 and 2018-present. The survey occurs in autumn. The survey uses a GOV trawl with a 20 mm codend liner. It covers the shelf of both the Bay of Biscay and the Celtic Sea. In 2017 there was a technical problem in the survey and it was not possible to provide the abundance index for the stock.

French Ressgasc groundfish survey (RESSGASC): years 1978 to 2002. Over the years 1978–1997 the RESSGASC surveys were conducted with quarterly periodicity. They were conducted twice a year after that (in spring and autumn). Survey data prior to 1987 have been excluded, because there was a change of vessel at that time. Weather conditions encountered by RESSGASC in 2002 gives to this index a poor reliability and it was decided not to use it. The survey uses a 25 m "Vendéen type" bottom trawl. It covers the Bay of Biscay. The survey ended in 2002.

Spanish Porcupine groundfish survey (SPPGFS-WIBTS-Q4): years 2001 to present. The area covered by this survey is the Porcupine bank extending from longitude 12° W to 15° W and from latitude 51° N to 54° N, covering depths between 180 and 800 m. The cruises are carried out every year in September on board RV "Vizconde de Eza", a stern trawler of 53 m and 1800 Kw. Numbers-at-age for this abundance index are estimated from otoliths collected during the survey.

Irish Groundfish Surveys (IGFS-WIBTS-Q4): years 2003 to present. This survey is conducted on board the *R.V. Celtic Explorer* in autumn in the west of Ireland and the Celtic sea. The survey uses GOV 36/47 (Grande Ouverture Verticale).

Irish Anglerfish and Megrim Survey (IAMS): year 2016 to present. This survey takes place in the 1st quarter each year since 2016 on the *R.V. Celtic Explorer* in the west of Ireland and Scotland. The main objective of the survey is to obtain biomass estimates for anglerfish and establish an abundance index for megrim in areas 6a (south of 58°N) and 7 (west of 8°W). However, it is also considered a good abundance index for hake and provides information on the sex-ratio.

B.4. Commercial CPUE

Commercial CPUEs indices provided to the ICES Working Group are not used in the current SS assessment. Landings-per-unit-effort time-series are available from the following fleets:

- The A Coruña trawler fleet, targeting mainly hake, operates in deeper waters close to the slope in divisions 7b-c, j–k, while the trawler fleet from Vigo, targeting megrim, works in shallower waters in Division 7j–h and catch hake as bycatch.

C. Assessment: data and method

Model currently used: Stock Synthesis (SS), (Methot and Wetzel, 2013).

Software used: Stock Synthesis V3.30 Richard Methot, NOAA Fisheries Seattle, WA.

Recent assessments and sensitivity analysis carried out.

An attempt to use a non-equilibrium surplus production model (ASPIC) was carried out in the 2004 WG (ICES, 2005) and preliminary fits of a length based stock assessment model have been presented in 2007 and 2008.

In the 1998 WG it was found that the SSB estimates for 1985–1987 were very sensitive to the q plateau options between age 5, 6, and 7 (which is the last true age). To reduce this effect, it was decided to extend the ten years window to a twelve-year period in order to tune to the longest available and well behaved fleet dataseries. In the 1999 and 2000 assessments, SSB estimates for 1985–1987 were still sensitive to the extent of the tuning period, and the longest (13 years and 14 years respectively) provided the best pattern for these years, whereas other estimates were very similar for other years. In 2001 assessment, it was decided to use the whole tuning data available and a taper time weighting to reduce the influence of the older years. At that time, this choice did not change radically the estimates of trends in F and SSB and those settings were maintained in 2002 to 2003 assessments.

In 2004, the group investigated again the influence of the taper time weighting and runs were conducted without taper and compared with the base-case run using a tri-cubic taper over a 20 year period. While the group agreed on the rationale behind the use of a taper to down-weight the years for which we may have less confidence, it expressed concerns over the large influence the use of this option has on the perception of the stock dynamics and the inability of the model to account, in a satisfactory manner, for uncertainty in the data.

Due to uncertainties in hake aging, in 2005, 2006 and 2007, the group also conducted a sensitivity analysis using a simulated ALK assuming a faster growth. In each of these years, several runs were thus conducted (An Update from the previous year and a Simulated ALK, see below).

In WGHMM 2007 (ICES, 2007), an update runs from 2006 has been carried out and the SPPGFS-WIBTS-Q4 survey was added to the surveys used to tune the model.

WKROUND 2010 (ICES, 2010b) implemented the first Stock Synthesis assessment model for the stock.

WKSOUTH 2014 (ICES, 2014) revised the configuration of the selectivity curves.

Current assessment
The assessment is a length-based approach using the Stock Synthesis assessment model. This approach allows direct use of the quarterly length composition data and explicit modelling of a retention process that partitions total catch into discarded and retained portions.

The underlying population can be partitioned in time to include as many seasons within a year as required. This is important where temporal aspects of biology (like growth in the case of hake), or fishing activity dictate finer than annual-level representation. However, all the basic input data must then be partitioned to the level of the underlying dynamics.

Recruitment is based on a Beverton–Holt function parameterized to include the equilibrium level of unexploited recruitment (R0) and the steepness (h) parameter, describing the fraction of the unexploited recruits produced at 20% of the equilibrium spawning biomass level. Annual deviations can be estimated for any portion of the modelled time period (or the whole period), and the expected recruitments are bias-corrected to reflect the level of variability (sigmaR, an input quantity) allowed in these deviations.

Growth is described through a von Bertalanffy growth curve with the distribution of lengths for a given age assumed to be normally distributed. The CV of these distributions is structured to include two parameters which can be estimated or fixed, defining the spread of lengths at a young and old age with a linear interpolation between. In addition to growth, the relationships between weight and length, fecundity and length as well as maturity-at-length are all generalized to allow parameters to be estimated or fixed, temporally invariant or not. All model parameters can vary over time either as a function of annual deviations about a mean level, user defined 'blocks' of years in which the parameters differ or a combination of the two.

All model expectations for comparison with data are generated as observations from a 'fleet', either a fishery or a survey/index of abundance. Each fleet has unique characteristics defining relative selectivity across age or size, and can be structured to remove catch or collect observations at a particular time of the year or season.

All fleets may be considered completely independent, or parameters may be shared among fleets where appropriate via 'mirroring'.

A suite of selectivity curves including logistic-based shapes of up to eight parameters, power functions and nonparametric forms can be explored through relatively simple modification of the input files.

The kinds of data that model expectations can be fit to include: absolute or relative abundance, length–frequency distributions, age frequency distributions (either total or conditional by length), length-at-age, body weight, and proportion discard. Each of these can be from the retained, discarded or total removals by a specific fleet. Each source has an error distribution (either normal, lognormal or multinomial) associated with it, described by either an input sample size or standard deviation.

Input data for SS

The overall fishery prosecuting the northern stock of hake has been categorized into 7 "fleets", 4 of which use trawl gears, whereas the remaining three use gillnet, longline and a combination of several gears (Table 4). They are based on a combination of the Fishery Units described above. For each fleet, estimates of landings in weight and length–frequency distributions are available. For some fleet only, discards in weight and length–frequency distribution are used.

Table 4. Fleets characteristics and data available for SS (Length–Frequency distribution (LFD) and weight of landings and discards).

Fleets	Description	FU	Landings (quarterly)	Discards (quarterly)
SPTRAWL7*	Spanish trawl in 7	04	Yearly : 1978–1989 (LFD+tonnage) Quarterly: 1990–2021 (LFD+tonnage)	1994, 1999, 2000, 2003–2021 (LFD + Weight)
FRNEP8	French trawl targeting *Nephrops* in 8	09	Yearly : 1978–1989 (tonnage) Yearly : 1985–1989 (LFD) Quarterly : 1990–2021 (LFD+tonnage)	2003–2021 (LFD + Weight)
SPTRAWL8	Spanish trawl in 8	14	Yearly : 1978–1989 (LFD+tonnage) Quarterly: 1990–2021 (LFD+tonnage)	2005–2021 (LFD + Weight)
TRAWLOTH	All other trawl	05 + 06 + 08 + 10	Yearly : 1978–1989 (LFD+tonnage) Quarterly: 1990–2021 (LFD+tonnage)	2005–2021 (LFD + Weight)
GILLNET	Gillnet all countries	03 + 13	Yearly : 1978–1989 (LFD+tonnage) Quarterly: 1990–2021 (LFD+tonnage)	2005–2021 (LFD + Weight)

Fleets	Description	FU	Landings (quarterly)	Discards (quarterly)
LONGLINE	Longline all countries	01 + 02 + 12	Yearly : 1978–1989 (LFD+tonnage) Quarterly: 1990–2021 (LFD+tonnage)	
OTHIST	Everything else all countries, up to 2012	15 + 16 + 00	Yearly : 1978–1989 (LFD+tonnage) Quarterly and Yearly: 1990–2012 (LFD+tonnage)	2003–2012 (Weight) 2003–2012 (Weight+LFD)
NSTRAWL	North Sea Trawlers since 2013	15 + 16 + 00	Quarterly and Yearly: 2013–2021 (LFD+tonnage)	Quarterly and Yearly: 2013–2021 (LFD+tonnage)
OTHERS	Everything else all countries since 2013	15 + 16 + 00	Quarterly and Yearly: 2013–2021 (LFD+tonnage)	Quarterly and Yearly: 2013–2021 (LFD+tonnage)

*** FU04 (and consequently SPTRAWL7) landings and discards contain small amount from area 6 as, in some cases, the sampling programme does not allow to make the distinction between area 7 & 6.**

For the two Spanish trawl fisheries, it is thought that discarding became much more substantial starting from 1998. For the French *Nephrops* fishery, discarding is thought to have occurred already from 1990. For the OTHERS fleet, since 2009 the discards are mainly formed by Scottish discards for which LFD are not available. The retention and selection of OTHERS fleet is thought to vary yearly because it is formed by a mixed of gears and countries. The remaining 3 fisheries (TRAWLOTH, GILLNET, LONGLINE) are assumed not to discard any fish.

Several surveys provide relative abundance indices of abundance and length distributions (Table 5).

Table 5. List of surveys used in SS.

Surveys	Area	Years	Quarter	Units
EVHOE-WIBTS-Q4	Bay of Biscay and Celtic Sea	1997–(y*-1)	4	numbers
RESSGASC	Bay of Biscay	1990–1997 1998–2001	1, 2 ,3 and 4 2 and 4	numbers
SPPGFS-WIBTS-Q4	Porcupine Bank	2001–(y*-1)	3	numbers
IGFS-WIBTS-Q4	North, West and South of Ireland	2003–(y*-1)	4	numbers
IAMS	Irish anglerfish and monkfish survey	2016–2021	1	biomass

* y = assessment year

No commercial fleet tuning data are used.

Length Frequency Distribution Data compilation (From InterCatch to SS)

In 2015 a problem with the calculation of length–frequency distributions (LFD) was detected. That year, the calculation was carried out using R statistical software instead of Intercatch. The new procedure allowed using a more detailed stratification of the data when calculating the LFDs and it solved the problem detected the previous year. In order to be consistent along time, the procedure was applied to the data since 2013 when Intercatch was first used. The LFDs obtained were in agreement with those observed before 2013.

In SS it is not necessary that all the data has a length distribution assigned, it is enough to provide the proportion at length of the catch for the whole stratum (fleet/quarter and catch category (landings or discards) combination). Furthermore, if for one stratum there is no LFD data available or the available data are not reliable the model can work without it. Hence, unlike in Intercatch in R no allocations were done in the stratums without LFD data.

For all the samples with observed LFDs, first the catch in weight by length was calculated using the weight-at-length relationship agreed for this stock (W(g)= 3.77e-6*L(cm)^3.168; ICES, 1991b). Then, for SPTRAWL7, FRNEP8, SPTRAWL8, GILLNET,LONGLINE, OTHER and OTHIST fleets all the samples within each stratum were aggregated by length class summing up the catch weight at length. The obtained length distribution of catch in weight was divided by total catch in the stratum to obtain the proportion of individuals in each length class, which was then used in SS. For TRAWLOTH fleet the data were further disaggregated. In TRAWLOTH the target species was taken into account and the data were divided in the samples coming from métiers with Nephrops as target stock and from métiers with demersal stocks as target. Within these groups the proportion by length was calculated in the same way done for the rest of the fleets. Finally, the overall proportion by length within the stratum was calculated using a weighted mean of the proportion in each group. The weighting factor was the total catch in weight in each group taking into account both sampled and non-sampled data.

The code use to produce the LFDs is available in the ICES TAF repository for hake assessment.

SS settings (input data and control files):

Years: 1978 to present, 1 area, 4 seasons, sex disaggregated.

Length Frequency Distribution are available on a yearly basis from 1978 to 1989 and on a quarterly basis from 1990 to present. No age data are used.
Initial equilibrium catch: annual average of five years (1978–1982) for each fishery.

Variability for landings, discards and survey abundance indices are entered as standard deviation in log-scale, as follows:

Landings (tonnes): 10% variability

Discards (tonnes): 50% variability

Survey abundance indices: variability externally estimated. As the latter represents only the surveys internal variability, extra variability was added (increment to CV in SS control file) according to how representative each survey was felt to be of stock abundance (i.e. the area coverage of the survey as compared to the spatial distribution of the stock). Surveys' CV were increased by 0.1 (EVHOE-WIBTS-Q4), 0.2 (RESSGASC, IGFS-WIBTS-Q4), 0.3 (SPPGFS-WIBTS-Q4).

Length compositions were assigned the following sampling sizes in the SS input data file, on the basis of how representative they were felt to be[1]:

Landings: 125 for all fleets, except SPTRAWL7 for which 50 was used for 1990–1997 and 200 was used from 1998 onwards

Discards: 50 for SPTRAWL7,SPTRAWL8, TRAWLOTH, GILLNET, OTHIST and OTHER, 80 for FRNEP8

Surveys: 125

All the sample size of all LFD was multiplied by 0.1 to reduce the contribution of the likelihood component of LFD to the overall likelihood.

Extra standard deviation is estimated for all the abundance indices.

M=0.4.

von Bertalanffy growth function is fixed: Linf=130 cm, K = 0.177319 and mean length-at-age 0.75 = 15.8392. Linf was chosen in 2010 benchmark (ICES, 2010b) and K and mean length-at-age 0.75 were fixed and chosen in 2014 benchmark using the estimates obtained in 2011 assessment (ICES, 2011). Same growth parameters apply to all fish (across morphs, years, etc)

Maturity ogive: length-based logistic, externally estimated and assumed constant over time.

Recruitment allocation for Quarter 3 estimated with respect to Quarter 2. Quarter 2 allocation is time-varying, with annual deviates. Quarter 1 and quarter 4 allocation set to 0.

Beverton–Holt stock–recruitment relationship: s sigma_R=0.4, steepness and R0 estimated.

Recruitment deviations starting in 1978 and finish in the last data year by default. However, if the working group believes these are not accurately estimated they could be replaced with the recruitment predicted from SS stock–recruit

[1] The log-likelihood for the fit to length composition observations from fishery or survey source, is defined according to a multinomial error structure. The absolute value of the sample size (which may be many thousands of fish measured) should not be interpreted literally. The input sample size scales the variance of the data. The recommended maximum level for the sample size was 400 in Fournier and Archibald (1982). In many recent synthesis applications, a value of 200 has been used (which produces an expected coefficient of variation (CV) of approximately 20% (Methot, 2000)).

relationship, i.e. removing recruitment deviations. Advanced options in recruitment were defined during the benchmark ICES (2022), it must be checked that they are still valid and update if necessary:

- Begin of ramp: 1974
- Begin of plateau: 1976
- Last year full bias adjustment in MPD: 2019
- End year of ramp in MPD: 2020
- Maximum bias adjustment in MPD: 0.95

F estimation method = 4 (fleet specific parameters, hybrid method). SPTRAWL7, TRAWLOTH, FRNEP8, SPTRAWL8, NSTRAWL and OTHERS Hybrid method and GILLNET, LONGLINE and OTHIST method 1.Surveys catchabilities constant over time.

RESSGASC survey entered as 4 separate surveys (1 per quarter). Both, catchabilities and selectivity's are quarter-specific.

Selectivity only length-based (no age selectivity considered).

Fleets' selectivity-at-length:

SPTRAWL7, FRNEP8, SPTRAWL8:

- Pattern 24 (double normal) with only the first 4 parameters estimated.
- Logistic retention
- Random walk from 1998 to the last year data in the first selectivity parameter (peak) and the L_{inf} retention.

TRAWLOTH: Pattern 1 (logistic) selectivity and retention. Random walk in the size inflection in selectivity and Linf retention, 1998-Last data year.

GILLNET: Pattern 24 (double normal) selectivity with only first and third parameters estimated, No random walk.

LONGLINE: Pattern 1 (logistic) with no random walk and no discards.

OTHIST and NSTRAWL: Pattern 1 (logistic) and discards. Random walk in the size inflection in selectivity and Linf retention, 1998-Last data year. In OTHIST random walk 2003–2012, in NSTRAWL; 2013-last data year.

OTHERS: Pattern 24 (double normal) selectivity with no discards and no random walk.

Retention patterns for fisheries with discards: length-logistic with asymptotic retention = 1 in all cases except for gillnetters. The asymptote in gillnetters, L50 and slope for all the fleets with discards are estimated by the model.

D. Short–term projections

- Model used: SS.
- Software used: SS.

- Initial stock size. Taken from the SS in the last assessment year.
- Recruitment in the last data year(s): if the working group believes these are not accurately estimated, they can be replaced with the recruitment predicted from SS stock–recruit relationship.
- Mean weights-at-age, maturity-at-age: average last 3 year.
- Discard proportions-at-age: average last 3 years
- Exploitation pattern: average last 3 years
- F status-quo average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year.
- F in the intermediate year: F status-quo
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship.
- Natural mortality: Age and dex dependent and time invariant as used in the assessment.
- Growth model: von Bertalanffy model, with the same parameters used in the assessment model.
- Maturity-at-length: The same time-invariant ogive as in the assessment is used for all years. Software used: EqSim

E. Medium-term projections

- No medium-term projections are conducted for this stock.

F. Long-term projections

- Model used: EqSim
- Software used: EqSim

The default setting for the biological vectors (weights-at-age, proportion mature at age, proportion natural and fishing mortality occurring before spawning…) is a 5-year window in which values for the simulation period are taken by resampling. According to ICES guidelines, the simulations should represent the current productivity state of the stock and make no inference on the direction of future changes. Based on this guideline, the mean values for the last 5 observed years were considered appropriate.

In the absence of an estimate of F_{cv} and F_{phi}, *EqSim* assumes default values of 0.212 and 0.423 respectively. These values were used.

The simulations were based on 1000 replicates of the stock, used the value of B_{lim} and B_{pa} defined above and considered MSY $B_{trigger} = B_{pa}$ (see rational below).

