



Food and Agriculture
Organization of the
United Nations



General Fisheries Commission
for the Mediterranean
Commission générale des pêches
pour la Méditerranée

Scientific Advisory Committee for fisheries (SAC)

Working Group on Stock Assessment of Demersal Species (WGSAD) Benchmark session for the assessment of European hake in GSAs 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 22, 23 and 26

FAO headquarters, Rome, Italy, 2–7 December 2019

REPORT¹

EXECUTIVE SUMMARY

The Working Group on Stock Assessment of Demersal Species (WGSAD) benchmark session for the assessment of European hake in geographical subareas (GSAs) 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 22, 23 was held at the headquarters of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy, 2–7 December 2019, and was attended by 41 experts from across the Mediterranean and beyond, including three external reviewers and technical staff from the FAO regional projects and the GFCM Secretariat. The session addressed various aspects of the assessment of European hake across the Mediterranean, focusing in particular on: i) issues related to the assessment units used, in particular in Western Mediterranean; ii) issues related to the input data and assumptions, in particular on biological parameters including growth, mortality, length-weight relationship and maturity; and iii) issues related to the assessment model used in the different units. Whenever possible, the session agreed on a benchmark assessment, or else provided the best possible advice based on the information available and the analysis carried out. A total of three benchmarks were agreed (assessment units GSAs 8-11, GSAs 12-16 and GSA 19); the basis for the advice on GSAs 1, 5, 6, 7 was also agreed, and precautionary advice was provided for five additional assessment units (GSAs 4, 20, 22, 23 and 26). Advice was also provided on the status of European hake in GSAs 1 and 3 combined, as the only way to have advice on GSA 3 and a way to provide complementary advice on GSA 1. Complementary advice was also provided in GSA 5. Among all the assessment units assessed, the status in three of the units was considered uncertain (GSAs 20, 22 and 23), while all other units assessed were considered to be in overexploitation. When possible, in addition to fishing mortality reference points, biomass reference points were also estimated, or else the relative biomass levels in relation to the observed time series were assessed.

¹ This meeting was supported by the European Union under grant agreement no SI2.795396.

Contents

1. TERMS OF REFERENCE FOR THE MEETING	3
2. PREVIOUS ADVICE AND IDENTIFIED UNCERTAINTIES	3
2.1. ADVICE IN THE CONTEXT OF THE GFCM	3
2.2. ADVICE IN THE CONTEXT OF THE STECF	4
3. STOCK ASSESSMENT	5
3.1. GENERAL CONSIDERATIONS	5
3.1.1. Stock assessment units and summary of tentative assessment models	5
3.1.2. Biological parameters	7
3.2. WESTERN MEDITERRANEAN	11
3.2.1. Comparison of combined and separate European hake assessments for GSAs 1, 3, 4, 5, 6 and 7 11	
3.2.2. Assessment unit: GSAs 1, 5, 6, 7	15
3.2.3. Assessment unit: GSAs 1 and 3	47
3.2.4. Assessment unit: GSA 4	59
3.2.5. Assessment unit: GSA 5	66
3.2.6. Assessment unit: GSA 6	71
3.2.7. Assessment unit: GSA 7	79
3.2.8. Assessment unit: GSAs 8, 9, 10 and 11	96
3.3. CENTRAL MEDITERRANEAN	133
3.3.1. Assessment unit: GSAs 12, 13, 14, 15 and 16	133
3.3.2. Assessment unit: GSA 19	162
3.3.3. Assessment unit: GSA 20	189
3.4. EASTERN MEDITERRANEAN	197
3.4.1. Assessment unit: GSA 22	197
3.4.2. Assessment unit: GSA 23	205
3.4.3. Assessment unit: GSA 26	213
4. REPORT OF THE EXTERNAL REVIEWERS	222
4.1. GSA GROUPINGS	223
4.2. BIOLOGICAL PARAMETERS	226
4.2.1. Growth	226
4.2.2. Natural mortality	226
4.2.3. Maturity	227
4.5. STOCK ASSESSMENTS	228
4.6. COMMENTS ON THE GFCM EUROPEAN HAKE BENCHMARK PROCESS	230
APPENDIX 1 - AGENDA	243
APPENDIX 2 - LIST OF PARTICIPANTS	244
APPENDIX 3 - TABLE OF ADVICE ON THE STATUS OF EUROPEAN HAKE (<i>MERLUCCIVUS</i> <i>MERLUCCIVUS</i>) IN THE GSAS ADDRESSED IN THIS BENCHMARK	247
APPENDIX 4 - INFORMATION ON STOCK IDENTITY	251
APPENDIX 5 - SUMMARY OF PREVIOUS STECF ASSESSMENTS	261

1. TERMS OF REFERENCE FOR THE MEETING

The meeting of the Working Group on Stock Assessment of Demersal Species (WGSAD) benchmark session for the assessment of European hake (*Merluccius merluccius*) in geographical subareas (GSAs) 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 22, 23 of the General Fisheries Commission for the Mediterranean (GFCM) was held at the Food and Agriculture Organization of the United Nations (FAO) headquarters in Rome, Italy, from 2–7 December 2019.