The detail of the configuration of the simulation is given in the box below.

```
sim_Trig <- eqsim_run( fit_bh,
                       Fcv = 0.212, Fphi = 0.423, SSBcv = 0,
                       rhologRec = rho,
                       Btrigger = Btrigger, Blim = Blim, Bpa = Bpa,
                       Nrun = 1000, Fscan = Fscan, verbose = F)
```

G. Biological reference points

	WG 1998	ACFM 1998	ACFM 2003	ACOM 2010	WKMSY REF4 (ICES, 2016)	WGBIE (ICES, 2019b)	WKANG HKE (ICES, 2022)
MSY $B_{trigger}$				not defined	45000	56000	78405
F_{MSY}				0.24	0.28	0.26	0.24
Flim	No proposal	0.28 (= Floss WG 98)	0.35 (= Floss WG 03)	not defined	0.87	0.84	0.73
Fpa	No proposal	0.20 (= Flim*e-1.645*0.2)	0.25 (= Flim*e-1.645*0.2)	not defined	0.62	0.60	0.54
Blim	No proposal	120 000 t (~ Bloss= B94)	100 000 t (~ Bloss= B94)	not defined	32000	40000	61563
Bpa	119 000 t (=Bloss= B94)	165 000 t (= Blim*e1.645*0.2)	140 000 t (= Blim*e1.645*0.2)	not defined	45000	56000	78405
Flower	not defined	not defined	not defined	not defined	0.18	0.18	0.147
Flupper	not defined	not defined	not defined	not defined	0.45	0.40	0.37

Biological Reference Points in force (ICES 2022)

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	78405	B_{pa}
	F_{MSY}	0.24	SS simulations
Precautionary approach	B_{lim}	61563	The median of the segmented regression stock–recruitment relationship breakpoint (Type 2 stock recruitment)
	B_{pa}	78405	$\exp(1.654 \times \sigma) \times B_{lim}$, $\sigma = 0.147$.
	F_{lim}	0.73	The F that provides a 50% probability for SSB to be above B_{lim}.
	F_{pa}	0.54	Fp.05 with ICES MSY AR: The F that provides a 95% probability for SSB to be above B_{lim}.
Management plan	F_{MGT}	Not defined	
	SSB_{MGT}	Not defined	
	MAP MSY $B_{trigger}$	78405	MSY $B_{trigger}$
	MAP B_{lim}	61563	B_{lim}
	MAP F_{MSY}	0.24	F_{MSY}

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Framework	Reference point	Value	Technical basis
	MAP range F_{lower}	0.147	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).
	MAP range F_{upper}	0.37	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY (ICES, 2019b).

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Annex 1. Control File

```
Columna1
#V3.30.18.beta: not an official version of SS;_safe;_compile_date:_Feb 11 2022;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.3
#_Stock_Synthesis_is_a_work_of_the_U.S._Government_and_is_not_subject_to_copyright_protection_in_the_United_States.
#_Foreign_copyrights_may_apply._See_copyright.txt_for_more_information.
#_User_support_available_at:NMFS.Stock.Synthesis@noaa.gov
#_User_info_available_at:https://vlab.noaa.gov/group/stock-synthesis
#_Source_code_at:_https://github.com/nmfs-stock-synthesis/stock-synthesis

#C growth parameters are estimated
#_data_and_control_files: bc7.dat // bc7_rw_01w.ctl
0 # 0 means do not read wtatage.ss; 1 means read and use wtatage.ss and also read and use growth parameters
1 #_N_Growth_Patterns (Growth Patterns, Morphs, Bio Patterns, GP are terms used interchangeably in SS3)
1 #_N_platoons_Within_GrowthPattern
#_Cond 1 #_Platoon_within/between_stdev_ratio (no read if N_platoons=1)
#_Cond 1 #vector_platoon_dist_(-1_in_first_val_gives_normal_approx)
#
3 # recr_dist_method for parameters: 2=main effects for GP, Area, Settle timing; 3=each Settle entity; 4=none (only when N_GP*Nsettle*pop==1)
1 # not yet implemented; Future usage: Spawner-Recruitment: 1=global; 2=by area
2 # number of recruitment settlement assignments
0 # unused option
#GPattern month area age (for each settlement assignment)
 1 4 1 0
 1 7 1 0
#
#_Cond 0 # N_movement_definitions goes here if Nareas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
#
1 #_Nblock_Patterns
 1 #_blocks_per_pattern
# begin and end years of blocks
```

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```
 1977 1977 # Block to simulate the off-set in recruitment, it was defined by RickMethot to mimic what SS3.24 did.
#
# controls for all timevary parameters
1 #_time-vary parm bound check (1=warn relative to base parm bounds; 3=no bound check); Also see env (3) and dev (5) options to constrain with base bounds
#
# AUTOGEN
 1 1 1 1 1 # autogen: 1st element for biology, 2nd for SR, 3rd for Q, 4th reserved, 5th for selex
# where: 0 = autogen time-varying parms of this category; 1 = read each time-varying parm line; 2 = read then autogen if parm min==-12345
#
#_Available timevary codes
#_Block types: 0: P_block=P_base*exp(TVP); 1: P_block=P_base+TVP; 2: P_block=TVP; 3: P_block=P_block(-1) + TVP
#_Block_trends: -1: trend bounded by base parm min-max and parms in transformed units (beware); -2: endtrend and infl_year direct values; -3: end and infl as fraction of base rar
#_EnvLinks:  1: P(y)=P_base*exp(TVP*env(y));  2: P(y)=P_base+TVP*env(y);  3: P(y)=f(TVP,env_Zscore) w/ logit to stay in min-max;  4: P(y)=2.0/(1.0+exp(-TVP1*env(y) - TVP2))
#_DevLinks:  1: P(y)*=exp(dev(y)*dev_se;  2: P(y)+=dev(y)*dev_se;  3: random walk;  4: zero-reverting random walk with rho;  5: like 4 with logit transform to stay in base min-max
#_DevLinks(more):  21-25 keep last dev for rest of years
#
#_Prior_codes:  0=none; 6=normal; 1=symmetric beta; 2=CASAL's beta; 3=lognormal; 4=lognormal with biascorr; 5=gamma
#
# setup for M, growth, wt-len, maturity, fecundity, (hermaphro), recr_distr, cohort_grow, (movement), (age error), (catch_mult), sex ratio
#_NATMORT
1 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate;_5=BETA:_Maunder_link_to_maturity
4 #_N_breakpoints
 0 1 5 15 # age(real) at M breakpoints
#
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_specific_K_incr; 4=age_specific_K_decr; 5=age_specific_K_each; 6=NA; 7=NA; 8=growth cessation
0.75 #_Age(post-settlement)_for_L1;linear growth below this
999 #_Growth_Age_for_L2 (999 to use as Linf)
-999 #_exponential decay for growth above maxage (value should approx initial Z; -999 replicates 3.24; -998 to not allow growth above maxage)
0 #_placeholder for future growth feature
#
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
#
```

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```
1 #_maturity_option: 1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern; 4=read age-fecundity; 5=disabled; 6=read length-maturity
2 #_First_Mature_Age
1 # fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option: 0=none; 1=female-to-male age-specific fxn; -1=male-to-female age-specific fxn
1 #_parameter_offset_approach for M, G, CV_G: 1- direct, no offset**; 2- male=fem_parm*exp(male_parm); 3: male=female*exp(parm) then old=young*exp(parm)
#_** in option 1, any male parameter with value = 0.0 and phase <0 is set equal to female parameter
#
#_growth_parms
#_ LO HI INIT PRIOR PR_SD PR_type PHASE env_var&link dev_link dev_minyr dev_maxyr dev_PH Block Block_Fxn
# Sex: 1 BioPattern: 1 NatMort :: Female natural mortality, proposed by M.Cardinale and taken from a mediterranean stock.
 0.15 3 1.19 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_1_Fem_GP_1
 0.15 1.4 0.64 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_2_Fem_GP_1
 0.15 0.4 0.34 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_3_Fem_GP_1
 0.15 0.4 0.2 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_4_Fem_GP_1
# Sex: 1 BioPattern: 1 Growth :: Female Growth params, proposed by M.Cardinale and taken from a mediterranean stock.
 4 25 21.902 16.165 0 0 2 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
 60 140 120 100 0 0 -3 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
 0.05 0.4 0.165 0.155 0 0 -3 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
 0.005 0.5 0.15 0.15 0 0 -6 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
 0.005 0.5 0.15 0.15 0 0 -6 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
# Sex: 1 BioPattern: 1 WtLen :: Female weight at length parameters, borrowed from S. Hake
 -1 1 3.77e-06 6.59e-06 0 0 -3 0 0 0 0 0 0 0 # Wtlen_1_Fem_GP_1
 2 4 3.15826 3.01221 0 0 -3 0 0 0 0 0 0 0 # Wtlen_2_Fem_GP_1
# Sex: 1 BioPattern: 1 Maturity&Fecundity :: Female maturity at length parameters, borrowed from S. Hake
 30 55 42.85 42.85 5 0 -3 0 0 0 0 0 0 0 # Mat50%_Fem_GP_1
 -1 1 -0.2 -0.2 0.5 0 -3 0 0 0 0 0 0 0 # Mat_slope_Fem_GP_1
 -3 3 1 1 0 0 -3 0 0 0 0 0 0 0 # Eggs/kg_inter_Fem_GP_1
 -3 3 0 0 0 0 -3 0 0 0 0 0 0 0 # Eggs/kg_slope_wt_Fem_GP_1
# Sex: 2 BioPattern: 1 NatMort :: male natural mortality, proposed by M.Cardinale and taken from a mediterranean stock.
 0 3 1.19 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_1_Mal_GP_1
 0 1.5 0.64 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_2_Mal_GP_1
 0 0.5 0.415 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_3_Mal_GP_1
 0 0.5 0.279 0.2 10 0 -3 0 0 0 0 0 0 0 # NatM_break_4_Mal_GP_1
```

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```
# Sex: 2 BioPattern: 1 Growth :: male Growth params, proposed by M.Cardinale and taken from a mediterranean stock.
 4 30 15.4262 0 0 0 2 0 0 0 0 0 0 0 # L_at_Amin_Mal_GP_1
 0 120 80 -0.4 0 0 -3 0 0 0 0 0 0 0 # L_at_Amax_Mal_GP_1
 0.1 0.6 0.23 0 0 0 -3 0 0 0 0 0 0 0 # VonBert_K_Mal_GP_1
 0.1 0.7 0.15 0 0 0 -3 0 0 0 0 0 0 0 # CV_young_Mal_GP_1
 0.1 0.7 0.15 0 0 0 -3 0 0 0 0 0 0 0 # CV_old_Mal_GP_1
# Sex: 2 BioPattern: 1 WtLen :: male weigth at length parameters , same as females
 -1 1 3.77e-06 6.59e-06 0 0 -3 0 0 0 0 0 0 0 # Wtlen_1_Mal_GP_1
 2 4 3.15826 3.01221 0 0 -3 0 0 0 0 0 0 0 # Wtlen_2_Mal_GP_1
# Hermaphroditism
# Recruitment Distribution
 -8 8 0 0 0 0 -2 0 0 0 0 0 0 0 # RecrDist_GP_1_area_1_month_4
 -12 12 -1.82923 -0.55 0 0 6 0 23 1978 2019 4 0 0 # RecrDist_GP_1_area_1_month_7
# Cohort growth dev base
 0 2 1 1 0 0 -3 0 0 0 0 0 0 0 # CohortGrowDev
# Movement
# Age Error from parameters
# catch multiplier
# fraction female, by GP
 1e-06 0.999999 0.5 0.5 0.5 0 -99 0 0 0 0 0 0 0 # FracFemale_GP_1
# M2 parameter for each predator fleet
#
# timevary MG parameters
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
 0.0001 2 1.5 0.5 0.5 6 -5 # RecrDist_GP_1_area_1_month_7_dev_se
 -0.99 0.99 0 0 0.5 6 -6 # RecrDist_GP_1_area_1_month_7_dev_autocorr
# info on dev vectors created for MGparms are reported with other devs after tag parameter section
#
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
```

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```
3 #_Spawner-Recruitment; Options: 1=NA; 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm; 8=Shepherd_3Parm; 9=RickerPower_3parm
0  # 0/1 to use steepness in initial equ recruitment calculation
0  #  future feature:  0/1 to make realized sigmaR a function of SR curvature
#_       LO        HI       INIT       PRIOR      PR_SD      PR_type     PHASE   env-var   use_dev   dev_mnyr   dev_mxyr    dev_PH     Block    Blk_Fxn #  parm_name
        11.5       16.2     13.7896      12.9         1          0        1        0        0        0        0        0        0        0 # SR_LN(R0)
         0.2      0.999    0.927075     0.999        0.2         0        2        0        0        0        0        0        0        0 # SR_BH_steep
         0.1          2       0.4        0.4         0.2         0       -1        0        0        0        0        0        0        0 # SR_sigmaR
          -5          5         0       -0.7          2          0       -1        0        0        0        0        0        1        1 # SR_regime
           0          0         0          0          0          0      -99        0        0        0        0        0        0        0 # SR_autocorr
# timevary SR parameters
 -5 5 -0.207899 -0.16 2 0 6 # SR_regime_BLK1add_1977
1 #do_recdev:  0=none; 1=devvector (R=F(SSB)+dev); 2=deviations (R=F(SSB)+dev); 3=deviations (R=R0*dev; dev2=R-f(SSB)); 4=like 3 with sum(dev2) adding penalty
1978 # first year of main recr_devs; early devs can preceed this era
2019 # last year of main recr_devs; forecast devs start in following year. This is turned off in the last year to remove the impact of retrospective pattern in recruitment. Similar to using the geometric mean. Consider using for the last two assessment years.
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 -6 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 4 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 1974 #_last_yr_nobias_adj_in_MPD; begin of ramp. These four years are the RAMP options and are tunned depending on the resultst. In principle
#_last_yr_fullbias_adj_in_MPD is [last data year -1] and  #_end_yr_for_ramp_in_MPD is last data year
 1976 #_first_yr_fullbias_adj_in_MPD; begin of plateau
 2019 #_last_yr_fullbias_adj_in_MPD
 2020 #_end_yr_for_ramp_in_MPD (can be in forecast to shape ramp, but SS3 sets bias_adj to 0.0 for fcast yrs)
 0.95 #_max_bias_adj_in_MPD (typical ~0.8; -3 sets all years to 0.0; -2 sets all non-forecast yrs w/ estimated recdevs to 1.0; -1 sets biasadj=1.0 for all yrs w/ recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -5 #min rec_dev
 5 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
#
```

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```
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
#_Yr Input_value
#
(...)
#Fishing Mortality info
0.3 # F ballpark value in units of annual_F
-2001 # F ballpark year (neg value to disable)
4 # F_Method:  1=Pope midseason rate; 2=F as parameter; 3=F as hybrid; 4=fleet-specific parm/hybrid (#4 is superset of #2 and #3 and is recommended)
2.9 # max F (methods 2-4) or harvest fraction (method 1)
# read list of fleets that do F as parameter; unlisted fleets stay hybrid, bycatch fleets must be included with start_PH=1, high F fleets should switch early
# (A) fleet, (B) F_starting_value (used if start_PH=1), (C) start_PH for parms (99 to stay in hybrid, <0 to stay at starting value)
# (A) (B) (C)  (terminate list with -9999 for fleet)
 1 0.05 99 # SPTRAWL7
 2 0.05 99 # TRAWLOTH
 3 0.05 99 # FRNEP8
 4 0.05 99 # SPTRAWL8
 5 0.05 1 # GILLNET
 6 0.05 1 # LONGLINE
 7 0.05 1 # OTHST
 8 0.05 99 # NSTRAWL
 9 0.05 99 # OTHERS
-9999 1 1 # end of list
4 #_number of loops for hybrid tuning; 4 good; 3 faster; 2 enough if switching to parms is enabled
#
#_initial_F_parms; for each fleet x season that has init_catch; nest season in fleet; count = 28
#_for unconstrained init_F, use an arbitrary initial catch and set lambda=0 for its logL
#_ LO HI INIT PRIOR PR_SD  PR_type  PHASE
 0.0001 2 0.114179 0.3 0.5 0 1 # InitF_seas_1_flt_1SPTRAWL7
 0.0001 2 0.0960197 0.3 0.5 0 1 # InitF_seas_1_flt_2TRAWLOTH
 0.0001 2 0.0370275 0.3 0.5 0 1 # InitF_seas_1_flt_3FRNEP8
 0.0001 2 0.288674 0.3 0.5 0 1 # InitF_seas_1_flt_4SPTRAWL8
 0.0001 2 0.0409992 0.3 0.5 0 1 # InitF_seas_1_flt_5GILLNET
```

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```
0.0001 2 0.0387274 0.3 0.5 0 1 # InitF_seas_1_flt_6LONGLINE
0.0001 2 0.0513533 0.3 0.5 0 1 # InitF_seas_1_flt_7OTHIST
0.0001 2 0.108343 0.3 0.5 0 1 # InitF_seas_2_flt_1SPTRAWL7
0.0001 2 0.158075 0.3 0.5 0 1 # InitF_seas_2_flt_2TRAW_OTH
0.0001 2 0.085726 0.3 0.5 0 1 # InitF_seas_2_flt_3FRNEP8
0.0001 2 0.301355 0.3 0.5 0 1 # InitF_seas_2_flt_4SPTRAWL8
0.0001 2 0.0494331 0.3 0.5 0 1 # InitF_seas_2_flt_5GILLNET
0.0001 2 0.0747584 0.3 0.5 0 1 # InitF_seas_2_flt_6LONGLINE
0.0001 2 0.09452 0.3 0.5 0 1 # InitF_seas_2_flt_7OTHIST
0.0001 2 0.0798011 0.3 0.5 0 1 # InitF_seas_3_flt_1SPTRAWL7
0.0001 2 0.116473 0.3 0.5 0 1 # InitF_seas_3_flt_2TRAW_OTH
0.0001 2 0.065684 0.3 0.5 0 1 # InitF_seas_3_flt_3FRNEP8
0.0001 2 0.258577 0.3 0.5 0 1 # InitF_seas_3_flt_4SPTRAWL8
0.0001 2 0.0520433 0.3 0.5 0 1 # InitF_seas_3_flt_5GILLNET
0.0001 2 0.055406 0.3 0.5 0 1 # InitF_seas_3_flt_6LONGLINE
0.0001 2 0.103883 0.3 0.5 0 1 # InitF_seas_3_flt_7OTHIST
0.0001 2 0.0890657 0.3 0.5 0 1 # InitF_seas_4_flt_1SPTRAWL7
0.0001 2 0.102735 0.3 0.5 0 1 # InitF_seas_4_flt_2TRAW_OTH
0.0001 2 0.0332452 0.3 0.5 0 1 # InitF_seas_4_flt_3FRNEP8
0.0001 2 0.170887 0.3 0.5 0 1 # InitF_seas_4_flt_4SPTRAWL8
0.0001 2 0.0436354 0.3 0.5 0 1 # InitF_seas_4_flt_5GILLNET
0.0001 2 0.0389517 0.3 0.5 0 1 # InitF_seas_4_flt_6LONGLINE
0.0001 2 0.0598805 0.3 0.5 0 1 # InitF_seas_4_flt_7OTHIST
#
(...)
#_Q_setup for fleets with cpue or survey data
#_1: fleet number
#_2: link type: (1=simple q, 1 parm; 2=mirror simple q, 1 mirrored parm; 3=q and power, 2 parm; 4=mirror with offset, 2 parm)
#_3: extra input for link, i.e. mirror fleet# or dev index number
#_4: 0/1 to select extra sd parameter
#_5: 0/1 for biasadj or not
#_6: 0/1 to float
#_ fleet link link_info extra_se biasadj float # fleetname
```

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```
   10   1   0   1   1   1 # EVHOE
   11   1   0   1   1   1 # RESSGASCQ1
   12   1   0   1   1   1 # RESSGASCQ2
   13   1   0   1   1   1 # RESSGASCQ3
   14   1   0   1   1   1 # RESSGASCQ4
   15   1   0   1   1   1 # PORCUPINE
   16   1   0   1   1   1 # IGFS
   17   1   0   1   1   1 # IAMS
-9999 0 0 0 0 0
#
#_Q_parms(if_any);Qunits_are_ln(q)
#_   LO   HI   INIT   PRIOR   PR_SD   PR_type   PHASE   env-var   use_dev   dev_mnyr   dev_mxyr   dev_PH   Block   Blk_Fxn # parm_name
   -25   25   -8.55299   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_EVHOE(10)
   0   1   0.224903   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_EVHOE(10)
   -25   25   -4.95835   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_RESSGASCQ1(11)
   0   1   0.270315   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_RESSGASCQ1(11)
   -25   25   -3.90854   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_RESSGASCQ2(12)
   0   1   0.220105   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_RESSGASCQ2(12)
   -25   25   -4.15764   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_RESSGASCQ3(13)
   0   1   0.0729454   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_RESSGASCQ3(13)
   -25   25   -5.07421   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_RESSGASCQ4(14)
   0   1   0.28681   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_RESSGASCQ4(14)
   -25   25   -8.26472   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_PORCUPINE(15)
   0   1   0.159159   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_PORCUPINE(15)
   -25   25   -9.11494   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_IGFS(16)
   0   1   0.248736   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_IGFS(16)
   -25   25   -7.70231   0   1   0   -1   0   0   0   0   0   0   0 # LnQ_base_IAMS(17)
   0   1   0.0117605   0.0001   0.01   0   4   0   0   0   0   0   0   0 # Q_extraSD_IAMS(17)
#_no timevary Q parameters
#
#_size_selex_patterns
#Pattern:_0; parm=0; selex=1.0 for all sizes
#Pattern:_1; parm=2; logistic; with 95% width specification
```

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#Pattern:_2; parm=6; modification of pattern 24 with improved sex-specific offset
#Pattern:_5; parm=2; mirror another size selex; PARMS pick the min-max bin to mirror
#Pattern:_11; parm=2; selex=1.0 for specified min-max population length bin range
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_6; parm=2+special; non-parm len selex
#Pattern:_43; parm=2+special+2; like 6, with 2 additional param for scaling (average over bin range)
#Pattern:_8; parm=8; double_logistic with smooth transitions and constant above Linf option
#Pattern:_9; parm=6; simple 4-parm double logistic with starting length; parm 5 is first length; parm 6=1 does desc as offset
#Pattern:_21; parm=2+special; non-parm len selex, read as pairs of size, then selex
#Pattern:_22; parm=4; double_normal as in CASAL
#Pattern:_23; parm=6; double_normal where final value is directly equal to sp(6) so can be >1.0
#Pattern:_24; parm=6; double_normal with sel(minL) and sel(maxL), using joiners
#Pattern:_25; parm=3; exponential-logistic in length
#Pattern:_27; parm=special+3; cubic spline in length; parm1==1 resets knots; parm1==2 resets all
#Pattern:_42; parm=special+3+2; cubic spline; like 27, with 2 additional param for scaling (average over bin range)
#_discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dead;_4=define_dome-shaped_retention
#_Pattern Discard Male Special
 24 1 0 0 # 1 SPTRAWL7
 1 1 0 0 # 2 TRAWLOTH
 24 1 0 0 # 3 FRNEP8
 24 1 0 0 # 4 SPTRAWL8
 24 1 0 0 # 5 GILLNET
 1 0 0 0 # 6 LONGLINE
 1 1 0 0 # 7 OTHIST
 1 1 0 0 # 8 NSTRAWL
 24 0 0 0 # 9 OTHERS
 24 0 0 0 # 10 EVHOE
 24 0 0 0 # 11 RESSGASCQ1
 24 0 0 0 # 12 RESSGASCQ2
 24 0 0 0 # 13 RESSGASCQ3
 24 0 0 0 # 14 RESSGASCQ4
 24 0 0 0 # 15 PORCUPINE
 24 0 0 0 # 16 IGFS
```

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 24 0 0 0 # 17 IAMS
#
#_age_selex_patterns
#Pattern:_0; parm=0; selex=1.0 for ages 0 to maxage
#Pattern:_10; parm=0; selex=1.0 for ages 1 to maxage
#Pattern:_11; parm=2; selex=1.0 for specified min-max age
#Pattern:_12; parm=2; age logistic
#Pattern:_13; parm=8; age double logistic
#Pattern:_14; parm=nages+1; age empirical
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_16; parm=2; Coleraine - Gaussian
#Pattern:_17; parm=nages+1; empirical as random walk  N parameters to read can be overridden by setting special to non-zero
#Pattern:_41; parm=2+nages+1; // like 17, with 2 additional param for scaling (average over bin range)
#Pattern:_18; parm=8; double logistic - smooth transition
#Pattern:_19; parm=6; simple 4-parm double logistic with starting age
#Pattern:_20; parm=6; double_normal,using joiners
#Pattern:_26; parm=3; exponential-logistic in age
#Pattern:_27; parm=3+special; cubic spline in age; parm1==1 resets knots; parm1==2 resets all
#Pattern:_42; parm=2+special+3; // cubic spline; with 2 additional param for scaling (average over bin range)
#Age patterns entered with value >100 create Min_selage from first digit and pattern from remainder
#_Pattern Discard Male Special
 0 0 0 0 # 1 SPTRAWL7
 0 0 0 1 # 2 TRAWLOTH
 0 0 0 1 # 3 FRNEP8
 0 0 0 1 # 4 SPTRAWL8
 0 0 0 1 # 5 GILLNET
 0 0 0 1 # 6 LONGLINE
 0 0 0 1 # 7 OTHIST
 0 0 0 1 # 8 NSTRAWL
 0 0 0 1 # 9 OTHERS
 0 0 0 1 # 10 EVHOE
 0 0 0 1 # 11 RESSGASCQ1
 0 0 0 1 # 12 RESSGASCQ2
```

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0 0 0 1 # 13 RESSGASCQ3
0 0 0 1 # 14 RESSGASCQ4
0 0 0 1 # 15 PORCUPINE
0 0 0 1 # 16 IGFS
0 0 0 1 # 17 IAMS
#
#_  LO  HI  INIT  PRIOR  PR_SD  PR_type  PHASE  env-var  use_dev  dev_mnyr  dev_mxyr  dev_PH  Block  Blk_Fxn # parm_name
# 1  SPTRAWL7 LenSelex
# In the lines hihglighted the last year must be equal to the last data year, it controls de random walk in the selectivities.
5  60  43.1905  15  0.01  0  2  0  23  1998  2020  3  0  0 # Size_DblN_peak_SPTRAWL7(1)
-6  2  -1.7129  -2  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_top_logit_SPTRAWL7(1)
-6  14  5.69899  4  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_ascend_se_SPTRAWL7(1)
1  50  6.60887  10  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_descend_se_SPTRAWL7(1)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_start_logit_SPTRAWL7(1)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_end_logit_SPTRAWL7(1)
0.001  60  21.5299  27  0.01  0  4  0  23  1998  2020  3  0  0 # Retain_L_infl_SPTRAWL7(1)
0.61  10.01  3.26221  0.81  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_width_SPTRAWL7(1)
-10  999  999  -10  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_asymptote_logit_SPTRAWL7(1)
0  0  0  0  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_maleoffset_SPTRAWL7(1)
# 2  TRAWLOTH LenSelex
5  60  26.0866  35  0.01  0  2  0  23  1998  2020  3  0  0 # Size_inflection_TRAWLOTH(2)
1  30  5.09762  15  0.01  0  2  0  0  0  0  0  0  0 # Size_95%width_TRAWLOTH(2)
1  50  14.649  27  0.01  0  4  0  23  1998  2020  3  0  0 # Retain_L_infl_TRAWLOTH(2)
0.61  30.01  7.10239  0.81  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_width_TRAWLOTH(2)
-10  999  999  -10  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_asymptote_logit_TRAWLOTH(2)
0  0  0  0  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_maleoffset_TRAWLOTH(2)
# 3  FRNEP8 LenSelex
5  30  15.6367  15  0.01  0  2  0  23  1998  2020  3  0  0 # Size_DblN_peak_FRNEP8(3)
-16  2  -14.2255  -2  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_top_logit_FRNEP8(3)
-15  14  0.952542  4  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_ascend_se_FRNEP8(3)
1  50  6.63876  10  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_descend_se_FRNEP8(3)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_start_logit_FRNEP8(3)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_end_logit_FRNEP8(3)
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10  40  23.2954  27  0.01  0  4  0  23  1998  2020  3  0  0 # Retain_L_infl_FRNEP8(3)
0.61  10.01  1.29307  0.81  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_width_FRNEP8(3)
-10  999  999  -10  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_asymptote_logit_FRNEP8(3)
0  0  0  0  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_maleoffset_FRNEP8(3)
# 4  SPTRAWL8 LenSelex
5  30  19.6159  15  0.01  0  2  0  23  1998  2020  3  0  0 # Size_DblN_peak_SPTRAWL8(4)
-10  2  -5.99816  -2  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_top_logit_SPTRAWL8(4)
-20  14  4.91908  4  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_ascend_se_SPTRAWL8(4)
1  50  6.68281  10  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_descend_se_SPTRAWL8(4)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_start_logit_SPTRAWL8(4)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_end_logit_SPTRAWL8(4)
1  40  12.5067  27  0.01  0  4  0  23  1998  2020  3  0  0 # Retain_L_infl_SPTRAWL8(4)
0.0001  10.01  1.0226  0.81  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_width_SPTRAWL8(4)
-10  999  999  -10  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_asymptote_logit_SPTRAWL8(4)
0  0  0  0  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_maleoffset_SPTRAWL8(4)
# 5  GILLNET LenSelex
25  95  88.3068  45  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_peak_GILLNET(5)
-15  0  -15  -3  0.01  0  -2  0  0  0  0  0  0  0 # Size_DblN_top_logit_GILLNET(5)
-10  10  5.78573  5.5  0.01  0  2  0  0  0  0  0  0  0 # Size_DblN_ascend_se_GILLNET(5)
0  20  20  7  0.01  0  -2  0  0  0  0  0  0  0 # Size_DblN_descend_se_GILLNET(5)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_start_logit_GILLNET(5)
-999  -999  -999  -999  0  0  -2  0  0  0  0  0  0  0 # Size_DblN_end_logit_GILLNET(5)
10  40  28.1014  27  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_infl_GILLNET(5)
0.61  10.01  4.51957  0.81  0.01  0  4  0  0  0  0  0  0  0 # Retain_L_width_GILLNET(5)
-10  10  3.31966  3.89182  0.01  0  3  0  0  0  0  0  0  0 # Retain_L_asymptote_logit_GILLNET(5)
0  0  0  0  0.01  0  -3  0  0  0  0  0  0  0 # Retain_L_maleoffset_GILLNET(5)
# 6  LONGLINE LenSelex
5  60  52.7027  35  0.01  0  2  0  0  0  0  0  0  0 # Size_inflection_LONGLINE(6)
1  30  11.0154  15  0.01  0  2  0  0  0  0  0  0  0 # Size_95%width_LONGLINE(6)
# 7  OTHIST LenSelex
5  80  42.7769  35  0.01  0  2  0  23  2003  2012  3  0  0 # Size_inflection_OTHIST(7)
1  30  21.5181  15  0.01  0  2  0  0  0  0  0  0  0 # Size_95%width_OTHIST(7)
10  60  26.6056  27  0.01  0  4  0  23  2003  2012  3  0  0 # Retain_L_infl_OTHIST(7)
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0.61 30.01 4.17745 0.81 0.01 0 4 0 0 0 0 0 0 0 # Retain_L_width_OTHIST(7)
-10 999 999 -10 0.01 0 -3 0 0 0 0 0 0 0 # Retain_L_asymptote_logit_OTHIST(7)
0 0 0 0 0.01 0 -3 0 0 0 0 0 0 0 # Retain_L_maleoffset_OTHIST(7)
# 8 NSTRAWL LenSelex
5 70 55.397 35 0.01 0 2 0 23 2013 2020 3 0 0 # Size_inflection_NSTRAWL(8)
1 30 29.4026 15 0.01 0 2 0 0 0 0 0 0 0 # Size_95%width_NSTRAWL(8)
10 60 55.6092 27 0.01 0 4 0 23 2013 2020 3 0 0 # Retain_L_infl_NSTRAWL(8)
0.61 10.01 5.53678 0.81 0.01 0 4 0 0 0 0 0 0 0 # Retain_L_width_NSTRAWL(8)
-10 999 999 -10 0.01 0 -3 0 0 0 0 0 0 0 # Retain_L_asymptote_logit_NSTRAWL(8)
0 0 0 0 0.01 0 -3 0 0 0 0 0 0 0 # Retain_L_maleoffset_NSTRAWL(8)
# 9 OTHERS LenSelex
25 120 96.3399 45 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_OTHERS(9)
-15 0 -8.75477 -3 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_OTHERS(9)
-10 10 5.96775 5.5 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_OTHERS(9)
-10 20 0.153214 7 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_OTHERS(9)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_OTHERS(9)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_OTHERS(9)
# 10 EVHOE LenSelex
5 30 11.2083 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_EVHOE(10)
-16 2 -12.9598 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_EVHOE(10)
0 10 1.80622 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_EVHOE(10)
1 50 6.17039 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_EVHOE(10)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_EVHOE(10)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_EVHOE(10)
# 11 RESSGASCQ1 LenSelex
5 30 17.2805 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_RESSGASCQ1(11)
-16 2 -12.0497 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_RESSGASCQ1(11)
0 10 2.63862 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_RESSGASCQ1(11)
1 40 5.64662 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_RESSGASCQ1(11)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_RESSGASCQ1(11)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_RESSGASCQ1(11)
# 12 RESSGASCQ2 LenSelex
5 30 8.39748 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_RESSGASCQ2(12)
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-16 2 -2.33989 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_RESSGASCQ2(12)
0 10 0.353514 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_RESSGASCQ2(12)
1 40 5.33148 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_RESSGASCQ2(12)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_RESSGASCQ2(12)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_RESSGASCQ2(12)
# 13 RESSGASCQ3 LenSelex
5 30 16.8253 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_RESSGASCQ3(13)
-16 2 -12.0865 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_RESSGASCQ3(13)
0 10 3.42839 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_RESSGASCQ3(13)
1 40 6.26865 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_RESSGASCQ3(13)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_RESSGASCQ3(13)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_RESSGASCQ3(13)
# 14 RESSGASCQ4 LenSelex
5 30 17.5283 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_RESSGASCQ4(14)
-16 2 -11.9695 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_RESSGASCQ4(14)
0 10 3.15434 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_RESSGASCQ4(14)
1 40 6.49983 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_RESSGASCQ4(14)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_RESSGASCQ4(14)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_RESSGASCQ4(14)
# 15 PORCUPINE LenSelex
4 80 66.7212 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_PORCUPINE(15)
-16 2 -11.5368 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_PORCUPINE(15)
0 10 6.67701 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_PORCUPINE(15)
0 40 4.6908 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_PORCUPINE(15)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_PORCUPINE(15)
999 999 999 999 0 0 2 0 0 0 0 0 0 0 # Size_DblN_end_logit_PORCUPINE(15)
# 16 IGFS LenSelex
4 30 12.5129 15 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_peak_IGFS(16)
-16 2 -11.3737 -2 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_top_logit_IGFS(16)
0 10 2.4533 4 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_ascend_se_IGFS(16)
1 40 6.71597 10 0.01 0 2 0 0 0 0 0 0 0 # Size_DblN_descend_se_IGFS(16)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_start_logit_IGFS(16)
-999 -999 -999 -999 0 0 -2 0 0 0 0 0 0 0 # Size_DblN_end_logit_IGFS(16)
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# 17   IAMS LenSelex
   4     70    52.909     15    0.01    0    2    0    0    0    0    0    0    0 # Size_DblN_peak_IAMS(17)
 -16      2   -7.00004    -2    0.01    0    2    0    0    0    0    0    0    0 # Size_DblN_top_logit_IAMS(17)
   0     10    5.08455     4    0.01    0    2    0    0    0    0    0    0    0 # Size_DblN_ascend_se_IAMS(17)
   5     40    22.4291    10    0.01    0    2    0    0    0    0    0    0    0 # Size_DblN_descend_se_IAMS(17)
-999   -999   -999      -999    0       0   -2    0    0    0    0    0    0    0 # Size_DblN_start_logit_IAMS(17)
-999   -999   -999      -999    0       0   -2    0    0    0    0    0    0    0 # Size_DblN_end_logit_IAMS(17)
# 1   SPTRAWL7 AgeSelex
# 2   TRAWLOTH AgeSelex
# 3   FRNEP8 AgeSelex
# 4   SPTRAWL8 AgeSelex
# 5   GILLNET AgeSelex
# 6   LONGLINE AgeSelex
# 7   OTHIST AgeSelex
# 8   NSTRAWL AgeSelex
# 9   OTHERS AgeSelex
# 10   EVHOE AgeSelex
# 11   RESSGASCQ1 AgeSelex
# 12   RESSGASCQ2 AgeSelex
# 13   RESSGASCQ3 AgeSelex
# 14   RESSGASCQ4 AgeSelex
# 15   PORCUPINE AgeSelex
# 16   IGFS AgeSelex
# 17   IAMS AgeSelex
#_No_Dirichlet parameters
# timevary selex parameters
#      LO      HI     INIT    PRIOR    PR_SD    PR_type   PHASE # parm_name
     0.0001    2      1.5      5       0.5       6     -5 # Size_DblN_peak_SPTRAWL7(1)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_DblN_peak_SPTRAWL7(1)_dev_autocorr
     0.0001    2      1.5      1       0.5       6     -5 # Retain_L_infl_SPTRAWL7(1)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Retain_L_infl_SPTRAWL7(1)_dev_autocorr
     0.0001    2      1.5      5       0.5       6     -5 # Size_inflection_TRAWLOTH(2)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_inflection_TRAWLOTH(2)_dev_autocorr
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```
     0.0001    2      1.5      5       0.5       6     -5 # Retain_L_infl_TRAWLOTH(2)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Retain_L_infl_TRAWLOTH(2)_dev_autocorr
     0.0001    2      1.5      5       0.5       6     -5 # Size_DblN_peak_FRNEP8(3)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_DblN_peak_FRNEP8(3)_dev_autocorr
     0.0001    2      1.5      1       0.5       6     -5 # Retain_L_infl_FRNEP8(3)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Retain_L_infl_FRNEP8(3)_dev_autocorr
     0.0001    2      1.5      5       0.5       6     -5 # Size_DblN_peak_SPTRAWL8(4)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_DblN_peak_SPTRAWL8(4)_dev_autocorr
     0.0001    2      1.5      5       0.5       6     -5 # Retain_L_infl_SPTRAWL8(4)_dev_se
     0.99     0.99    0        0       0.5       6      6 # Retain_L_infl_SPTRAWL8(4)_dev_autocorr
     0.0001    2      1.5      5       0.5       6     -5 # Size_inflection_OTHIST(7)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_inflection_OTHIST(7)_dev_autocorr
     0.0001    2      1.5      1       0.5       6     -5 # Retain_L_infl_OTHIST(7)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Retain_L_infl_OTHIST(7)_dev_autocorr
     0.0001    2      1.5      1       0.5       6     -5 # Size_inflection_NSTRAWL(8)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Size_inflection_NSTRAWL(8)_dev_autocorr
     0.0001    2      1.5      1       0.5       6     -5 # Retain_L_infl_NSTRAWL(8)_dev_se
    -0.99     0.99    0        0       0.5       6     -6 # Retain_L_infl_NSTRAWL(8)_dev_autocorr
# info on dev vectors created for selex parms are reported with other devs after tag parameter section
#
0  #  use 2D_AR1 selectivity(0/1)
#  no 2D_AR1 selex offset used
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read and autogen if tag data exists; 1=read
#_Cond  -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
# deviation vectors for timevary parameters
#  base   base first block   block  env  env   dev   dev   dev   dev   dev
#  type  index  parm trend pattern link  var  vectr link _mnyr  mxyr phase  dev_vector
# (...)
#  Input variance adjustments factors:
 #_1=add_to_survey_CV
```