The objective of the meeting was to perform a full analysis and review of the information and methods used to provide advice on the status of the stock, focusing on the consideration of old and new data sources as well as old and new (or improved) assessment models and assumptions. In particular, the benchmark meeting addressed the following terms of reference (ToRs) proposed by the GFCM Scientific Advisory Committee on fisheries (SAC) at its twentieth session (Morocco, June 2018) and approved by the forty-second session of the GFCM (FAO headquarters, Rome, Italy, October 2018):

- identification of all problems and issues associated to the data, assumptions and methodologies used for the current assessment;
- identification and provision of extra data required to address the above problems;
- identification of appropriate alternative methodologies to be tested on top of existing ones;
- final revision of and agreement on data, assumptions (including all biological parameters) and assessment methods proposed;
- performance of the assessments;
- comparison of the outcomes and selection of the most appropriate ones for the provision of advice, in light of respective shortcomings and advantages;
- estimation of adequate reference points and analysis of their robustness; and
- provision of advice on the status of the stock based on the outcomes of the chosen model with respect to the estimated reference points.

In line with the adopted ToRs and in order to ensure the best quality advice is provided, the benchmark session was attended by stock and methodological experts, both from the area/subregion and outside, and counted as well the presence of an external expert reviewer (see list of participants in Appendix 2).

Following the benchmark assessment, all historical data, assumptions and models will be fixed for the successive three to four years and assessments presented in this time period are expected to provide updates incorporating data from the most recent year(s).

2. PREVIOUS ADVICE AND IDENTIFIED UNCERTAINTIES

2.1. Advice in the context of the GFCM

European hake is a GFCM priority species in all Mediterranean subregions (western, central, Adriatic and eastern Mediterranean). Also, it is the species that is assessed in the largest number of GSAs (64 percent of all the Mediterranean GSAs). Assessments of European hake within the GFCM date back from the beginning of the stock assessment Working Groups, and the latest assessments provided by the WGSAD cover GSAs 1 and 3 (joint), 4, 5, 6, 7, 09-11 (joint), 12-16 (joint) and 22. In addition, a benchmark of European hake in the Adriatic Sea (GSAs 17-18) was carried out on 15–18 January 2019. A summary of the latest advice on European hake within the GFCM is included in the table below.

GSA	Year	Method	F_{curr}	F_{0.1}	Ratio	Advice	Comments
1-3 joint	2017	XSA, Y/R	1.30	0.21	6.5	In overexploitation, relatively low biomass	Update
4	2017	VIT, Y/R	1.3	0.2	6.5	In overexploitation, relatively low biomass	New assessment (3 years of data)
5	2017	a4a	1.34	0.18	7.4	In overexploitation, relatively low biomass	Changed from XSA to a4a
6	2017	a4a	1.40	0.20	7.0	In overexploitation, relatively low biomass	Update
7	2017	XSA, Y/R	1.81	0.12	15.1	In overexploitation, relatively low biomass	Update
9-11 joint	2017	A4a	0.55	0.14	3.9	In overexploitation, relatively low biomass	New assessment. Results consistent with SS3 for GSA 9
12-16 joint	2017	XSA, Y/R	0.91	0.20	4.6	In overexploitation, relatively low biomass	Update
22	2016	SPiCT	0.39	0.33	1.17	In overexploitation, relatively low biomass	New assessment. Change in fishing pattern from 2010

2.2. Advice in the context of the STECF

The Scientific, Technical and Economic Committee for Fisheries (STECF) carried out assessments for European hake stocks in several Expert Working Groups (EWGs). In 2017, STECF EWG 17-15 carried out assessments by GSA separately for European hake in GSAs 19, 20, 22 and 23. In 2019, the STECF EWG 19-10 evaluated European hake in GSAs 1, 5, 6-7, 9, and 10-11, these two assessments had been carried out in several years, most recently in October 2019. The most recent advice on the status of stocks from the STECF is summarized below and stock assessment model outputs are summarized in Appendix 5.

GSA	Year	Method	F_{curr}	F_{0.1}	Ratio	Advice	Comments
1, 5, 6, 7	2018	a4a	1.84	0.38	4.84	Reduce fishing mortality towards F0.1	STECF EWG 19- 10
9, 10, 11	2018	a4a	0.74	0.22	3.4	Reduce fishing mortality towards F0.1	STECF EWG 19- 10
19	2017	a4a	1.42	0.16	8.9	Reduce fishing mortality towards F0.1	STECF EWG 17- 15
20	2017	SPiCT	--	--	--	No advice	STECF EWG 17- 15
22	2017	SPiCT	--	--	--	No advice	STECF EWG 17- 15
23	2017	SPiCT	--	--	--	No advice	STECF EWG 17- 15

The STECF considered that having evaluated the European hake assessments provided for GSAs 1, 5, 6-7, 9, and 10-11 over several years, these were giving stable results and are good candidates for a benchmark. The evaluations of hake in GSA 19 require further development but with addition of more years there is scope to improve this assessment. The STECF EWG noted that for all the stocks evaluated in GSAs 20, 22 and 23, there were considerable uncertainty in the Greek landings data. The differences between the EU data collection framework (DCF) and other sources (FAO and Greek statistical services) were substantial. While some of the DCF data are missing due to years when it was not collected, for those years that should have been covered the estimated landing are substantially different, this is particularly the case for European hake in the three areas. Using the best data available, it was difficult to obtain coherent results for most stocks. Since 2017,

some additional data have become available but there are still some concerns regarding potential assessments for these stocks.