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```
#_2=add_to_discard_stddev
#_3=add_to_bodywt_CV
#_4=mult_by_lencomp_N
#_5=mult_by_agecomp_N
#_6=mult_by_size-at-age_N
#_7=mult_by_generalized_sizecomp
#_Factor Fleet Value
-9999 1 0 # terminator
#
1 #_maxlambdaphase
1 #_sd_offset; must be 1 if any growthCV, sigmaR, or survey extraSD is an estimated parameter
# read 17 changes to default Lambdas (default value is 1.0)
# like_comp codes: 1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin; 17=F_ballpark; 18=initEQregime
#like_comp fleet phase value sizefreq_method
4 1 1 0.1 1
4 2 1 0.1 1
4 3 1 0.1 1
4 4 1 0.1 1
4 5 1 0.1 1
4 6 1 0.1 1
4 7 1 0.1 1
4 8 1 0.1 1
4 9 1 0.1 1
4 10 1 0.1 1
4 11 1 0.1 1
4 12 1 0.1 1
4 13 1 0.1 1
4 14 1 0.1 1
4 15 1 0.1 1
4 16 1 0.1 1
4 17 1 0.1 1
-9999 1 1 1 1 # terminator
```

Stock Annex: Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Southern stock hake (hke.27.8c9a)
Working Group	Working Group for the Bay of Biscay and the Iberic waters Ecoregion (WGBIE)
Last updated	February 2022
Revised by	WKANGHAKE (2022); Santiago Cerviño and Andreia Silva
Timeline of revisions	WKSOUTH (ICES, 2014); WGBIE 2016.

A. General

A.1. Stock definition

Southern hake stock comprises the Atlantic coast of the Iberian Peninsula corresponding to the ICES divisions 8.c and 9.a. The Northern limit is in the Spanish – French boundary and the Southern one in Gibraltar Strait. These boundaries were defined based on management considerations without a biological basis.

Atlantic and Mediterranean European hake are usually considered different stocks due to the differences in biology (i.e. growth rate or spawning season) of the populations in both areas. In the Northeastern Atlantic, there is no clear evidence of the existence of multiple hake populations, although Roldán *et al.* (1998) based on genetic studies states that *"the data (…) indicate that the population structure within the Atlantic is more complex than the discrete northern and southern stocks proposed by ICES"*. There is likely a degree of transfer between the Southern and Northern hake stocks, and recent studies on population genetics support that (Balado *et al*., 2003; Pita *et al*., 2010; Pita *et al*., 2011), however, there is at present a lack of data to quantify the number of migrations between stocks.

A.2. Fishery

Hake in divisions 8.c and 9.a is caught in a mixed fishery by the Spanish and Portuguese fleets (trawls, gillnetters, longliners and artisanal fleets).

The Spanish trawl fleet is quite homogeneous and uses mainly two gears, pair trawl and bottom trawl. The percentage of hake present in the landings is small as there are other important target species (i.e. anglerfish, megrims, Norway lobster, blue whiting, horse mackerel and mackerel). During recent years there has been an increase in Spanish trawlers using a new High Vertical Opening gear towed by single vessels and targeting the pelagic species listed above. In contrast, the artisanal fleet is very heterogeneous and uses a wide variety of gears; traps, large and small gillnet, longlines, etc. The trawl fleet landings length composition, since the implementation of the minimum landing size in 1991, has a mode of around 29–31 cm depending on the year. Artisanal fleets target different components of the stock depending on the gear used. Small gillnets catch smaller fish than gillnets and longlines, which target mainly large fish and have length composition with a mode above 50 cm. Hake is an important component of the catch for these fleets mainly due to the high prices that they reach in Iberian markets.

Hake is caught by the Portuguese fleet in the trawl and artisanal mixed fisheries together with other fish and crustacean species. These include horse mackerel, anglerfish, megrim, mackerel, Spanish mackerel, blue whiting, red shrimp (*Aristeus antennatus*), rose shrimp (*Parapenaeus longirostris*) and Norway lobster. The trawl fleet comprises two distinct components - the trawl fleet catching demersal fish (70 mm mesh size) and the trawl fleet targeting crustaceans (55 mm mesh size). The fleet targeting fish species operates along the entire Portuguese coast at depths between 100 and 200 m. The trawl fleet targeting crustaceans operates mainly in the southwest and south in deeper waters, from 100–750 m. The most important fishing harbours from Northern Portugal are: Matosinhos, Aveiro and FigueiraFoz, from Central Portugal, are: Nazaré, Lisboa and Sines and from Southern Portugal are: Portimão and Vila Real Santo António. The artisanal fleet lands hake mainly in the fishing harbours of the Centre. The main fishing harbours are Póvoa do Varzim (North), Sesimbra (Centre) and Olhão (South). Landings recorded by month show that the majority of the hake landings occur from May until October for both fleets.

A.3. Ecosystem aspects

European hake presents indeterminate fecundity and asynchronous development of the oocytes (Andreu, 1956; Muruaet *al*., 1998; Domínguez-Petit, 2007). It is a serial or batch spawner (Murua *et al*., 1996). Duration of spawning season at the population level may differ between areas (Pérez and Pereiro, 1985; Alheit and Pitcher, 1995; Ungaro *et al*., 2001; Domínguez-Petit, 2007); but a latitudinal gradient exists such that the latest peaks of spawning occur in higher latitudes. In general, adults breed when water temperatures reach 10º or 12ºC, changing their bathymetric distribution depending on the region they are in and the local current pattern, releasing eggs at depths from 50 to 150 m (Murua *et al*., 1996; 1998; Alheit and Pitcher, 1995). In general, males mature earlier than females. Size at maturity is determined by density-dependent factors like abundance or age/length population structure and density-independent factors like environmental conditions or fishing pressure (Domínguez *et al*., 2008). L50 varies between areas; in the Atlantic populations are between 40–47 cm (Lucio *et al*., 2002; Piñeiro and Saínza, 2003; Domínguez-Petit, 2007). Besides, temporal fluctuations in size at maturity within the population have been also observed which could reflect changes in growth rate (Domínguez *et al*., 2008). Changes in maturity parameters affect stock reproductive potential because smaller and younger females have different reproductive attributes than larger and older individuals (Trippel *et al*., 1997; Mehault *et al*., 2010). Maternal physiological status, spawning experience (recruit or repeat spawners) or food rations during gametogenesis are all known to alter fecundity, egg and larval quality, as well as the duration of the spawning season (Hislop *et al*., 1978; Kjesbu *et al*., 1991; Trippel, 1999; Marteinsdottir and Begg, 2002). Change in stock structure entails a compensatory response of age/size at maturity because the depletion of large fish can be compensated by increased egg production by young fish (Trippel, 1995).

Hake recruitment indices have been related to environmental factors (Sanchez and Gil, 2000). High recruitments occur during intermediate oceanographic scenarios and decreasing recruitment is observed in extreme situations. In Galicia and the Cantabrian Sea, generally moderate environmental factors such as weak Poleward Currents, moderate upwelling and good mesoscale activity close to the shelf lead to strong recruitments. Hake recruitment leads to well-defined patches of juveniles, found in localized areas of the continental shelf. These concentrations vary in density according to the strength of the year class, although they remain generally stable in size and spatial location. These authors have related the year-on-year repetition of the spatial patterns to environmental conditions. In the eastern, progressively narrowing, shelf of the Cantabrian Sea, years during which there is massive inflow of the eastward shelf edge current produce low recruitment indices, due to larvae and prerecruits being transported away from spawning areas to the open ocean.

In Portuguese continental waters the abundance of small individuals is higher between autumn and early spring. In the Southwest main concentrations occur at 200–300 m depth, while in the South they are mainly distributed at coastal waters. In the North of Portugal recruits are more abundant between 100–200 m water depths. These different depth-areas associations may be related with the feeding habits of the recruits, since the zooplankton biomass is relatively higher at those areas.

Hake is a highly *ichthyophagous* species with *euphausiids* although decapod prawns are an important part of its diet for smaller hake (>20 cm). In Galicia and the Cantabrian Sea hake is one of the apex predators in the demersal community, occupying together with anglerfish one of the highest trophic levels (Velasco *et al*., 2003). Its diet at > 30 cm is mainly composed of blue whiting, while other species such as horse mackerel and clupeids are only important in shallow waters and in smaller individuals that also feed on other small fish. Along the Portuguese coast the diet of hake is mainly composed of crustaceans (particularly decapods) and fish. The main food items include blue whiting, sardine, snipefish, decapods and mysids. Cannibalism in the diet of hake is highly variable depending on predator size, alternative prey abundance, year or season. Cannibalism in stomach content observations ranged from 0 to 30% of total volume, with mean values about 5%; this produces a high natural mortality in younger ages.

B. Data

B.1. Commercial catch

Landings

The landings data used in the Southern Hake assessment are based on: (i) Portuguese sales notes compiled by the National Fisheries and Aquaculture Directorate; (ii) Spanish sales notes and owners associations data compiled by IEO; and (iii) Basque Country sales notes and Ship Owners data compiled by AZTI. Since 2011 Spanish landings are submitted by the national authority, which is a different procedure from the past scientific estimations. Scientific landings estimates are presented to ICES as UNALLOCATED

From 1982 to 1993 only annual landings and annual length distribution (only until 80 cm as a plus group) for Spain were available. The length distributions of landings were computed by quarter after 1994. Raising procedures are performed at the national labs before submitting the data for the period before 1994, it was assumed a quarterly catch ratio as the mean of 1994–1999. Annual length distributions were imputed as such since ss can deal with this.

Discards

A Spanish Discard Sampling Programme is being carried out in divisions 8.c and 9.a North since 2003. The series provides information on discarded catch in weight and number and length distributions for Southern hake. Spanish sampling was carried out in 1994, 1997, 1999–2000 and from 2003 onwards. The number of trips sampled by the Spanish program was distributed by three trawl métiers: OTB_DEF_>=55; OTB_MPD_>=55 and PTB_MPD_>=55. Total discards were estimated raising sampling with effort. This series was revised and computed by quarter from 2004 onwards.

The Portuguese Discard Sampling Programme started in 2003 (second semester) and is based on a quasi-random sampling of co-operative commercial vessels. Two trawl fleets are sampled in this programme: Crustacean Trawl and Fish Trawl fleets. The discards estimation method was revised to take into account fishing hours as auxiliary variable and include outlier analysis.

B.2. Biological

An international length-weight relationship for combined sexes for the whole period (no time-trends was observed) has been revised in WKANGHAKE (2022).

a = 0.00000377;

b = 3.16826).

Hake is a dimorphic species where males mature at smaller size than females and also attain smaller asymptotic size (Cerviño, 2014, Murua, 2010). A sex separated model was developed in ss. The model considers that growth and M are different by sex and only female maturity are required to estimate Spawning-stock biomass.

Age information (otoliths) are collected by IEO, AZTI and IPMA. However, due to doubts on growth patterns and unstable ageing criteria. A von Bertalanffy growth model was implemented. A constant growth period before age 1 was estimated in 20.5 cm. Afterwards different vonBertalanffy parameters for males and females were set after sensitivity analysis, assuming a females L_{inf} = 110 cm:

L_{inf} female = 110 cm

K female = 0.14 year -1

L_{inf} male = 73.73 cm

K male = 0.14 year -1

Natural mortality taken from Mediterranean hake with minor modifications to consider differences by sex. M was assumed to decrease with age and having a common M for males and females at age 0 and 1 (inmature ages) and a higher M for males (because slower size at age) afterwards. M changes at age in 4 breakpoints (ages 0, 1, 5 and 15) with linear interpolations between breakpoints. The breakpoints Ms are the following:

sex	Age 0	Age 1	Age 5	Age 15
Female	1.19	0.64	0.34	0.2
Male	1.19	0.64	0.4	0.27

Maturity proportions-at-length was estimated for females based on data since 1982 for Spain and Portugal. A common maturity for the whole period was implemented in the ss model with the following parameters:

L50 = 42.36

Slope = -0.265

WKANGHAKE recommend to review the biology of both hakes and implement it thought a interbenchmark.

B.3. Surveys

The Spanish October groundfish (spGFS-WIBTS-Q4 / G2784) survey uses a stratified random sampling design with half hour hauls and covers the northwest area of Spain from Portugal to France during September/October since 1983 (except 1987).

Two groundfish surveys are carried out annually in the Gulf of Cadiz - in March (spGFS-cspr-WIBTS-Q4 / G7511), from 1994, and in November (spGFS-caut-WIBTS-Q4 / G4309), from 1997. A stratified random sampling design with 5 bathymetric strata, covering depths between 15 and 700 m, is used in this area, with one hour hauls. Hake otoliths have been collected since 2000.

The Portuguese October groundfish (ptGFS-WIBTS-Q4 / G8899) survey has been carried out in Portuguese continental waters since 1979 on board the RV "Noruega" and RV "Capricórnio". Work on calibration of these vessels showed a higher catchability of Capricórnio, in particular at lower sizes, as a consequence these years were calibrated. The main objective of this survey is to estimate hake's abundance indices to be used in stock assessment (Anon., 2008). A stratified sampling design was used from 1989 until 2004. In2005 a new hybrid random-systematic sampling design was introduced, composed by a regular grid with a set of additional random locations (Jardim and Ribeiro Jr., 2007; Jardim and Ribeiro Jr., 2008). The tow duration was 60 minutes until 2001 and reduced to 30 minutes for subsequent years, based on results of an experiment showing no significant differences in the mean abundance and length distribution between the two tow durations (Cardador personal communication, 2007).

B.4. Commercial CPUE

Effort series are collected from Portuguese and Spanish logbooks and compiled by IPMA and IEO.

Hake catches from the Spanish fleet operating in Iberian waters (8.c and 9.a) were standardized using two sources of data. Data were obtained from i) onboard observers (OAB) for 3 trawl métiers (baka, jurelera and pareja) and 1 gillnet métier (volanta) from 2003 to 2020, and from ii) logbooks (DEA) for the bottom-set longlines from 2009 to 2020. Data included for each haul or fishing operation i the catch, the vessel characteristics (LOA = Length overall), fishing operation information (HD = haul duration, FT = fishing time, DE = haul depth) and spatio-temporal data that varied depending on the source. The standardization process was based on fitting mixed-effects models assuming a Gamma distribution with a log link using the INLA approach as follows:

For OAB data:

$$C_i = \alpha + Year_i + Quarter_i + LOA_i + HD_i + DE_i + u_i \text{ with } u_i \sim \text{GMRF}(0,\Sigma)$$

For DEA data:

$$C_i = \alpha + Year_i + Quarter_i + LOA_i + FT_i + a_r + \epsilon_i \text{ with } a_r \sim \text{N}(0,\sigma_a^2)$$

Trawls were combined in one CPUE index making a mean weighted by the inverse of vartiance. Longliners and gillneters were also combined in one using the same methodology.

C. Historical Stock Development

Until 2008 this stock was assessed with XSA models based on ages estimated from ALK. In 2009 a Bayesian VPA was introduced instead. Since 2010, based on the decisions of the Benchmark, a length-based model with GADGET was introduced. GADGET model was rejected in 2020 and a category 3 system with a relative biomass index was used to provide catch advice in 2020 and 21. A Stock Synthesis model was developed under the benchmark WKANGHAKE in 2022.

C.1. Model description

The stock is assessed using Stock Synthesis (https://vlab.noaa.gov/web/stock-synthesis). The main model settings are outlined below and follow the structure of the SS input files. Any settings not described below can be assumed to be the default as indicated in the manual (Methot *et al.*, 2021)

Starter file

- **SSversion**: 3.30
- **F_report_unts:** 5 (unweighted average F for range of ages)
- **F_age_range:** 1–7 ages.

Data file

- **Start year**: 1960
- **nseas:** 4. Commercial data are aggregated by year
- **Nsubseasons:** 2. A separate ALK is calculated for each sub-season; this allows appropriate fitting of the length cohorts in surveys that do not take place in the middle of the year.
- **spawn_month:** 1.
- **Ngenders:** 2. Length composition by sex is available for both surveys.
- **Nages:** 15.
- **N_areas:** 1.
- **Nfleets:** 10
    - FL1_trawlers; commercial fleet; units: biomass.
    - FL2_volpal; commercial fleet; units: biomass
    - FL3_artisanal; commercial fleet; units: biomass
    - FL4_cdfrawl; commercial fleet; units: biomass
    - SpSurv; spGFS-WIBTS-Q4 / G2784
    - PtSurv; ptGFS-WIBTS-Q4 / G8899
    - CdSurv; spGFS-caut-WIBTS-Q4 / G4309
    - SpCPUE_trawlers
    - SpCPUE_volpal
    - PtCPUE (zero weight in the current model)
- **Catch** (note: this is SS terminology but refers to landings only)

- catch_se for both fleets is 0.1 from 1960 to 1982; 0.075 from 1983 to 93; 0.05 from 1994 onwards.
- Fleets 1 and 2 is assumed to have equilibrium catches before the start of the time-series.

- **CPUE**

  Both survey indices are provided as biomass and the error is provided on the lognormal scale.
- **N_discard_fleets**: 1
  - FL1_Trawls; units: biomass; error type: normal
- **Length bins for the population and data**
  - 1cm length bins from 4 to 40
  - 2 cm length bin from 40 to 100
  - 5 cm length bin from 100 to 130cm;
- **Length composition data structure**
  - Length data are available for the 4 commercial fleets, 3 surveys and 3 CPUEs (mirrored to the corresponding fleets).
  - 1984–93: yearly until 80 cm plus
  - 1994 to present: quarterly
- **Age data:** No age data are available
- **Environmental data**: None
- **Generalised size comp data**: None
- **Tag-Recapture data:** None
- **Stock (Morph) comp data:** None
- **Selectivity priors:** None

Control file

- **EmpiricalWAA:** 0 (not available)
- **N_GP:** 1 (single growth pattern)
- **N_platoon**: 1 (single platoon)
- **recr_dist_method:** 3 – each Settle entity.
- **recr_settlements:** 2
- **N_Block_Patterns:** 2
- **natM_type:** 4 breakpoints (Age-0, 1, 5, 15).
- **GrowthModel:** 1 (VonB)
- **Growth_Age_for_L1:** 1
- **Growth_Age_for_L2:** 999 (L2=Linf)
- **maturity_option:** 1 (length logistic)
- **First_Mature_Age:** 2 (ages below this age will have maturity set to zero.)

- **fecundity_option:** 1 (linear eggs/kg on body weight)
- **MG_params:** All biology parameters are fixed and based on life-history information and ss sencitivity analysis performed during the WKANGHAKE:
    - L_at_Amin_Fem_GP_1 20.4
    - L_at_Amax_Fem_GP_1 110
    - VonBert_K_Fem_GP_1 0.14 (estimated by the model, then fixed)
    - CV_young_Fem_GP_1 0.15
    - CV_old_Fem_GP_1 0.15
    - Wtlen_1_Fem_GP_1 0.00000377
    - Wtlen_2_Fem_GP_1 3.16826
    - Mat50%_Fem_GP_1 42.5
    - Mat_slope_Fem_GP_1 -0.265
    - Eggs/kg_inter_Fem_GP_1 1
    - Eggs/kg_slope_Fem_GP_1 0
    - L_at_Amin_Mal_GP_1 20.4
    - L_at_Amax_Mal_GP_1 73.73
    - VonBert_K_Mal_GP_1 0.14
    - CV_young_Fem_GP_1 0.15
    - CV_old_Mal_GP_1 0.15
    - Wtlen_1_Mal_GP_1 0.00000377
    - Wtlen_2_Mal_GP_1 3.16826
    - CohortGrowDev 1
    - FracFemale_GP_1 0.5
- **SR_function:** 3 (Beverton-holt)
- **SR_params:** all fixed except R0
    - SR_LN(R0) estimated in phase 1
    - SR_BH_steep 0.88
    - SR_sigmaR 0.6
    - SR_regime 0
    - SR_autocorr 0
- **do_recdev:** 1
- **MainRdevYrFirst:** 1983
- **MainRdevYrLast:** last data year (surveys and discards can inform Rdev)
- **Recfev_phase:** 3
- **last_early_yr_nobias_adj:** 1965
- **first_yr_fullbias_adj:** 1989

- **last_yr_fullbias_adj:** 2019
- **first_recent_yr_nobias_adj:** last data year+1
- **max_bias_adj:** 0.972
- **F_Method:** 4 Fleet-specific parameter/hybrid F (recommended).
- **Fleet_Params:**
    - Fleet 1: start F 0.05; phase 1
    - Fleet 2: start F 0.05; phase 1
    - Fleet 3: start F 0.05; phase 99
    - Fleet 4: start F 0.05; phase 1
- **Init_F**: estimated by the model. there was fishing before 1960.
- **Q_options:**
    - Fleet 3 (IBTS): link 1 (simple Q); no extra se; no bias adj; float
    - Fleet 4 (MONK): link 1 (simple Q); no extra se; no bias adj; float
    - SpSurv; link 1 (simple Q); extra se; no bias adj; float
    - PtSurv; link 1 (simple Q); extra se; no bias adj; float
    - CdSurv; link 1 (simple Q); extra se; no bias adj; float
    - SpCPUE_trawlers:_ link 1 (simple Q); no extra se; no bias adj; float
    - SpCPUE_volpal: link 1 (simple Q); no extra se; no bias adj; float
    - PtCPUE (zero weight in the current model)
- **size_selex_types:**
    - FL1_Trawl: Pattern 1 (logistic); discards (with time-varying Retain_L_infl)
    - FL2_Gillnets: Pattern 1 (logistic); discards
    - FR_IE_IBTS: Pattern 24 (double-normal)
    - IE_MONK: Pattern 1 (logistic)
- **age_selex_types:** - None
- **size_selex_para:**
    - FL1_trawlers; 24 (double normal) with discards
    - FL2_volpal; 1 (logistic)
    - FL3_artisanal; 24 (double normal)
    - FL4_cdfrawl; 24 (double normal)
    - SpSurv; 24 (double normal)
    - PtSurv; 24 (double normal)
    - CdSurv; 24 (double normal)
    - SpCPUE_trawlers; 24 (double normal)
    - SpCPUE_volpal; 24 (double normal)

  - PtCPUE (zero weight in the current model)
- **size_selex_params_tv**: time varying retention size at inflection
  - dev_se fixed at 2.5
  - auocorr fixed at 0
- **Use_2D_AR1_selectivity:** 0
- **TG_custom:** 0
- **DoVar_adjust:** 1
- **maxlambdaphase:** 1
- **sd_offset:** 1
- **N_lambdas:** 0

Phases

The phases were set according to the following rule-of-thumb:

- Phase 1: R0 and Ms
- Phase 2: biology (+ time varying bio parameters or next phase)
- Phase 3: main recdev
- Phase 4: early recdev
- Phase 5: Main sel para
- Phase 6: Other sel para
- Phase 7: time varying para in sel

Annual updates

Every year when the model is updated the following settings are also reviewed:

- The recruitment deviation end year, and if informative, the parameterization of the recruitment biased correction ramp.
- The time varying parameters in the retention curve
- The weighting of the length composition using the Dirichlet method.

G. Biological Reference Points

Biological reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks (2021). Reference points were taken from SS model. The ICES R package msy was used (eqsim approach) only for risk assessment purposes. The approach is detailed in the WKANGHAKE report (ICES, 2022).

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	7556 t	B_{pa}
	F_{msy}	0.221	SS3 simulations
Precautionary approach	B_{lim}	6011 t	Segmented regression change point.
	B_{pa}	7556 t	$\exp(1.654 \times \sigma) \times B_{lim}$, $\sigma = 0.139$.

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Framework	Reference point	Value	Technical basis
	F_{lim}	0.694	The F that provides a 50% probability for SSB to be above B_{lim}.
	F_{pa}	0.558	F_{p05} with ICES MSY AR: The F that provides a 95% probability for SSB to be above B_{lim}.
	F_{MGT}	Not defined	
	SSB_{MGT}	Not defined	
	MAP MSY $B_{trigger}$	7556 t	MSY $B_{trigger}$
	MAP B_{lim}	6011 t	B_{lim}
	MAP F_{msy}	0.221	F_{msy}
Management plan	MAP range F_{lower}	0.151	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
	MAP range F_{upper}	0.311	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.

H. Short term predictions settings

The following are default forecast options although a change in the selected years can be considered by WGBIE whether the group considers there is a good reason (e.g. changes in trends) to do it.

- Biology (Mean weights-at-age, maturity-at-age): already modelled as time invariants. No need to choose a year range
- Discard proportions-at-age: as estimated by the retention model
- Exploitation pattern: average last 3 years
- F *status-quo* average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year.
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship.
- Recruitment in the last data year(s): if the working group believes these are not accurately estimated it can be replaced with the recruitment predicted from SS stock–recruit relationship.

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Stock Annex: Black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a-b and 8.d (Celtic Seas, Bay of Biscay)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Black-bellied anglerfish (ank.27.78abd)
Working group	Working Group on Bay of Biscay and Iberian Waters Ecoregion (WGBIE)
Last updated	February 2022
Revised by	WKANGHAKE (2022)
Timeline of revisions	WKANGLER (ICES, 2018): new stock annex, previously only a combined annex for the two *Lophius* species in the area was available.
	WGBIE 2018 meeting: minor additions.
Main modifications	WKANGHAKE (ICES, 2022): new assessment model; reference points; forecast.
Last Benchmarked	WKANGHAKE (ICES, 2022)

A. General

A.1 Stock definition

ICES considers black anglerfish in areas 27.7 and 27.8abd to be a stock for assessment purposes. However, there is evidence of considerable potential for long-distance migration and it is not clear whether this stock definition is appropriate. Because there is currently insufficient information to change the stock boundaries, the current stock definition remains unchanged.

The TACs are set separately for areas 27.7 and 27.8 but for the two species of anglerfish combined (*L piscatorius* and *L. budegassa*).

A.2 Fishery

A.2.1 General description

Both species of anglerfish (*L piscatorius* and *L. budegassa*) are taken in a mixed fishery, mainly with hake, megrim and *Nephrops*.

The fishery for anglerfish developed in the late 1960s and landings quickly reached around 25 thousand tonnes (for both *Lophius* species combined). Since then, landings have fluctuated between 20 and 40 thousand tonnes per year.

France takes the vast majority of the landings; followed by Spain, the UK and Ireland. Minor landings have been recorded for Belgium, Germany and Portugal.

A.3 Ecosystem aspects

Black anglerfish occur throughout the Northeast Atlantic and in the Mediterranean and Black sea. They are most abundant at depths of 200–500 m. Juveniles are mainly found offshore in the western Celtic Sea and sometimes in the Bay of Biscay.

Anglerfish are ambush predators who feed opportunistically on passing prey and are attracted using a fleshy lure on the *illicium*. The diet is dominated by fish and, to a lesser extent, cephalopods. Small gadoids have relatively high importance in their diet (Power *et al.*, unpublished). Cannibalism appears to be rare (Laurenson and Priede, 2005).

There are no reports of predators that specifically target anglerfish in European waters (Thangstad *et al.*, 2006). Indirect predation by seals of netted fish is common though, and seals may prey directly on anglerfish as well. Anglerfish remains are commonly found in the stomachs of sperm whales (e.g Martin and Clarke, 1986). In Faroese waters, juvenile anglerfish remains have been found in the stomachs of large cod (Thangstad *et al.*, 2006).

B. Data

B.1 Commercial catch

B.1.1 Landings data (tonnage and length composition)

Landings are generally reported for the two species combined (*L piscatorius* and *L. budegassa*). The combined landings are split into species at the national level, based on the species composition in the sampling data. Some countries use annual proportions of the two species; others estimate proportions by fleet, port and/or quarter. Spain catches the largest proportion of *L. budegassa* (around 50%) while the UK catches the smallest proportion (around 5% *L. budegassa*).

Some countries applied minor corrections for underreported landings.

In recent years landings data have been reported by quarter, ICES division and métier level 6. While the logbook data can be reported at this level of disaggregation, the sampling programmes are unable to support estimates for such a large number of strata (four quarters, 13 divisions, ~20 métiers). Therefore, the number of samples in each stratum is generally low, and aggregation of these data tends to result in imprecise length composition data. The landings length distributions of the recent period (2002–onwards) appear to be poorer at tracking cohorts than the data obtained from the period before that (1986–2001) when each country produced national estimates based on the stratification of their sampling programme.

The large number of métiers was reduced to a small number of gear groups (level 4 métiers):

- OTB_DEF (otter trawls targeting demersal fish)
- OTB_CRU (otter trawls targeting *Nephrops*)
- GNS DEF (gillnets targeting demersal fish)
- TBB_DEF (beam trawls targeting demersal fish)
- MIS_MIS (miscellaneous or unknown métiers)

The catches are dominated by OTB_DEF (consistently around 80%); OTB_CRU take about 10%; GNS_DEF take around 5% of the catches; TBB_DEF around 5%.

For landings strata that have no sampling data, the length–frequency distributions are imputed from samples of the same country, quarter and year, if available, otherwise from the combined sample data from all countries in the relevant quarter and year.

French landings

France takes nearly 50% of the landings of this stock. The sample sizes are generally between ten and 50 trips per stratum for the dominant strata. Overall, less than half the landings have sample data associated with them, resulting in considerable imputations.

Spanish landings

Spain took around 40% of the landings until 2013, after which this declined to around 20%. Spanish sample sizes are generally low (< 10 trips), even for strata that dominate the overall landings. However, most of the landings have sample data associated with them, so there is virtually no imputation required.

UK (England) landings

The UK generally takes less than 5% of the landings. The sample sizes vary considerably from year-to-year and between strata, however, England has very few strata that contribute more than 1% to the total estimate. Slightly more than half of the landings have associated sample data, resulting in considerable imputations.

Irish landings

Ireland takes 5–10% of the landings. Irish sample sizes are generally low (< 10 trips per stratum) but Ireland has very few strata that contribute more than 1% to the total estimate. About two-thirds of the landings have associated sample data, resulting in a moderate amount of imputations.

Other landings

The remainder of the landings are mainly from Belgium, and Scotland. They contribute very little to the overall landings.

Landings input for the model

Landings data (tonnage and length composition) were merged into two fleets for the model:

- Fleet 1: All trawl gears, all countries
- Fleet 2: All gillnets, all countries

Historic landings (1950–1985) of *Lophius budegassa* were reconstructed from the official landings statistics of the combined *Lophius* species by applying the average species proportions for the period 1986–1989 in the landings by country, gear group (trawls and gillnets) and ICES area (27.7 and 27.8).

B.1.2 Discards estimates (tonnage and length composition)

Discarding in this stock is quite variable and in the order of 10–25% by weight. For landings strata with missing discards, the discard volume was estimated using the proportions of the catch that were discarded for similar strata using the following hierarchy:

1. If discard data were available for the same country, gear group and year, these discard proportions were applied to the landings of the strata with missing discards;
2. If discard data were only available for the same gear group and year, these discard proportions were applied;

3. If discard data were only available for the year, these discard proportions were applied.

The correlation between landings and discards is quite poor, however, no alternative method is available and the overall contribution of discards to the catch is relatively small.

French discards

The sample sizes of the French discard estimates are relatively high (10–20 trips per stratum). However, most landings strata did not have associated discard estimates, which resulted in considerable imputations, making the overall discard estimates very uncertain.

Spanish discards

The Spanish discard estimates generally have a high sample size, the reason for this appears to be that all Spanish sampling data were combined and subsequently split out across the strata. This is likely to provide a more precise and accurate estimate than the French approach.

UK (England) discards

English sample sizes for discards are variable but generally > 10 trips for the most significant strata.

Irish discards

Irish sample sizes were relatively low and data were estimated on an annual basis and subsequently divided across the strata based on the proportion of landings in each stratum. As anglerfish grow quickly during their first few years, the quarterly length distributions will be inaccurate.

Other discards

Discards by other countries are expected to be minor and are imputed using the ratio of discards to landings from the countries that provided discard data.

Discard input for the model

Like the landings, discard data (tonnage and length composition) were merged into two fleets for the model:

- Fleet 1: All trawl gears, all countries
- Fleet 2: All gillnets, all countries

B.1.3 Recreational catches

Recreational catches are assumed to be zero.

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B.2 Biological sampling

B.2.1 Maturity

Spawning females are very rarely observed, which makes it difficult to estimate maturity. Based on estimates from the literature and sampling data from Ireland, the mean length-at-first maturity was estimated to be around 65 cm for females.

Table B.1. Estimates of L50 (mean length at first maturity) of *L. budegassa* at various latitudes from the literature and unpublished data.

Reference	Area	Latitude	Sex	L50
Landa, 2014	8.c and 9.a	42	F	53
Landa, 2014	8.c and 9.a	42	M	36
Azevedo, 1996	Portugal	40	F	56
Azevedo, 1996	Portugal	40	M	37.6
Duarte, 2001	Iberian coast	40	F	53.6
Duarte, 2001	Iberian coast	40	M	38.6
Quincoces, 1998	Biscay	45	F	64.5
Quincoces, 1998	Biscay	45	M	34.5
Ireland, unpubl.	W Ire	54	F	65
Ireland, unpubl.	W Ire	54	M	50

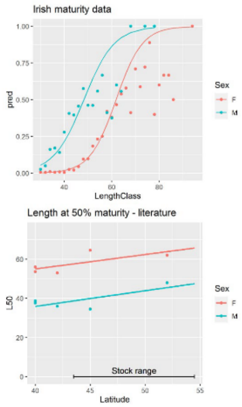

Figure B1. The plots show maturity-at-length from Irish surveys (top-right) and L50 estimates from various locations (bottom-right). The stock area (27.7,8abd) ranges from 44.5 to 54.5 degrees latitude.

B.2.2 Natural mortality

Lorenzen (1996) estimates for natural mortality were applied to young ages (where predation can be assumed to be the main source of natural mortality). For large fish, there is no clear relationship between size and M in Lorenzen's analysis (although this is not explored in the 1996 paper). Applying Lorenzen's estimates of M for older (large) fish would result in an unrealistically low M for old fish. Therefore, from age 4 onwards, M was fixed at the estimate from the FishLife R library, which takes account of the life history and taxonomic hierarchy of the stock. There was no basis to assume different M for the two sexes; length-at-age for the young ages (where Lorenzen applies) is almost identical for males and females.

Age 0	Age 1	Age 2	Age 3	Age 4+
1.00	0.72	0.44	0.34	0.32

B.2.3 Growth

Based on length–frequency analyses (supported by tagging data), WKANGHAKE (ICES, 2022) estimated the von Bertalanffy growth parameters for females as below. An SS model run was then performed to estimate L_{inf} and K for males and these parameters were subsequently fixed.

	L_{inf}	K	t0
Females	129	0.101	0.009
Males	78	0.197	0.099

B.2.4 Length–weight

WKANGHAKE (ICES, 2022) estimated the length-weight parameters for this stock to be: a = 1.77e-05 and b = 2.95

B.3 Surveys

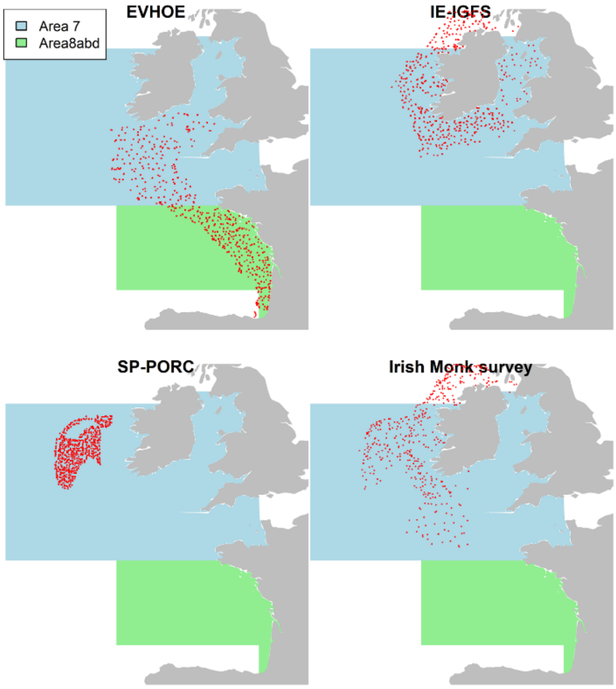

Figure B1. Spatial coverage of the available surveys. Red points indicate trawl positions; the full time-series is plotted so the number of trawl positions is not an indication of the annual number of trawls completed. The blue area represents 27.7 and the green area is 27.8abd.

B.3.1 Western IBTS Q4 EVHOE and IGFS surveys (France/Ireland)

The Irish IBTS Q4 groundfish survey (IGFS) covers areas 27.7bgjk. The French EVHOE survey covers areas 27.7j8ab. Both surveys use a GOV trawl and are coordinated and standardized under WGIBTS. Together the two surveys cover the majority of the stock area up to depths of 200–300 m. This is where most of the young fish occur. Older fish migrate to deeper waters, and may not be fully available to these surveys.

The surveys are combined by simply weighting their contributions by the area covered by each survey series (IGFS gets a weight of 45% and EVHOE 55%). No correction is made for the small area of overlap. A more sophisticated method of estimating a combined index by accounting for spatio-temporal autocorrelation as well as differences in catchability between the two surveys is also available. The index using this method is very similar to the weighted average of the two indices and was used to replace the index value for 2017 when a large part of the survey area was not covered and the 'traditional' index could not be calculated.

WKANGHAKE (2022) decided to include the combined Irish/French biomass index and sex-disaggregated length composition data in the assessment model.

B.3.2 Western IBTS Q4 Porcupine Survey (Spain)

The Spanish Groundfish Survey in the Porcupine bank (SP-Porc) covers ICES divisions 27.7c,k and a small portion of 27.7b corresponding to the Porcupine Bank and the adjacent area in western Irish waters, covering depths between 180 and 800 m.

This survey catches very few black anglerfish and is therefore not used in the assessment.

B.3.3 Irish Anglerfish and Megrim Survey (Ireland)

Irish anglerfish survey data in area 27.7 are available for the years 2007, 2008 (under the acronym SIAMISS), 2016 onwards (IAMS). These surveys were designed to estimate the biomass of anglerfish and they cover a significant part of the stock in all depths up to 1000 m. Note that the combined SIAMISS-IAMS survey index is also known as the Irish Monkfish survey or IRL_MONK survey.

WKANGHAKE (ICES, 2022) decided to include the combined IAMS biomass index and sex-disaggregated length composition data in the assessment model.

B.4 Commercial CPUE

WKANGLER (ICES, 2018) rejected the use of commercial CPUE data due to concerns about changes in efficiency, targeting behaviour, quota restrictions, technical measures, discarding and compliance. However, trends in effort, landings and LPUE or CPUE may be used by the assessment working group as auxiliary information. WKAngHake (ICES, 2022) supported this approach and did not evaluate commercial CPUE data.

B.5 Other relevant data

Official landings data are available for the combined *Lophius* species since 1903. While the historic data cannot be separated into the two species and may suffer from inaccurate reporting, they provide useful insights into the development of the fisheries before the period covered by the assessment.

C Assessment methods and settings

The stock is assessed using Stock Synthesis (https://vlab.noaa.gov/web/stock-synthesis).

The main model settings are outlined below and follow the structure of the SS input files. Any settings not described below can be assumed to be the default as indicated in the manual (Methot *et al.*, 2021).

Starter file

- **SSversion**: 3.30
- **F_report_unts:** 5 (unweighted average F for range of ages)
- **F_age_range:** 3–10.

Data file

- **nseas:** 1. Commercial data are aggregated by year
- **Nsubseasons:** 4. A separate ALK is calculated for each sub-season; this allows appropriate fitting of the length cohorts in surveys that do not take place in the middle of the year.
- **spawn_month:** 1.
- **Ngenders:** 2. Length composition by sex is available for both surveys.
- **Nages:** 15.
- **N_areas:** 1.
- **Nfleets:** 4
    - FL1_Trawls; commercial fleet; units: biomass.
    - FL2_Gillnets; commercial fleet; units: biomass
    - FR_IE_IBTS; Combined French-Irish IBTS Q4 groundfish surveys
    - IE_IAMS; Irish Q1 Anglerfish and Megrim Survey (a.k.a IE_MONK)
- **Catch** (note: this is SS terminology but refers to landings only)
    - catch_se for both fleets is 0.2 from 1950 to 1999 and 0.1 from 2000 onwards.
    - Fleet 1 is assumed to have equilibrium catches before the start of the time-series.
- **CPUE**
  Both survey indices are provided as biomass and the error is provided on the lognormal scale.
- **N_discard_fleets**: 2
    - FL1_Trawls; units: biomass; error type: normal