3. STOCK ASSESSMENT

3.1. General considerations

3.1.1. Stock assessment units and summary of tentative assessment models

Over the past two years, European hake in the Mediterranean was assessed as multiple stocks, some that aggregate multiple GSAs (Table 3.1.1.1, Figure 3.1.1.1). A review of information on stock identity was completed to determine the most appropriate benchmark units for the western assessments (GSAs 1-11) and to provide recommendations on possible GSA groupings for future assessments in the central (GSAs 12-16) and eastern Mediterranean (GSAs 20-26).

The information available provides strong evidence of a distinct boundary between European hake populations in the Atlantic Ocean and Mediterranean Sea, but population structure within the Mediterranean is less certain. The STOCKMED project provides extensive information on spatial patterns of Mediterranean European hake (Fiorentino *et al.* 2014), but did not have sufficient information for several GSAs, and there is work in progress that is expected to fill some information gaps (TRANSBORAN, Hidalgo *et al.*, 2018; MED_UNITS, CopeMed II 2019). Information from neutral genetic characters indicates broad-scale populations in the western Mediterranean (GSAs 1-16), central Mediterranean (GSAs 17-19) and eastern Mediterranean (22-25) that are reproductively isolated on an evolutionary timescale (Milano *et al.*, 2014), with considerable advection of eggs and larvae among areas providing connectivity of early life stages among GSAs in those regions (López-Jurado *et al.*, 2015; El Yaagoubi, 2019; Hidalgo *et al.*, 2019b; Radici *et al.* SAFENET). Finer-scale differences in selected characters (e.g., allozymes, growth rates, size at maturity) and natural tags (e.g., parasites) suggest limited movement, local selection of post-larval life stages, and some demographic independence on an ecological timescale, which may be more relevant to stock assessment.

Considering that connectivity among GSAs appears to be at early life stages, larval transport is intermittent, and there is limited movement of juveniles and adults among areas, GSAs with different recruitment patterns can be appropriately modeled as unit stocks to estimate recruitment and survival of recruits for comparison with yield per recruit reference points, but stock-recruit relationships may be confounded for small areas because of intermittent mixing of eggs and larvae. Therefore, spawner per recruit reference points would be appropriate for conserving spawning potential in all areas for self-recruitment and recruitment subsidies. An intermediate to a spatially-structured stock assessment of multiple areas would be an integrated fleet-based stock assessment, modeling areas as fleets.

There are some uncertainties in stock identity for European hake in the central and eastern Mediterranean, but they appear to be less controversial. Therefore, benchmark methods will maintain the current assessment units for those basins (e.g., GSAs 12-16, GSAs 17-18, GSA 19, GSA 20, GSA 22 and GSA 26; Table 3.1.1.1). The benchmark session considered several revised groupings of GSAs in the western Mediterranean. The working group and reviewers agreed to include GSA 8 with in the GSAs 9-10-11 European hake assessment as the benchmark method. This decision is supported by similar growth of European hake in GSA 8 and GSAs 9-10-11 as well as significant correlation of survey biomass trends in GSAs 8 and 9 (Fiorentino *et al.*, 2014).

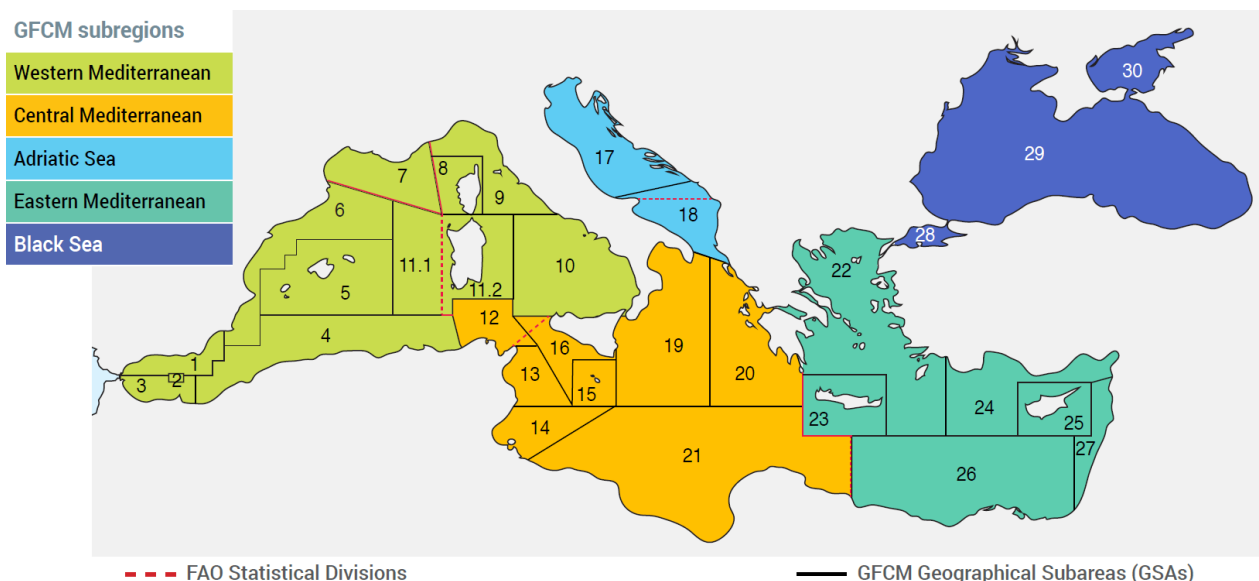
The benchmark session agreed that uncertainties about stock identity for GSAs 1-7 will be reconsidered when final results and conclusions from TRANSBORAN and MED_UNITS are available. More specifically:

- The grouping of GSAs 1 and 3 (and possibly GSA 4) will be reconsidered after the final results and conclusions of TRANSBORAN are available (in 2020).
- The grouping of GSAs 1, 5, 6 and 7 will be reconsidered after the MED_UNITS results and conclusions are available (in 2021).
- GSA groupings in the central and eastern Mediterranean will be reconsidered in future European hake benchmarks, because information from MED_UNITS will be available.

Until final decisions on GSA groupings from GSAs 1-7 are made, advice should consider recent GSA groupings (GSAs 1-3 and GSAs 1-5-6-7) as well as previous separate-area assessments (GSA 4, GSA 5, GSA 6 and GSA 7). Advice based on assessment of European hake in GSAs 1-3 is supported by genetic similarity (Milano *et al.*, 2014), intermittent mixing of eggs and larvae between GSA 1 and GSA 3 (El Yaagoubi, 2019), and similar growth (Fiorentino *et al.*, 2014). Advice based on both the joint assessment of European hake in GSAs 1-5-6-7 as well as separate GSA assessments in each area will account for different fishing patterns until an integrated fleet-structured basin-wide assessment is possible. The joint GSAs 1-5-6-7 European hake assessment is supported by genetic similarity (Cimmurata *et al.*, 2005; Milano *et al.*, 2014), multi-disciplinary cluster analysis and similar parasite prevalence in GSAs 1-5-6-7 (Fiorentino *et al.*, 2014). Separate assessments of European hake in each of these GSA are supported by asynchronous survey trends among GSAs (Fiorentino *et al.*, 2014; Hidalgo *et al.*, 2019a), the apparent barrier to larval mixing between GSA 1 and GSA 6 at the Almeria-Oran front (TRANSBORAN; CopeMed II 2019), and the apparent ecosystem barrier between the Balearic Islands (GSA 5) and the Iberian Shelf (GSA 6; Quetglas *et al.*, 2012). Among these alternative GSA groupings, assessments with better data and model diagnostics can be selected as preferred models for the basis of advice, and other models can be considered as sensitivity analyses or supplemental information.

Table 3.1.1.1. Mediterranean European hake stocks, geographical subareas (GSAs) and assessment methods evaluated in the benchmark, with the most recent reference

GSA	Label	Reference
1 and 3	Alboran Sea	HKE_GSA_01-03_2017_ESP_MAR.pdf
4	Algeria	HKE_GSA_04_2017_DZA.pdf
5	Balearic Islands	HKE_GSA_05_2016_ESP.pdf
6	Balearic Sea	HKE_GSA_06_2017_ESP.pdf
7	Gulf of Lion	HKE_GSA_07_2017_ESP_FRA.pdf
1, 5, 6, 7	Western Med	STECF 19-10 - MED stock assessments_part 1.pdf
8-11	Tyrrhenian Sea	STECF 19-10 - MED stock assessments_part 1.pdf
12-16	Strait of Sicily	HKE_GSA_12-16_2017_ITA_MLT_TUN.pdf
17-18	Adriatic Sea*	GFCM_WGSAD_hke17-18_2019_Report
19	West Ionian Sea	STECF 17-15 - Med stock assessments 2017-p2.pdf
20	East Ionian Sea	STECF 17-15 - Med stock assessments 2017-p2.pdf
22	Aegean Sea	HKE_GSA_22_2016_GRC.pdf
23	Crete	Never assessed
26	South Levant Sea	Never assessed
* benchmarked January 2019		



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - South of Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Figure 3.1.1.1. Geographical subareas (GSAs), General Fisheries Commission for the Mediterranean

3.1.2. Biological parameters

In this section, we concentrate specifically on parameterization requirements for stock assessment models for European hake. In this context the approach used in the benchmark for European hake in GSAs 17-18 was also considered. The following aspects were discussed at the meeting, the basis and use in the assessments:

- growth;
- growth L to W;
- spawning time: F&M before spawning;
- stock weights;
- fraction mature; and
- natural mortality.

3.1.2.1. Growth

The different growth models by sex, male and female and combined sex by GSA are given in Figures 3.1.2.1 to 3.1.2.3 and Table 3.1.2.1. It was observed that growth tends to be faster in the more westerly GSAs. The separation of male and female growth is clear, supporting the decision to use sex separated growth for European hake where data are available. The WG accepted the use of these growth curves for these stock assessments.

Table 3.1.2.1. Growth equation parameters by assessment areas

GSA	Sex	Linf	k	t0
9, 10- 11	M	60	0.265	-0.06
9, 10-11	F	95	0.16	-0.06
1, 5, 6-7	C	110	0.178	0
4	C	85.5	0.18	-0.71
1 and 3	C	108	0.21	-0.115
5, 6-7	F	100.7	0.236	0
5, 6-7	M	72.8	0.233	0
12-16	F	100	0.12	0
12-16	M	55	0.23	0
19	M	73	0.1453	-0.7295
19	F	111	0.1024	-0.5969
26	C	68.5	0.29	-0.31

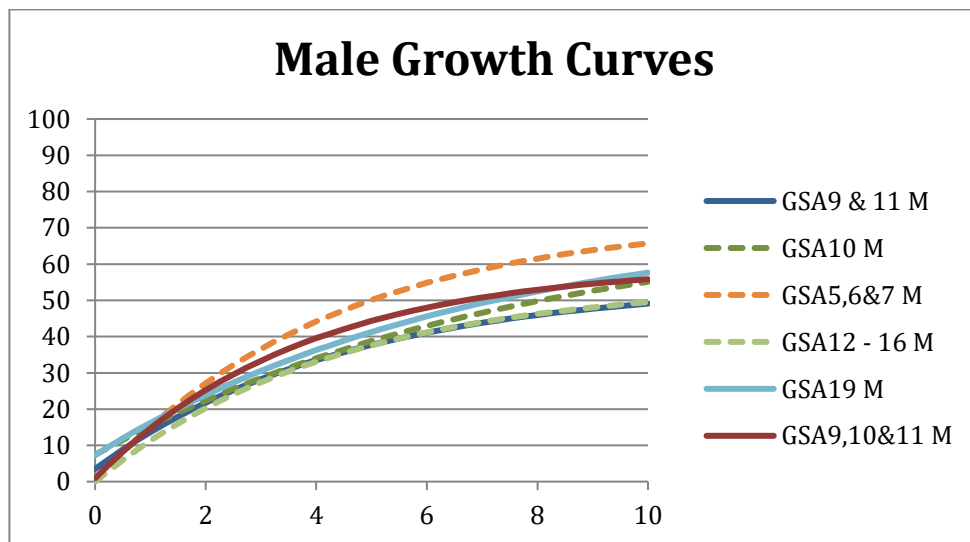


Figure 3.1.2.1. Growth of male European hake for assessment by GSA

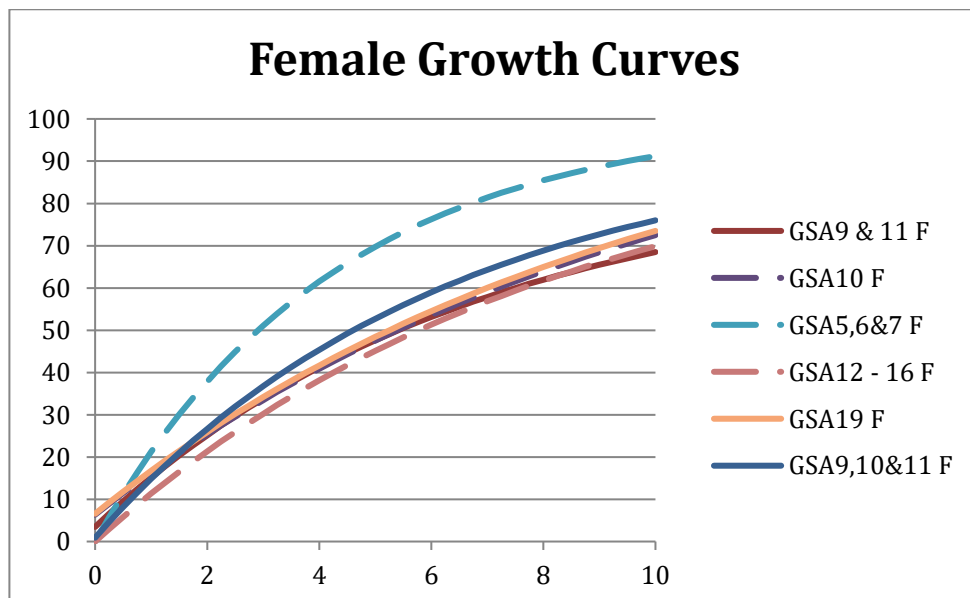


Figure 3.1.2.2. Growth of female European hake for assessment by GSA

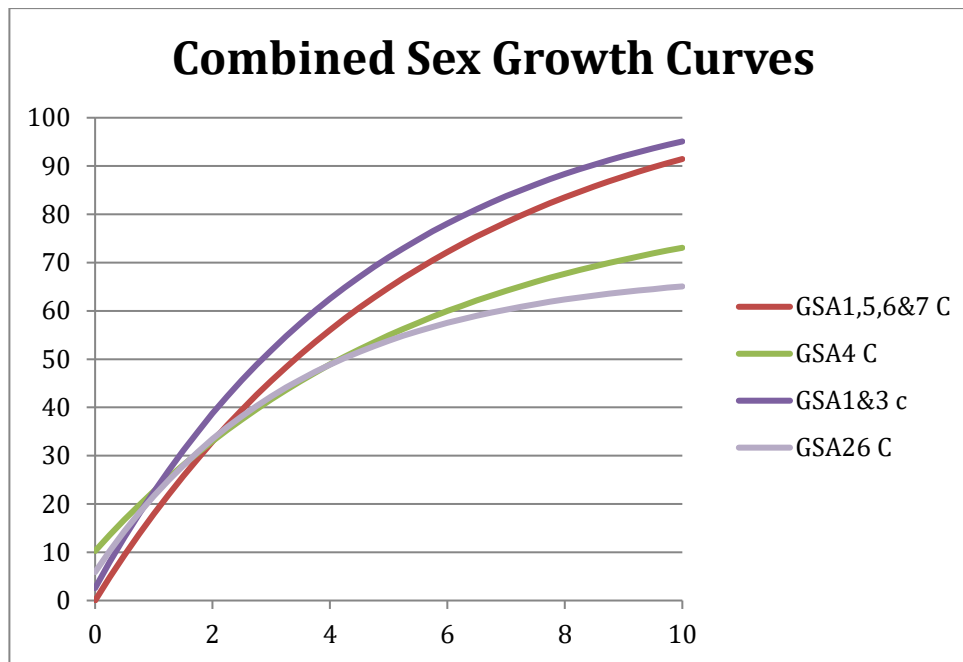


Figure 3.1.2.3. Growth of European hake by GSA for assessment, males and females combined

3.1.2.2. Length to weight functions

The different length to weight parameters by sex, male and female, and combined sex by GSA are given in Table 3.1.2.2 and the relationships are illustrated in Figure 3.1.2.4. It was observed that there is no major separation of male and female growth. The WG accepted the use of these growth curves for these stock assessments.

Table 3.1.2.2. Length to weight relationship coefficients for European hake by GSA for assessments for males and females combined

GSA	Sex	A	b
9, 10-11	M	0.005009	3.107705
9, 10-11	F	0.004645	3.133
1, 5, 6-7	C	0.00677	3.0351
4	C	0.0039	3.1387
1 and 3	c	0.004	3.053
5, 6-7	F	0.0085	2.96
5, 6-7	M	0.0085	2.96
12-16	F	0.0054	3.05
12-16	M	0.006	3.08
19	M	0.005	3.05
19	F	0.0055	3.1
26	C	0.0046	3.119

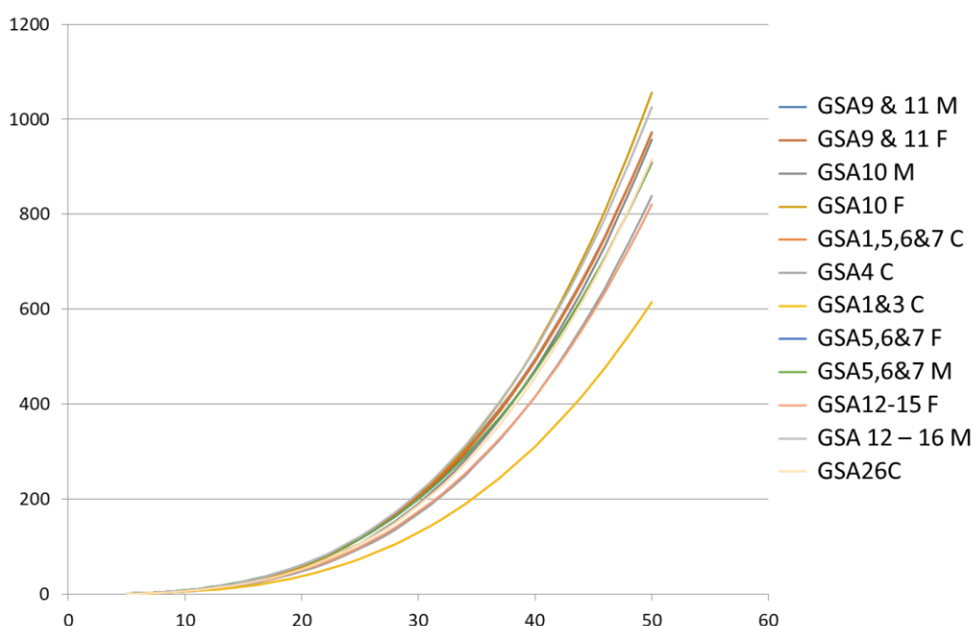


Figure 3.1.2.4. Length to weight relationships for European hake by GSA for assessment for males and females combined

3.1.2.3. Spawning time and stock weights

European Hake is known to spawn through the year, with several separate spawning events. For all the stocks, the major spawning event occurs early in the year. There is likely some variability among years. The spawning time is used in the calculation of spawning stock biomass (SSB) for each year, the proportion of annual F and M is included, and the stock weights should account for growth from the beginning of the year. It was decided that the best option was to align the time for F to 1 January SSB and ensure that stock weights are aligned to 1 January too, so this is self-consistent. This also helps as SSB is now calculated independently from F and M in the first few months of the year, so estimating SSB is done. Changes in SSB are used in management to inform on the state of the stock, however, the purpose of this is to capture the state of the stock, short term fluctuation in SSB are not informative for management, so standardizing the time point at the beginning of the year is helpful, as SSB is then independent of F in the following year. This simplifies the short-term forecast.

To be consistent with the stock numbers at spawning time of 1 January, the stock weights should also be for 1 January. These are computed as unweighted mean weight over the lengths assigned to each age through the slicing process.

3.1.2.4. Fraction mature

Data on fraction mature is available from catch and survey sampling, and from a number of reported studies. The maturity at length and maturity at age are available for different GSAs in Figures 3.1.2.5 and 3.1.2.6, respectively.