    - FL2_Gillnets; units: biomass; error type: normal; years with very small discard estimates were removed to improve the model fit.
- **Length bins for the population and data**
    - 2 cm length bins from 2 to 130 cm; 5 cm bins from 130–140
- **Length composition data structure**
    - Length data are available for the 2 commercial fleets and 2 survey fleets. Length data for the early years of the IE_IAMS were not used.
    - Bin compression: 0.001; stronger compression does not allow the sex-ratio of the largest fish to be fitted because there are almost no males in those size bins which leads those bins to be compressed.
    - Dirichlet option selected for all four fleets
- **Age data:** No age data are available
- **Environmental data**: None
- **Generalised size comp data**: None
- **Tag-Recapture data:** None
- **Stock (Morph) comp data:** None

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- **Selectivity priors:** None

Control file

- **EmpiricalWAA:** 0 (not available)
- **N_GP:** 1 (single growth pattern)
- **N_platoon**: 1 (single platoon)
- **recr_dist_method:** 4 – none, (growth pattern x settlement x area = 1).
- **recr_dist_pattern:** All recruitment assumed to occur in month 1 at age 0
- **N_Block_Designs:** 0
- **natM_type:** 3 (Age-specific M).
- **GrowthModel:** 1 (VonB)
- **Growth_Age_for_L1: 1**
- **Growth_Age_for_L2:** 999 (L2=Linf)
- **maturity_option:** 1 (length logistic)
- **First_Mature_Age:** 2 (ages below this age will have maturity set to zero.)
- **fecundity_option:** 1 (linear eggs/kg on body weight)
- **MG_params:** All biology parameters are fixed and based on life history information compiled during the WKANGHAKE data compilation workshop:
    - L_at_Amin_Fem_GP_1 12.5
    - L_at_Amax_Fem_GP_1 129
    - VonBert_K_Fem_GP_1 0.101
    - CV_young_Fem_GP_1 0.244 (estimated by the model, then fixed)
    - CV_old_Fem_GP_1 0.1 (assumed)
    - Wtlen_1_Fem_GP_1 0.0000177
    - Wtlen_2_Fem_GP_1 2.95
    - Mat50%_Fem_GP_1 65
    - Mat_slope_Fem_GP_1 -0.15
    - Eggs/kg_inter_Fem_GP_1 1
    - Eggs/kg_slope_Fem_GP_1 0
    - L_at_Amin_Mal_GP_1 12.5
    - L_at_Amax_Mal_GP_1 78
    - VonBert_K_Mal_GP_1 0.197
    - CV_young_Fem_GP_1 0.244 (estimated by the model, then fixed)
    - CV_old_Mal_GP_1 0.1 (assumed)
    - Wtlen_1_Mal_GP_1 0.0000177
    - Wtlen_2_Mal_GP_1 2.95
    - CohortGrowDev 1
    - FracFemale_GP_1 0.5
- **SR_function:** 3 (Beverton-holt)
- **SR_params:** all fixed except R0
    - SR_LN(R0) estimated in phase 1
    - SR_BH_steep 0.93
    - SR_sigmaR 0.5
    - SR_regime 0
    - SR_autocorr 0
- **do_recdev:** 1
- **MainRdevYrFirst:** 1986 (first data year)
- **MainRdevYrLast:** last data year (surveys and discards can inform Rdev)
- **Recfev_phase:** 2
- **last_early_yr_nobias_adj:** 1951 (suggested by r4ss)
- **first_yr_fullbias_adj:** 1990.7 (suggested by r4ss)
- **last_yr_fullbias_adj:** last data year (suggested by r4ss)

- **first_recent_yr_nobias_adj:** last data year+1 (suggested by r4ss)
- **max_bias_adj:** 0.9297 (suggested by r4ss)
- **F_Method:** 4 Fleet-specific parameter/hybrid F (recommended).
- **F_4_Fleet_Params:**
  - Fleet 1: start F 0.30; phase 1
  - Fleet 2: start F 0.05; phase 2
- **Init_F**: there was some fishing before 1950; however, the model estimated initial F to be very low hitting the boundary of 1e-3 in most runs but in some runs initial F converged on a very high value. As it does not affect the rest of the model, the value was fixed at 0.01.
- **Q_options:**
  - Fleet 3 (IBTS): link 1 (simple Q); no extra se; no bias adj; float
  - Fleet 4 (MONK): link 1 (simple Q); no extra se; no bias adj; float
- **size_selex_types:**
  - FL1_Trawl: Pattern 1 (logistic); discards (with time-varying Retain_L_infl)
  - FL2_Gillnets: Pattern 1 (logistic); discards
  - FR_IE_IBTS: Pattern 24 (double-normal)
  - IE_MONK: Pattern 1 (logistic)
- **age_selex_types:** - None
- **size_selex_para:**
  - Main para estimated in phase 5, others in phase 3
  - Retention para estimated in phase 5 and 6; random walk on retention inflection parameter from 2005 onwards due to the gradual adoption of minimum market weight.
- **dirichlet_params:**
  - Estimates in phase 8 for all 4 fleets
- **size_selex_params_tv**: time varying retention size at inflection
  - dev_se fixed at 2.5
  - auocorr fixed at 0
- **Use_2D_AR1_selectivity:** 0
- **TG_custom:** 0
- **DoVar_adjust:** 1
- **maxlambdaphase:** 1
- **sd_offset:** 1
- **N_lambdas:** 0

Phases

The phases were set according to the following rule-of-thumb:

- Phase 1: R0 and Ms
- Phase 2: biology (+ time varying bio parameters or next phase)
- Phase 3: main recdev
- Phase 4: early recdev
- Phase 5: Main sel para and q (when estimated, not in this cases as we are using floats)
- Phase 6: Other sel para
- Phase 7: time varying para in sel
- Last phase: Dirichlet parameters

Annual updates

Every year when the model is updated the following settings are also reviewed:

- The recruitment deviation end year, and if informative, the parameterization of the recruitment biased correction ramp.
- The time-varying parameters in the retention curve
- The weighting of the length composition using the Dirichlet method.

D Short-term prediction

The following are default forecast options. The working group will review these annually and adapt as necessary:

- Mean weights-at-age, maturity-at-age; discard proportions-at-age: average last 3 years
- Exploitation pattern: average last 3 years
- F status-quo: average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year.
- F in the intermediate year: F status-quo
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship.
- Recruitment in the last data year(s): this may not be accurately estimated it can be replaced with the recruitment predicted from Stock Synthesis stock–recruit relationship.

E Biological reference points

Biological reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks (2021). The ICES R package MSY was used (EqSim approach). The approach is detailed in the WKANGHAKE report (ICES, 2022).

The reference points are as follows:

Reference point	Value	Rationale
B_{lim}	12 073	SSB (2004); lowest SSB with high recruitment
B_{pa}	16 776	B_{lim} with assessment error
MSY $B_{trigger}$	16 776	B_{pa}
F_{lim}	Undefined	The estimate of F_{lim} was inconsistent with F_{pa} and therefore was not defined.
F_{pa}	0.257	F with 95% probability of SSB $\geq B_{lim}$ (BH with $B_{trigger}$)
F_{MSY}	0.163	Stochastic simulations (BH with $B_{trigger}$)
$F_{MSY\ lower}$	0.112	Stochastic simulations (BH with $B_{trigger}$)
$F_{MSY\ upper}$	0.245	Stochastic simulations (BH with $B_{trigger}$)
B_{MSY}5pc	17 902	5% probability of SSB < B_{lim}

F Other issues

F.1 Stock assessment–historic overview

YEAR	2000(?)–2007	2008–2021	2022 ONWARDS
Model	XSA	None – survey trends	Stock Synthesis
Software	vpa.exe/ FLXSA		SS 3.30
Landings	1986–		1986-
Discards			2003-
Age data	2–14+		
Length data			1986-
Fleets	FR-FU04 - landings	FR-EVHOE (2008–17)	FL1 Trawl (catch)
	FR-FU14 – landings	IE_IGFS (2016,17 only)	FL2 Gillnets (catch)
	SP-VIGOTR7 – landings	SP-PORC (2016,17 only)	FR_IE_IBTS (survey)
	SP-BAKON7 – landings	FR_IE_IBTS (2017–21)	IE_IAMS (survey)
	SP-BAKON8 – landings		
	FR-EVHOE – survey		

The stock was assessed using XSA up to 2007. However, it became apparent that the age data were not reliable and cohorts could not be accurately tracked. From 2008 to 2021 the catch advice was based on survey trends only. The 2018 benchmark (ICES, 2018) developed an age-based assessment model (a4a) which used length splitting to derive numbers-at-age but this model was not accepted due to its sensitivity to assumed growth M parameters. Therefore, the advice continued to be based on survey trends until 2021. Since 2022 the advice is based on the Stock Synthesis model described here.

F.2 Management and advice

The TACs are set separately for areas 27.7 and 27.8 but for the two species of anglerfish combined (*L piscatorius* and *L. budegassa*).

G References

ICES. 2018. Report of the Benchmark Workshop on Anglerfish Stocks in the ICES Area (WKANGLER), 12–16 February 2018, Copenhagen, Denmark. ICES CM 2018/ACOM:31. 177 pp.

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Lorenzen, K. "The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture." Journal of fish biology 49.4 (1996): 627–642.

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Methot RD., Wetzel CR, Taylor IG, Doering KL, and Johnson KF (October 1, 2021). Stock Synthesis User Manual Version 3.30.18 NOAA Fisheries Seattle, WA.

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Thangstad, T. 2006. Anglerfish (*Lophius* spp) in Nordic waters. Nordic Council of Ministers.

Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2014. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72(1), 82–92.

Stock Annex: White anglerfish (Lophius piscatorius) in Subarea 7 and divisions 8.a–b and 8.d (Celtic Seas, Bay of Biscay)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	White anglerfish (mon.27.78abd)
Working group	Working Group on Bay of Biscay and Iberian Waters Ecoregion (WGBIE)
Last updated	February 2022
Revised by	WKANGHAKE (2022)
Timeline of revisions	WKANGLER (ICES, 2018): new stock annex, previously only a combined annex for the two *Lophius* species in the area was available. WGBIE 2018 meeting: minor additions.
Main modifications	WKANGHAKE (ICES, 2022): new assessment model; reference points; forecast.
Last Benchmarked	WKANGHAKE (ICES, 2022)

A. General

A.1 Stock definition

ICES considers white anglerfish in areas 27.7 and 27.8abd to be a stock for assessment purposes. However there is evidence of considerable potential for long-distance migration and it is not clear whether this stock definition is appropriate. Because there is currently insufficient information to change the stock boundaries, the current stock definition remains unchanged (except the inclusion of area 27.7a in 2018).

The TACs are set separately for areas 27.7 and 27.8 but for the two species of anglerfish combined (*L piscatorius* and *L. budegassa*).

A.2 Fishery

A.2.1 General description

Both species of anglerfish (*L piscatorius* and *L. budegassa*) are a taken in a mixed fishery, mainly with hake, megrim and *Nephrops*.

The fishery for anglerfish developed in the late 1960s and landings quickly reached around 25 thousand tonnes (for both *Lophius* species combined). Since then, landings have fluctuated between 20 and 40 thousand tonnes per year.

France takes the vast majority of the landings; followed by Spain, the UK and Ireland. Minor landings have been recorded for Belgium, Germany and Portugal.

A.2.2 Fishery management regulations

A.3 Ecosystem aspects

White anglerfish occur throughout the Northeast Atlantic and in the Mediterranean and Black sea. They are most abundant at depths of 200–800 m but also occur in coastal waters. Juveniles are mainly found offshore; medium-sized fish migrate inshore and the adults move offshore again. Therefore, anglerfish may exploit a number of ecological niches at various stages of their life cycle.

Anglerfish are ambush predators who feed opportunistically on passing prey, which is attracted using a fleshy lure on the *illicium*. The diet is dominated by fish and, to a lesser extent, cephalopods. Small gadoids have a relatively high importance in their diet (Power *et al*., unpublished).

There are no reports of predators that specifically target anglerfish in European waters (Thangstad *et al*., 2006). Indirect predation by seals of netted fish is common though and seals may prey directly on anglerfish as well. Anglerfish remains were found in one stranded sperm whale in the Netherlands (Santos *et al*., 2002). In Faroese waters juvenile anglerfish remains have been found in the stomachs of large cod (Thangstad *et al*., 2006).

B. Data

B.1 Commercial catch

B.1.1 Landings data

Landings are generally reported for the two species combined (*L piscatorius* and *L. budegassa*). The combined landings are split into species at national level, based on the species composition in the sampling data. Some countries use annual proportions of the two species, others estimate proportions by fleet, port and/or quarter. Spain catches the smallest proportion of *L. piscatorius* (around 50%) while the UK catches the largest proportion (around 95% *L. piscatorius*).

Some countries applied minor corrections for underreported landings.

In recent years landings data have been reported by quarter, ICES division and métier level 6. While the logbook data can be reported at this level of disaggregation, the sampling programmes are unable to support estimates for such a large number of strata (four quarters, 13 divisions, ~20 métiers). Therefore the number of samples in each stratum is generally low and aggregation of these data tends to result in imprecise estimates. The landings length distributions of the period covered by the latest data call (2002–2016) appear to be poorer at tracking cohorts than the data obtained from the period before that (1986–2001) when each country produced national estimates based on the stratification of their sampling programme.

The large number of métiers was reduced to a small number of gear groups (level 4 métiers):

- OTB_DEF (otter trawls targeting demersal fish)
- OTB_CRU (otter trawls targeting *Nephrops*)
- GNS DEF (gillnets targeting demersal fish)
- TBB_DEF (beam trawls targeting demersal fish)
- MIS_MIS (miscellaneous or unknown métiers)

The catches are dominated by OTB_DEF (consistently around 65%); GNS_DEF take just under 20% of the catches; TBB_DEF around 10% and OTB_CRU around 5%.

For landings strata that have no sampling data, the length–frequency distributions are imputed from samples of the same country, quarter and year, if available, otherwise from the combined sample data from all countries in the relevant quarter and year.

The historic WG landings did not include landings from area 27.7a. Official landings from EUROSTAT were added to the landings submitted to InterCatch (all *Lophius* landings in 27.7a were assumed to be *L. piscatorius* as survey data indicate that *L budegassa* does not occur there), Additionally, certain countries with minor landings did not submit these to InterCatch for the full period, Again, the official landings were used in these cases, multiplied by the international proportion of *L. piscatorius* in the combined *Lophius spp.* landings.

Table B1. Overview of official landings that were added to the landings reported to InterCatch

Country	Period	Avg proportion of total landings
All countries 27.7a landings	1986–2017	3%
Belgium	2002–2011	3%
Germany	2002–2016	0.7%
Netherlands	2002–2015	0.02%

French landings

France takes nearly 60% of the landings of this stock. The sample sizes are generally between ten and 50 trips per stratum for the dominant strata. Overall, less than half the landings have sample data associated with them, resulting in considerable imputations.

Spanish landings

Spain takes 10–20% of the landings. Spanish samples sizes are generally low (< 10 trips), even for strata that dominate the overall landings. However, most of the landings have sample data associated with them, so there is virtually no imputation required.

UK (England) landings

The UK also takes 10–20% of the landings. The sample sizes vary considerably from year-to-year and between strata, however England has very few strata that contribute more than 1% to the total estimate. Slightly more than half of the landings have associated sample data, resulting in considerable imputations.

Irish landings

Ireland takes just under 10% of the landings. Irish sample sizes are generally low (<10 trips) but Ireland has very few strata that contribute more than 1% to the total estimate. About two-thirds of the landings have associated sample data, resulting in a moderate amount of imputations.

Other landings

The remainder of the landings are mainly from Belgium, Scotland. They contribute very little to the overall landings.

B.1.2 Discards estimates

Discarding in this stock is relatively minor (in the order of 5–10%). For landings strata with missing discards, the discard volume was estimated using the proportions of the catch that were discarded for similar strata using the following hierarchy:

1. If discard data were available for the same country, gear group and year, these discard proportions were applied to the landings of the strata with missing discards;
2. If discard data were only available for the same gear group and year, these discard proportions were applied;
3. If discard data were only available for the year, these discard proportions were applied.

The correlation between landings and discards is quite poor, however no alternative method is available and the overall contribution of discards to the catch is relatively small.

For the period 1986 to 2002 no discard data were available. For this period the discards were estimated from the mean proportion of the catch that was discarded during the period 2003–2016 (6.77%).

French discards

The sample sizes of the French discard estimates are relatively high (>20 trips). However, most landings strata did not have associated discard estimates which resulted in considerable imputations, making the overall discard estimates very uncertain.

Spanish discards

The Spanish discard estimates generally have a high sample size, the reason for this appears to be that all Spanish sampling data were combined and subsequently split out across the strata. This is likely to provide a more precise and accurate estimate than the French approach.

UK (England) discards

English sample sizes for discards are variable but generally >10 trips for the most significant strata.

Irish discards

Irish sample sizes were relatively low and data were estimated on an annual basis and subsequently divided across the strata based on the proportion of landings in each stratum. As anglerfish grow quickly during their first few years, the quarterly length distributions will be inaccurate.

Other discards

Belgium provided discard estimates for 2012 and 2013 only.

B.1.3 Recreational catches

Recreational catches are assumed to be zero.

B.2 Biological sampling

B.2.1 Maturity

Spawning females are very rarely observed which makes it difficult to estimate maturity. Based on estimates from the literature and sampling data from Ireland, the mean length-at-first maturity was estimated to be around 82 cm for females.

Reference	Area	Latitude	Sex	L50
Dyb in Thangstad, '06	W Norway	62	F	61
Dyb in Thangstad, '06	W Norway	62	M	57
Dyb in Thangstad, '06	North Sea	58	F	83
Dyb in Thangstad, '06	North Sea	58	M	57
Offstad, 2017	Faroe	62	F	84
Offstad, 2017	Faroe	62	M	58
Colmenero, 2017	NW med	40	F	60
Colmenero, 2017	NW med	40	M	49
Alfonso-Dias, 1996	W Scot	56	F	73.5
Alfonso-Dias, 1996	W Scot	56	M	48.9
Laurenson, 2003	Shetland	60	F	98
Laurenson, 2003	Shetland	60	M	58
Duarte, 2001	Iberian coast	40	F	93.9
Duarte, 2001	Iberian coast	40	M	50.3
Gordon, 2001	W Scot	56	F	92
Gordon, 2001	W Scot	56	M	56
Quincoces, 1998	Biscay	45	F	73.2
Quincoces, 1998	Biscay	45	M	52.7
Larensen, 2007	Shetland	60	F	96.7
Larensen, 2007	Shetland	60	M	60.6
Larensen, 2007	W Scot	56	F	93.8
Larensen, 2007	W Scot	56	M	57.1
Larensen, 2007	Rockall	56	F	104.4
Larensen, 2007	Rockall	56	M	57.3
Ireland, unpubl	W Ireland	54	F	85
Ireland, unpubl	W Ireland	54	M	60

6

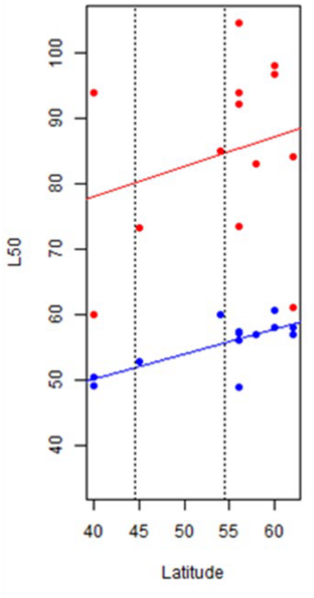

Figure and Table B.1. Estimates of L50 (mean length-at-first maturity) of *L. piscatorius* at various latitudes from the literature and unpublished data. The dotted lines indicate the extent of the stock area (27.7, 8.a, 8.b, 8.d; 44.5–54.5 degrees North).

B.2.2 Natural mortality

Lorenzen (1996) estimates for natural mortality were applied to young ages (where predation can be assumed to be the main source of natural mortality). For large fish there is no clear relationship between size and M in Lorenzen's analysis (although this is not explored in the 1996 paper). Applying Lorenzen's estimates of M for older (large) fish would result in an unrealistically low M for old fish. Therefore, from age 3 onwards, M was fixed at the estimate from the FishLife R library, which takes account of the life-history and taxonomic hierarchy of the stock. There was no basis to assume different M for the two sexes; length-at-age for the young ages (where Lorenzen applies) is almost identical for males and females.

Age 0	Age 1	Age 2	Age 3+
1.00	0.57	0.4	0.36

B.2.2 Growth

Based on length–frequency analyses (supported by tagging data), WKANGHAKE (ICES, 2022) estimated the von Bertalanffy growth parameters for females as below. The K for males is estimated within the model while the other parameters are fixed.

	L_{inf}	K
Females	165	0.112
Males	100	*

*Estimated within the model