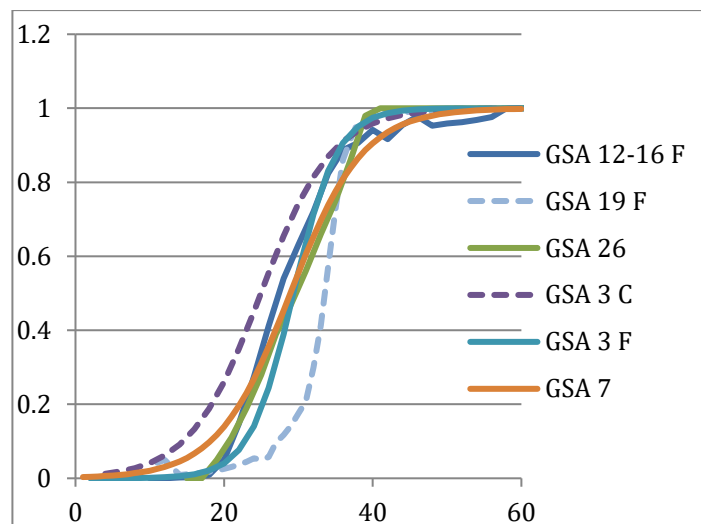


Figure 3.1.2.5. Maturity at length for different GSAs

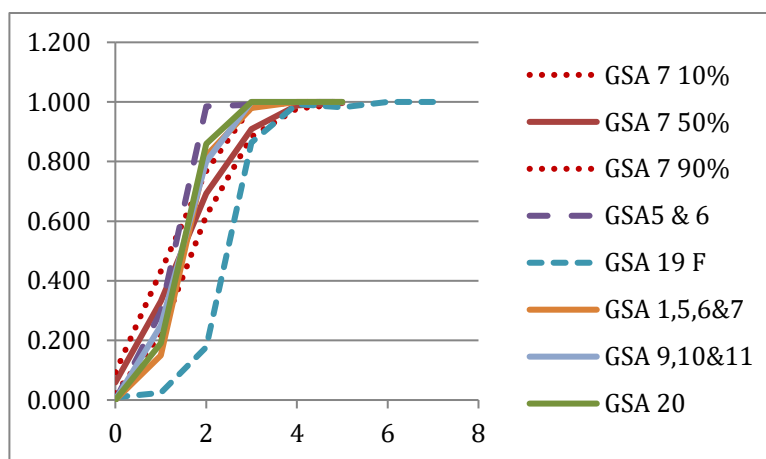


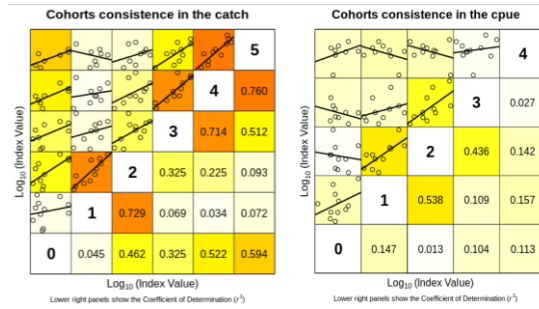
Figure 3.1.2.6. Maturity at age for different GSAs

3.2. Western Mediterranean

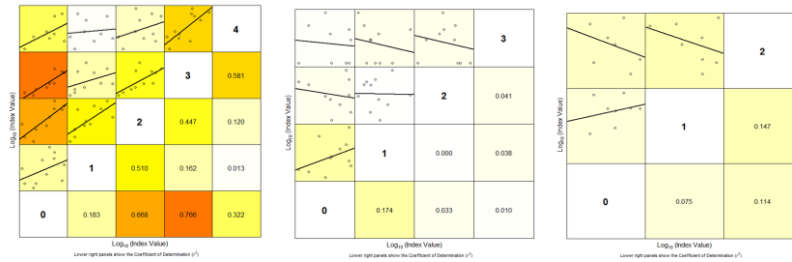
3.2.1. Comparison of combined and separate European hake assessments for GSAs 1, 3, 4, 5, 6 and 7

A benchmark decision on most appropriate GSA groupings for European hake assessments will be postponed until final results from TRANSBORAN and MED_UNITS are available. Until final decisions on GSA groupings for GSAs 1-7 are made, advice will consider recent GSA groupings (GSAs 1-3 and GSAs 1-5-6-7) as well as previous separate-area assessments (GSA 4, GSA 5, GSA 6 and GSA 7). Among these alternative GSA groupings, assessments with better diagnosis on data consistency and model fits can be selected as preferred models for the basis of advice, and other models can be considered as sensitivity analyses or supplemental information.

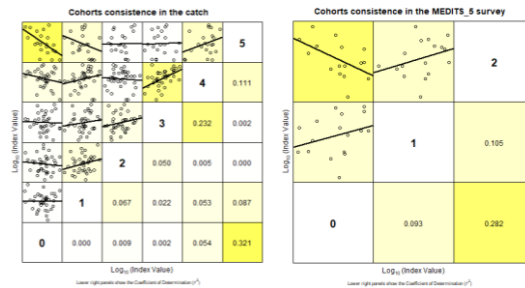
The benchmark decided to evaluate combined and separate GSA assessments based on the quality of input data (e.g. cohort tracking of year classes in fishery and survey data), model diagnostics (e.g. residual patterns, retrospective patterns), and models estimates (e.g. realism of estimated selectivity or exploitation status). Correlations of catch-at-age in the fisheries and surveys suggest that data quality is better after grouping GSAs 1-5-6-7, with the exception of the strongest cohort tracking in GSA 7. Correlations of catch-at-age for GSAs 1-5-6-7 indicate strong cohort tracking in the fishery and moderate cohort tracking in the survey.