The cv-s in growth for young and old are assumed fix. The cv for young was estimated in the model and after fixed. The spawning happens through all the year and therefore the cv also is larger than for old fish. The cv for old fish is difficult to estimate within the model and therefore was assumed smaller since the growth between older fish becomes more similar to age: cv_young = 0.25 and cv_old = 0.1.

B.2.4 Length–weight

WKANGLER (ICES, 2018) estimated the length-weight parameters for this stock to be: a = 3.03e-05 and b = 2.82

B.3 Surveys

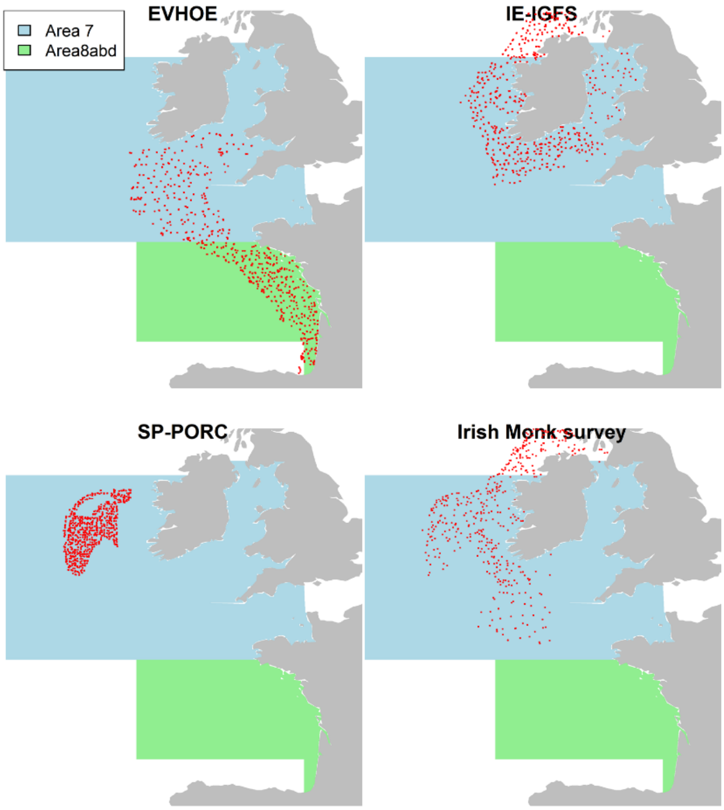

Figure B1. Spatial coverage of the available surveys. Red points indicate trawl positions; the full time-series is plotted so the number of trawl positions is not an indication of the annual number of trawls completed. The blue area represents 27.7 and the green area is 27.8abd.

B.3.1 Western IBTS Q4 EVHOE and IGFS surveys (France/Ireland) – FR_IE_IGFS

The Irish IBTS Q4 groundfish survey (IGFS-WIBTS-Q4; G7212) covers areas 27.7bgjk. The French EVHOE-WIBTS-Q4 (G9527) survey covers areas 27.7j8ab. Both surveys are coordinated and largely standardized under WGIBTS and both use a GOV trawl. Together the two surveys cover the majority of the stock area up to depths of 200–300 m. This is where most of the young fish occur. Older fish migrate to deeper waters and are not fully available to these surveys.

Data for Irish and French IBTS Q4 groundfish surveys (IGFS and EVHOE) were obtained from DATRAS, quality checked and cleaned. The two surveys were combined by weighting their average catches by the area covered by each survey series (IGFS gets a weight of approximately 45% and EVHOE 55%). Because the main recruitment area appears to change over time and sometimes occurs in the Irish survey area, sometimes in the French area and sometimes in both; the combined survey gives a more coherent recruitment signal than the two separate surveys.

An index of catch numbers-at-length per hour fished was calculated for the years 2003 onwards.

B.3.2 Western IBTS Q4 Porcupine Survey (Spain) – SP_Porc

The Spanish Groundfish Survey in the Porcupine bank (SpGFS -WIBTS-Q3; G5768) covers ICES divisions 27.7c,k and a small portion of 27.7b corresponding to the Porcupine Bank and the adjacent area in western Irish waters from longitude 12°W to 15°W and from latitude 51°N to 54°N, covering depths between 180 and 800 m. The survey takes place at the end of the third quarter (September), and the beginning of 4th quarter.

This survey catches larger anglerfish than the French and Irish IBTS surveys. The available survey index consists of catch numbers-at-length per 30 minutes fished for the years 2001 onwards.

B.3.3 Irish Anglerfish and Megrim Survey (Ireland) – IE_Monksurvey

Irish anglerfish survey data in area 27.7 are available for the years 2007, 2008 (under the acronym SIAMISS), 2016 onwards (IAMS). These surveys were designed to estimate the biomass of anglerfish and they cover a significant part of the stock in all depths up to 1000 m.

The survey index consists of catch numbers-at-length per swept-area.

The midpoint of the survey period is in January or February. However, because the survey data are available for the current year at the time of the assessment working group, it is beneficial to include the current year's survey in the assessment. The only way to do that in the current assessment framework is to offset the survey by a small amount so the survey is nominally taking place on the 31st of December of the previous year.

B.4 Commercial CPUE

WKANGLER (2018) rejected the use of commercial CPUE data due to concerns about changes in efficiency, targeting behaviour, quota restrictions, technical measures, discarding and compliance. However, trends in effort, landings and LPUE or CPUE may be used by the assessment working group as auxiliary information. WKANGHAKE (ICES, 2022) supported this approach and did not evaluate commercial CPUE data.

B.5 Other relevant data

Official landings data are available for the combined *Lophius* species since 1903. While the historic data cannot be separated into the two species and may suffer from inaccurate reporting, they provide useful insights in the development of the fisheries during before the period covered by the assessment.

C. Assessment methods and settings

The stock is assessed using Stock Synthesis (https://vlab.noaa.gov/web/stock-synthesis).

The main model settings are outlined below and follow the structure of the SS input files. Any settings not described below can be assumed to be the default as indicated in the manual (Methot et al 2021).

Starter file

- **SSversion**: 3.30
- **F_report_unts**: 5 (unweighted average F for range of ages)
- **F_age_range**: 3–15. The base case has logistic selectivity for the French Trawler FR_TR fleet with full selection from around age 3 onwards so the oldest age is not important; age 15 was chosen as it is not exceedingly rare.

Data file

- **styr:** 1950. Reasonably reliable landings data start in this year
- **endyr:** 2020
- **nseas:** 1. quarterly data are available but mainly discards data seem to be collected by year and after divided into season, therefore, data does not show any seasonal pattern.
- **Nsubseasons:** 4. A separate ALK is calculated for each sub-season; this allows appropriate fitting of the length cohorts in surveys that do not take place in the middle of the year.
- **spawn_month:** 1. Following the same assumption as in the growth analysis done for white anglerfish in the WD04 which assumes 1rst of January as the birth date.
- **Ngenders:** 2. Sexual dimorphism is known to occur; length composition by sex is available for both surveys.
- **Nages:** 30. This seems sufficient, because the model shows a continuous pattern with age and length.
- **N_areas:** 1. Differences between areas are known to exist but a multi-area model was considered too complicated at this stage and remains to be explored.
- **Nfleets:** 4
  - GNS; Gillnets commercial fleet; units: biomass.
  - TR_FR; French trawlers commercial fleet; units: biomass.
  - TR_OTHER; Other trawlers commercial fleet; units: biomass.
  - TR_SP; Spanish trawlers commercial fleet; units: biomass.
  - FR_IE_IBTS; survey; units: numbers. Combined French-Irish IBTS Q4 groundfish surveys
  - IE_MONKSURVEY; survey; units: numbers. Irish Q1 Anglerfish and Megrim Survey
  - SpGFS; survey; units: numbers. Western IBTS Q4 Porcupine Survey.

- **Catch** (note: this is SS terminology but refers to landings only)
  - catch_se for both fleets is 0.2 from 1950 to 1999 and 0.1 from 2000 onwards.
  - The landings previous to 1950 are assumed to be 0 for all the commercial fleets, due to the very low catches at the beginning of the time-series.
- **CPUE**
  The three survey indices are provided as biomass and the error is provided on the lognormal scale (converted from normal scale using the equation in the SS manual).

- **N_discard_fleets**: 4
  - GNS; units: biomass; error type: normal
  - TR_FR; units: biomass; error type: normal
  - TR_OTHERS; units: biomass; error type: normal
  - TR_SP; units: biomass; error type: normal

  - Discards data are available from 2003. We assume in the model that discards also happens in the past. A cv of 0.2 is assumed with a normal discard error type.
  - Discards data <100 t for GNS (2018,2019) and TR_FR (2006,2007), discards <350t (2006,2007,2008) for TR_OT and discards<20 t TR_SP (2015,2017,2018,2019,2020) were removed since the big jump within the data of each fleet was making difficult to the model to fit discards.

- **Length bins for the population and data**
  - 2 cm length bins from 2 to 130 cm; 10 cm bins from 130–180
- **Length composition data structure**
  - Length data are available for the 4 commercial fleets and 3 survey fleets. Length data for the early years of the IE_MONKSURVEY were not used.
  - Length composition of commercial fleets were available from 1986 for landings of each fleet and from 2003 for discards and aggregated for both sex in both cases.
  - The length data of the IBTS joint index and IE_MONKSURVEY are disaggregated by sex.
  - The time-series of SPGFS survey starts in 2001, of FR-IE-IBTS starts in 2003 and IE_MONKSURVEY in 2007 with no data between 2009 and 2015.
  - IE_MONKSURVEY usually is at the beginning of the year but we assumed that it happens at the end of the previous year, in order to be considered in the assessment of that year.
  - For the commercial fleets the sample sizes were based on number of trips reported to InterCatch. For the surveys, the sample size is the number of hauls.
  - Bin compression: 0.001; stronger compression does not allow the sex-ratio of the largest fish to be fitted because there are almost no males in those size bins which leads those bins to be compressed.
  - Dirichlet option selected for all four fleets

- **Age data:** No age data are available
- **Environmental data**: None
- **Generalised size comp data**: None
- **Tag-Recapture data:** None
- **Stock (Morph) comp data:** None
- **Selectivity priors:** None

Control file

- **EmpiricalWAA:** 0 (not available)

- **N_GP:** 1 (single growth pattern)
- **N_platoon**: 1 (single platoon)
- **recr_dist_method:** 4 – none, no parameters (growth pattern x settlement x area = 1).
- **recr_dist_pattern:** All recruitment assumed to occur in month 1 at age 0
- **N_Block_Designs:** 1
- **blocks_per_pattern: 1**
- **begin and end years of blocks:** 2007 2021
- **natM_type:** 3 (Age-specific M).
- **natM:** Lorenzen for young ages and flat for ages older than 3 where predation is not the main source of natural mortality. M for older ages based on the fishlife library, taking account of the life history of the stock. See WD06 for more details. There was no basis to assume different M for the two sexes; length-at-age for the young ages (where Lorenzen applies) is almost identical for males and females.

Age 0	Age 1	Age 2	Age 3+
1.00	0.57	0.4	0.36

- **GrowthModel:** 1 (VonB)
- **Growth_Age_for_L1: 1**
- **Growth_Age_for_L2:** 999 (L2=Linf)
- **maturity_option:** 1 (length logistic)
- **First_Mature_Age:** 2 (ages below the first mature age will have maturity set to zero.)
- **fecundity_option:** 1 (linear eggs/kg on body weight)
- **MG_params:** Most of the biology parameters are fixed and based on life history information compiled during the WKANGHAKE data compilation workshop. The parameters that are estimated the initial value is given is listed below:
    - L_at_Amin_Fem_GP_1 19.2601 (initial value, estimated in phase 2)
    - L_at_Amax_Fem_GP_1 165
    - VonBert_K_Fem_GP_1 0.112
    - CV_young_Fem_GP_1 0.25 (estimated by the model, then fixed)
    - CV_old_Fem_GP_1 0.1 (assumed)
    - Wtlen_1_Fem_GP_1 3.03e-05
    - Wtlen_2_Fem_GP_1 2.82
    - Mat50%_Fem_GP_1 82
    - Mat_slope_Fem_GP_1 -0.1001
    - Eggs/kg_inter_Fem_GP_1 1
    - Eggs/kg_slope_Fem_GP_1 0
    - L_at_Amin_Mal_GP_1 27.5495 (initial value, estimated in phase 2)
    - L_at_Amax_Mal_GP_1 100
    - VonBert_K_Mal_GP_1 0.210458
    - CV_young_Fem_GP_1 0.25 (estimated by the model, then fixed)
    - CV_old_Mal_GP_1 0.1 (assumed)
    - Wtlen_1_Mal_GP_1 3.03e-05
    - Wtlen_2_Mal_GP_1 2.82
    - CohortGrowDev 1
    - FracFemale_GP_1 0.5
- **SR_function:** 3 (Beverton-holt)
- **SR_params:** all fixed except R0
    - SR_LN(R0) 11.6155 (initial value,estimated in phase 1)

- SR_BH_steep 0.92
    - SR_sigmaR 0.6
    - SR_regime 0
    - SR_autocorr 0
- **do_recdev:** 1
- **MainRdevYrFirst:** 1986 (first data year)
- **MainRdevYrLast:** 2020 (there is information from the surveys and discards to inform Rdev)
- **Recdev_phase:** 3
- **To read 13 advanced options:** 1
- **recdev_early_start (0=none; neg value makes relative to recdev_start):** -6
- **recdev_early_phase:** 4
- **forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1):** 0
- **lambda for Fcast_recr_like occurring before endyr+1:** 1
- **last_early_yr_nobias_adj:** 1976.5 (suggested by r4ss)
- **first_yr_fullbias_adj:** 1986.3 (suggested by r4ss)
- **last_yr_fullbias_adj:** 2020 (suggested by r4ss)
- **first_recent_yr_nobias_adj:** 2020.4 (suggested by r4ss)
- **max_bias_adj:** 0.9591 (suggested by r4ss)
- **F_Method:** 4 Fleet-specific parameter/hybrid F (recommended).
- **F_4_Fleet_Params:**
    - GNS: start F 0.5; phase 1
    - TR_FR: start F 0.5; phase 1
    - TR_OTHER: start F 0.5; phase 1
    - TR_SP: start F 0.5; phase 1

- **Init_F**: there was some fishing before 1950; however, the model estimated initial F to be very low,and therefore it was assumed the catches to be equal to 0 previous to 1950.
- **Q_options:**
    - IBTS: link 1 (simple Q); extra se 1; no bias adj; float
    - MONK: link 1 (simple Q); no extra se; no bias adj; float
    - SPGFS: link 1 (simple Q); no extra se; no bias adj; float
- **Q_options:**
    - LnQ_base_FR-IE-IBTS(5): -10.0485
    - Q_extraSD_FR-IE-IBTS(5): 0.0769716 (initial values,estimated phase 4)
    - LnQ_base_IE_MONKSURVEY(6): -7.63264
    - LnQ_base_SPGFS(7): -9.99782
- **size_selex_types:**
    - GNS: Pattern 27 (spline 3 knots);
        - Retention curve
    - TR_FR: Pattern 24 (double normal with logistic shape)
        - the peak parameter initial value 25.4259, prior in 25.4259, with normal distribution with sd=1 and estimated in phase5.
        - Retention curve (with time-varying Retain_L_infl from 2003 to 2020, estimated in phase 7)
    - TR_OTHERS: Pattern 27 (spline 3 knots);
        - discards (with time-varying Retain_L_infl from 2003 to 2020, estimated in phase 7)
    - TR_SP: Pattern 27 (spline 3 knots);
        - Time block in the first value of the spline.

        - Retention curve.
    - FR_IE_IBTS: Pattern 24 (double normal);
    - MONK: Pattern 1 (logistic);
    - SPGFS: Pattern 24 (double normal with logistic shape)
- **age_selex_types:** - None
- **size_selex_para:**
    - Main para estimated in phase 5, others in phase 3
    - Retention para estimated in phase 5 and 6; random walk on retention inflection parameter from 2005–2020 due to the gradual adoption of minimum market weight.
- **dirichlet_params:**
    - Estimates in phase 8 for TR_OTHERS, TR_SP, FR-IE-IBTS, MONK. For the others the value were close to 5 and hitting the boundary so those parameters were removed.
- **size_selex_params_tv**:
    - time varying retention size at inflection for TR_FR and TR_OTHERS
        - dev_se fixed at 0.5
        - auocorr fixed at 0
    - time block in the value 1 of TR_SP: -2.53223 (initial value, estimated in phase 7)
- **Use_2D_AR1_selectivity:** 0
- **TG_custom:** 0
- **DoVar_adjust:** 1
- **maxlambdaphase:** 1
- **sd_offset:** 1
- **N_lambdas:** 0

Phases

The phases were set according to the following rule-of-thumb:

- Phase 1: R0 and Ms
- Phase 2: biology (+ time varying bio parameters or next phase)
- Phase 3: main recdev
- Phase 4: early recdev
- Phase 5: Main sel para and q (when estimated, not in this cases as we are using floats)
- Phase 6: Other sel para
- Phase 7: time varying para in sel
- Last phase: Dirichlet parameters

D. Update of the model

Every year with the update of the model, if the new data available are considered informative, then the terminate year of the recruitment deviates should be updated as well as the parameterization of the recruitment biased correction ramp.

The time varying parameters in the retention curve of French trawlers and other trawlers should be updated as well as the time block for the Spanish trawlers.

E. Short-term prediction

The following are default forecast options. The working group will review these annually and adapt as necessary:

- Mean weights-at-age; maturity-at-age; discard proportions-at-age: average last 3 years;
- Exploitation pattern: average last 3 years;
- F status-quo: average last 3 years unless there is a clear trend in F, in which case F can be rescaled to the last year;
- F in the intermediate year: F status-quo
- Recruitment in the intermediate and forecast years: predicted from Stock Synthesis stock–recruit relationship;
- Recruitment in the last data year(s): this may not be accurately estimated; therefore, the default approach will be to replace recruitment in the last year with that predicted from Stock Synthesis stock–recruit relationship.

F. Biological reference points

Biological reference points were established by following the ICES fisheries management reference points for category 1 and 2 stocks (2021). The ICES R package MSY was used (EqSim approach). The approach is detailed in the WKANGHAKE report (ICES, 2022).

The reference points are as follows:

Reference point	Value	Rationale
B_{lim}	19525	SSB (2004); lowest SSB with high recruitment
B_{pa}	25113	B_{lim} with assessment error
MSY $B_{trigger}$	25113	B_{pa}
F_{lim}	Undefined (0.259)	F with 50% probability of SSB > B_{lim} (segreg without $B_{trigger}$), This is inconsistent with F_{pa} (which was estimated using a different stock–recruit relationship) and therefore F_{lim} will be undefined.
F_{pa}	0.237	F with 95% probability of SSB ≥ B_{lim} (BH with $B_{trigger}$)
F_{MSY}	0.19	Stochastic simulations (BH with $B_{trigger}$)
F_{MSY}Lower	0.13	Stochastic simulations (BH with $B_{trigger}$)
F_{MSY}Upper	0.237	The estimated value for F_{MSY}Upper was over F_{pa} value, therefore, we assume F_{MSY}Upper = F_{pa}
B_{MSY}5pc	25278	5% probability of SSB < B_{lim}

G. Other issues

G.1 Stock assessment: historic overview

YEAR (Y)	2000(?)–2006	2006–2017	2018–2021	2022 ONWARDS
Model	XSA	None – survey trends	a4a	Stock Synthesis
Software	vpa.exe/ FLXSA		FLa4a	SS 3.30
Landings	1986–		1986–	1950-
Duscards				2003-
Age data	1–13+		0–7+	
Length data				1986
Fleets	FR-FU04 - commercial	FR-EVHOE	FR_IE_IBTS – survey	Gillnets (GNS)
	SP-VIGO7 – commercial	IE_IGFS (2016, 17 only)	IE_Monk – survey	French trawlers (TR_FR)
	SP-CORU – commercial	SP-PORC (2016, 17 only)	SP-PORC – survey	Other trawlers (TR_Others)
	EW0FU06 – commercial			Spanish trawlers (TR_SP)
	FR-EVHOE – survey			FR_IE_IBTS – survey
				IE_Monk – survey
				SP-PORC – survey

The stock was assessed using XSA up to 2007. However, it became apparent that the age data were not reliable and cohorts could not be accurately tracked. From 2008 to 2021 the catch advice was based on survey trends only. The 2018 benchmark (ICES, 2018) developed an age-based assessment model (a4a) which used length splitting to derive numbers-at-age but this model was not accepted due to its sensitivity to assumed growth M parameters. Therefore, the advice continued to be based on survey trends until 2021. Since 2022 the advice is based on the Stock Synthesis model described here.

G.2 Management and advice

The TACs are set separately for areas 27.7 and 27.8 but for the two species of anglerfish combined (*L piscatorius* and *L. budegassa*).

H. References

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Annex 5: Reviewer reports

Lisa Ailloud (USA), Dean Courtney (USA), Matthew Smith (USA)

The Benchmark Workshop WKAngHake covered the assessments of hake (*Merluccius merluccius*) in divisions 8.c and 9.a (southern hake, hke.27.8c9a), hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a-b, and 8.d (northern hake, hke.27.3a46-8abd), white anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a-b and 8.d (Mon.27.78abd) and black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a-b and 8.d (Ank.27.78abd). All assessments were carried out in Stock Synthesis.

1.1 Southern hake

The Southern hake model was highly complex: 2 sexes, 4 seasons, and a large number of fleets and data streams. Though the stock assessment team put in considerable effort towards improving model fits and diagnostics, two points of concern remain: 1. the model results (population scaling and final depletion estimate) were highly sensitive to the choice of selectivity shape (logistic vs. dome shaped) of the fleet catching the largest fish (*volpal*), and 2. the model had great difficulty converging. Ultimately, a logistic shape was used in the final run and standard errors were obtained from the inverted hessian, so the model was deemed acceptable for use in management.

Future Research

Given the convergence issues encountered, future work should focus on simplifying the model back to a state where convergence diagnostics are acceptable and parameter correlations are reduced.

1) Investigate model convergence.

1.1. Continue to evaluate the effects of fixing stock recruit steepness (*h*) and growth (*k*) at values obtained independently from the stock assessment model. For example, evaluate the effects of using informative priors on steepness (*h*) and growth (*k*) on model performance.

1.2. Evaluate the effects of estimated parameters high gradients on the resulting parameter estimates as well as model performance and convergence; e.g. as obtained from r4ss output for the final Southern hake (SHAKE) model from the benchmark workshop:

```
$maximum_gradient_component
[1] 0.0249607

$parameters_with_highest_gradients
```

Parameter	*Value*	*Gradient*
Size_DblN_descend_se_cdTrw(4)	*6.4332000*	*0.02496070*
SR_LN(R0)	*13.0806000*	*-0.01032760*
F_fleet_2_YR_2018_s_2	*0.2409130*	*-0.00732945*
Size_DblN_descend_se_trawlers(1)	*7.4336000*	*0.00674981*
F_fleet_1_YR_1967_s_1	*0.0847686*	*0.00623345*

For example, investigate alternative model configurations or parameterization to reduce the number of estimated parameters with high gradients in order to achieve the overall maximum gradient "converge_criterion" (1e-04) identified in the starter.ss file.

1.3. Evaluate alternative model configurations for time varying selectivity in the control_fixed.ss file. The current order of parameters in the control_fixed.ss file differs from that obtained from Stock Synthesis AUTOGEN feature and also from that indicated in control.ss_new for the final SHAKE model:

control_fixed.ss

 # begin and end years of blocks

1960 1993

…

 # 1 trawlers LenSelex

LO	*HI*	*INIT*	*PRIOR*	*PR_SD*	*PR_type*	*PHASE*	*…*
4	*30*	*27.711*	*27*	*0.01*	*0*	*5*	*…*
0.01	*10*	*1.65486*	*0.8*	*0.01*	*0*	*5*	*…*

	env-var	*use_dev*	*dev_mnyr*	*dev_mxyr*	*dev_PH*	*Block*	*Blk_Fxn*	*# parm_name4*
…	*0*	*3*	*1994*	*1997*	*5*	*1*	*2*	*# Retain_L_infl_trawlers(1)*
…	*0*	*0*	*0*	*0*	*0*	*1*	*2*	*# Retain_L_width_trawlers(1)*

…

 # timevary selex parameters (obtained from Stock Synthesis AUTOGEN feature)

#_	*LO*	*HI*	*INIT*	*PRIOR*	*PR_SD*	*PR_type*	*PHASE*	*# parm_name*
	4	*30*	*27.711*	*27*	*0.01*	*0*	*5*	*# Retain_L_infl_trawlers(1)_BLK1repl_1960*
	0.0001	*2*	*0.5*	*0.5*	*0.5*	*6*	*-5*	*# Retain_L_infl_trawlers(1)_dev_se*
	-0.99	*0.99*	*0*	*0*	*0.5*	*6*	*-6*	*# Retain_L_infl_trawlers(1)_dev_autocorr*
	0.01	*10*	*1.65486*	*0.8*	*0.01*	*0*	*5*	*# Retain_L_width_trawlers(1)_BLK1repl_1960*

1.4. Correct the last two likelihood component codes for the lambda values (0.3) in the control_fixed.ss file. The current likelihood component code (4=length) in the control_fixed.ss file differs from the likelihood component code (6=SizeFreq) expected for SizeFreq data (**bold**) for the final SHAKE model:

 # Like_comp codes: 1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch; 9=init_equ_catch;

 # 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin; 17=F_ballpark; 18=initEQregime

#like_comp fleet phase value sizefreq_method

1 10 1 0 1

4 10 1 0 1

4 1 1 0.3 1

4 2 1 0.3 1

4 3 1 0.3 1

4 4 1 0.3 1

4 5 1 0.3 1

4 6 1 0.3 1

4 7 1 0.3 1

4 8 1 0.3 1

4 9 1 0.3 1

6 1 1 0.3 1

6 2 1 0.3 1

-9999 1 1 1 1 # terminator

1.5. Evaluate the effect of alternative model configurations consistent with those implemented for the final Northern hake (NHAKE) model from the benchmark workshop. For example 1) the final NHAKE model uses parameter_offset_approach 1 (direct), while the final SHAKE model uses parameter_offset_approach 2 [male=fem_parm*exp(male_parm)]; and 2) the final NHAKE model fixes the parameter RecrDist_GP_1_area_1_month_4, while the final SHAKE model estimates the parameter RecrDist_GP_1_area_1_month_1.

2) Evaluate the effects of estimated parameter correlations ≥ 0.95 and ≤ 0.001 on the resulting parameter estimates as well as model performance and convergence; e.g. as obtained from r4ss output for the final SHAKE model from the benchmark workshop:

$cormessage1

[1] Range of abs(parameter correlations) is 1.37448e-10 to 1

$cormessage2

[1] 1 correlation above threshold (cormax=0.95)

$cormessage3

	label.i	label.j	corr
1	RecrDist_GP_1_area_1_month_7	RecrDist_GP_1_area_1_month_1	1

$cormessage7

[1] 7 uncorrelated parameters below threshold (cormin=0.01)

$cormessage8

Par	name	max
713	Size_DblN_top_logit_artisanal(3)	0.001566450
717	Size_DblN_top_logit_cdTrw(4)	0.000299636
720	Size_DblN_peak_SpSurv(5)	0.000505727
721	Size_DblN_top_logit_SpSurv(5)	0.000230428
722	Size_DblN_ascend_se_SpSurv(5)	0.000999102
728	Size_DblN_peak_CdSurv(7)	0.001137920
729	Size_DblN_ascend_se_CdSurv(7)	0.001137920

For example, the parameters "RecrDist_GP_1_area_1_month_7" and "RecrDist_GP_1_area_1_month_1" have a correlation equal to one indicating that these parameters are highly correlated (parameter redundancy). Evaluate the effect of this high correlation on parameter estimation, for example by either fixing one of the parameters or estimating one or both of the parameters with informative priors. Additionally, several double normal selectivity parameters are uncorrelated, indicating that some of these selectivity parameters may benefit from applying diffuse priors, as described in the Stock Synthesis manual.

3) Evaluate alternative model configurations to address the trend in negative recruitment deviations at the beginning of the recruitment time series in the final SHAKE model. E.g., 1) Consider starting early recruitment deviations in 1965 consistent with the "1965.6 last_early_yr_nobias_adj_in_MPD" obtained from r4ss bias adjustment ramp for recruitment deviations for the final SHAKE model; and 2) Consider adding a Stock Recruit Regime Parameter (SR_regime) and time block in the year before the start of data (1959), consistent with the final NHAKE model.

1.2 Northern hake

Overall, the assessment model was configured properly and showed good diagnostics. Given that life history data was limited, there remains considerable uncertainty surrounding basic input parameters (e.g. maturity, growth, length-weight relationship). Forecasts were carried out following ICES procedures with reasonable assumptions. One notable deviation was the decision to eliminate the last two years of model estimated recruitment from the forecast calculations and replace them with recruitment estimates derived directly from the stock-recruitment relationship. This was appropriate for this assessment given the strong retrospective pattern in the model estimated recruitment; however, the decision should be re-evaluated during subsequent assessments to ensure that it remains warranted. Reference points derived from the forecast seem appropriate for the stock and suitable for management. Given the overall suitability of the final model configuration and positive diagnostic performance, it is likely that future benchmarks could derive the reference points and related management quantities directly from stock synthesis should procedural restrictions allow. Using Synthesis directly, allows the full complexity and uncertainty of the SS assessment model to be captured in the estimated management quantities and their associated errors. Control rules that achieve the desired risk tolerance of ICES could be developed and applied creating a more streamlined and consistent assessment process.

Future Research

We recommend that future work focus on understanding trends apparent in the maturity data, and improving stock and sex specific estimates of life history parameters to avoid having to borrow from neighbouring stocks. Regarding length composition, the majority of fleets failed the mean length residuals runs test and several fleets exhibited strong systematic patterns (i.e. TRAWLOTH, GILLNET, OTHIST) indicating that selectivity for those fleets/years was likely mis-specified. Efforts were attempted to try and improve some of the poor fits during the benchmark but time constraints did not allow for all issues to be resolved. Fleet structure and time varying aspects of selectivity and retention should be further refined in advance of the next benchmark assessment.

Future work could also evaluate the effects of estimated parameter correlations ≥ 0.95 and ≤ 0.001 on the resulting parameter estimates as well as model performance and convergence; e.g. as obtained from r4ss output for the final NHAKE model from the benchmark workshop:

$cormessage1

[1] Range of abs(parameter correlations) is 5.702e-14 to 0.967742

$cormessage2

[1] 5 correlations above threshold (cormax=0.95)

$cormessage3

	label.i	label.j	corr
1	SR_BH_steep	SR_LN(R0)	-0.954298
2	Size_DblN_ascend_se_OTHERS(9)	Size_DblN_peak_OTHERS(9)	0.952749
3	Size_DblN_ascend_se_RESSGASCQ2(12)	Size_DblN_peak_RESSGASCQ2(12)	0.967742
4	Size_DblN_ascend_se_IGFS(16)	Size_DblN_peak_IGFS(16)	0.950193
5	Size_DblN_ascend_se_IAMS(17)	Size_DblN_peak_IAMS(17)	0.961245

$cormessage7

[1] 18 uncorrelated parameters below threshold (cormin=0.01)

$cormessage9

[1] Lowest 10 parameters uncorrelations below threshold (to print more, increase 'printlowcor' input):

$cormessage10

	Parameter name	max
644	RecrDist_GP_1_area_1_month_7_DEVrwalk_1978	1.21900e-08
890	Size_inflection_NSTRAWL(8)_DEVrwalk_2013	1.16904e-05
898	Retain_L_infl_NSTRAWL(8)_DEVrwalk_2013	1.24455e-05
641	Size_DblN_top_logit_IAMS(17)	8.84502e-05
643	Size_DblN_descend_se_IAMS(17)	8.84502e-05
582	Size_DblN_top_logit_FRNEP8(3)	1.21614e-04
613	Size_DblN_top_logit_EVHOE(10)	1.55648e-04
617	Size_DblN_top_logit_RESSGASCQ1(11)	1.65760e-04
633	Size_DblN_top_logit_PORCUPINE(15)	2.70329e-04
588	Size_DblN_top_logit_SPTRAWL8(4)	2.77263e-04

For example, the parameters SR_BH_steep and SR_LN(R0) have a high correlation (near negative one) indicating that these parameters are highly correlated. Future research could evaluate the effect of this high correlation on parameter estimation. For example, Lee et al. (2012) "suggest that steepness is reliably estimable inside the stock assessment model only when the model is correctly specified for relatively low productive stocks with good contrast in spawning stock biomass. If the stock has never been highly depleted or has always been highly depleted, then recruitment data is not available from low or moderate/high spawning stock size, which is needed to inform estimates of steepness." Consequently, it may be important to investigate the effects of estimating steepness within the NHAKE model, for example by evaluating the effects of fixing the steepness parameter at an estimate obtained independently from the stock assessment model, or by estimating the steepness parameter within the stock assessment model using an informative prior obtained independently from the stock assessment model.

Additionally several double normal selectivity parameters are either highly correlated or are uncorrelated, indicating that these selectivity parameters may benefit from re-parameterization including 1) reducing the number of estimated selectivity parameters by combining fleets of similar length composition or mirroring selectivity among these fleets with similar length composition as described in the Stock Synthesis manual, and 2) applying diffuse priors for some uncorrelated parameters selectivity, as described in the Stock Synthesis manual.

1.3 White anglerfish

Overall, the assessment model was configured properly and showed good diagnostics. The model exhibited some minor instability (jitters) and an inability to match the observed discards for the TR_SP fleet. These issues should be further evaluated before the next benchmark assessment. In particular, improvements in the sex-specific life history parameters and a better understanding of stock delimitation may help resolve some of the model instability and data conflicts observed. An externally derived selectivity pattern for the SPGFS survey or improved standardization of the composition data prior to being input in SS may also improve model diagnostics.

1.4 Black-bellied anglerfish

Overall, the assessment model was configured properly and showed good diagnostics. The model setup was fairly parsimonious and future work should focus on increasing realism to try and resolve some of the misfits apparent in the fits to the sex ratio and length composition data (e.g. sex-specific M, relaxing the assumption that all fleets have a logistic selectivity). A sensitivity run estimating growth resulted in unrealistically low estimates of asymptotic lengths for both males and females. This result provides a further line of evidence that the strict assumption of logistic selectivity for all fleets deserves further exploration.

Another issue that will need to be addressed prior to the next benchmark assessment is the apparent conflict between the MONK survey and the IBTS survey. It is likely that the issue lies in part in the spatial distribution of the two surveys, with IBTS covering the entire range of the assessment area while MONK is restricted to North of the 48° latitude. While the MONK index shows a decreasing trend in recent years, the IBTS index shows a steep increasing trend from 2015 to 2018 with 2018-2020 observations being the highest in the time series. Given that the IBTS has a strong influence on the final depletion level and fishing mortality estimates (see section 4.1.5.5.), it will be important to explore alternative spatial configurations and/or stock definitions in future modeling efforts (if and when the data allow).

Future work could also evaluate the effects of estimated parameter correlations ≥ 0.95 on the resulting parameter estimates as well as model performance and convergence; e,g, as obtained from r4ss output for the final Black-bellied anglerfish model (ank.27.78abd_finalSSmodel) from the benchmark workshop:

$cormessage1

[1] Range of abs(parameter correlations) is 1.11805e-07 to 0.973781

$cormessage2

[1] 1 correlation above threshold (cormax=0.95)

$cormessage3

	label.i	label.j	corr
1	Size_DblN_ascend_se_FR_IE_IBTS(3)	Size_DblN_peak_FR_IE_IBTS(3)	0.973781

$cormessage7

[1] No uncorrelated parameters below threshold (cormin=0.01)

The parameters Size_DblN_ascend_se_FR_IE_IBTS(3) and Size_DblN_peak_FR_IE_IBTS(3) have a high correlation (near one) indicating that these parameters are highly correlated. Future research could evaluate the effect of this high correlation on parameter estimation, for example by either fixing one of the parameters or estimating one or both of the parameters with informative priors.

1.5 Conclusions

Reviewers participated in all aspects of the data and benchmark workshops (virtually) as well as intersessional model development via email and web conference calls. The reviewers agree with the data input and model decisions made during the benchmark workshop for all four stocks. Consequently, the reviewers conclude that the stock assessment model results for all four stocks are acceptable for use in management.

1.6 References

Hui-Hua Lee, Mark N. Maunder, Kevin R. Piner, Richard D. Methot. 2012. Can steepness of the stock–recruitment relationship be estimated in fishery stock assessment models? Fisheries Research 125–126: 254-261.https://doi.org/10.1016/j.fishres.2012.03.001.