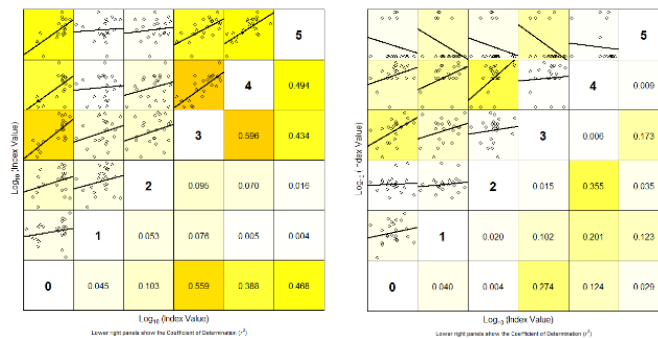
Correlations of catch-at-age for GSAs 1-3 indicate moderate cohort tracking in the fishery and weak cohort tracking in the surveys (MEDITS, and CIMD).



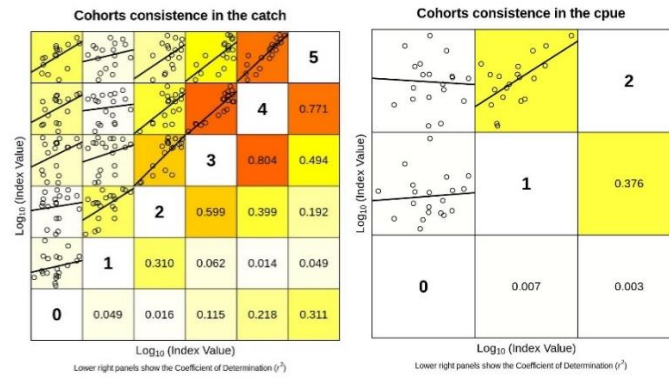
Correlations of catch-at-age for GSA 5 indicate weak cohort tracking in the fishery and in the survey.



Correlations of catch-at-age for GSA 6 indicate moderate cohort tracking in the fishery and weak cohort tracking in the survey.

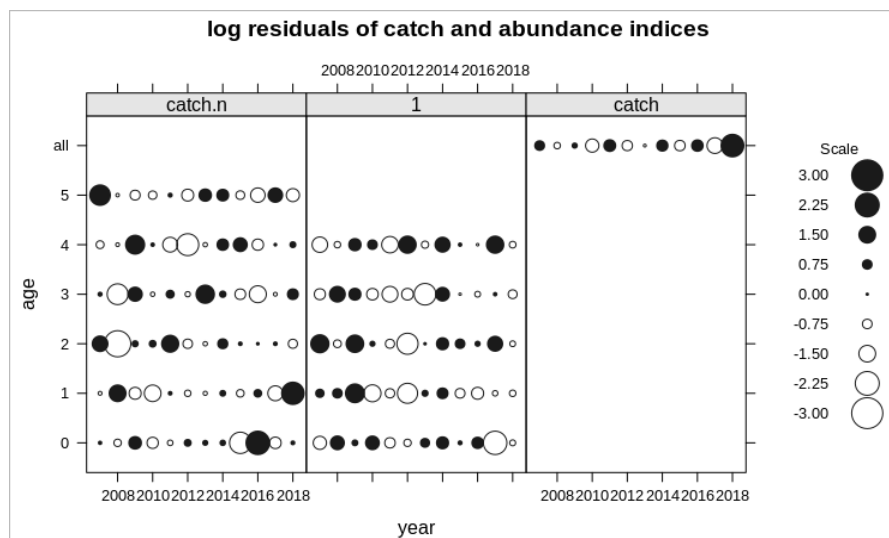


Correlations of catch-at-age for GSA 7 indicate strong cohort tracking in the fishery and moderate cohort tracking in the survey.

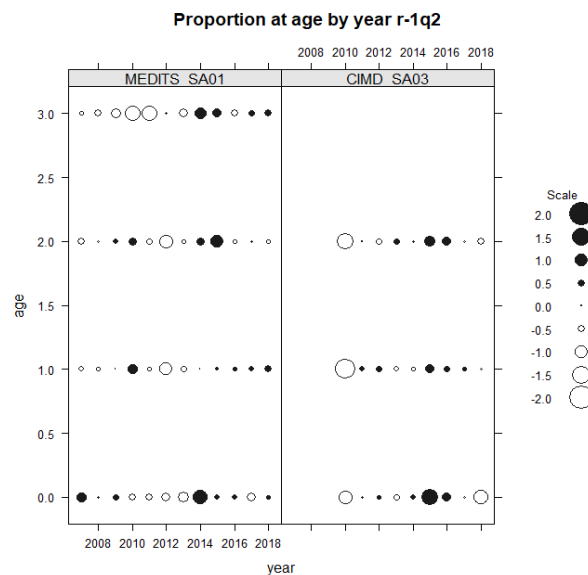


Model residuals suggest no major diagnostic problems in the assessments of European hake in GSAs 1-5-6-7, GSAs 1-3, and GSA 6, but there is a major residual pattern in the GSA 7 assessment.

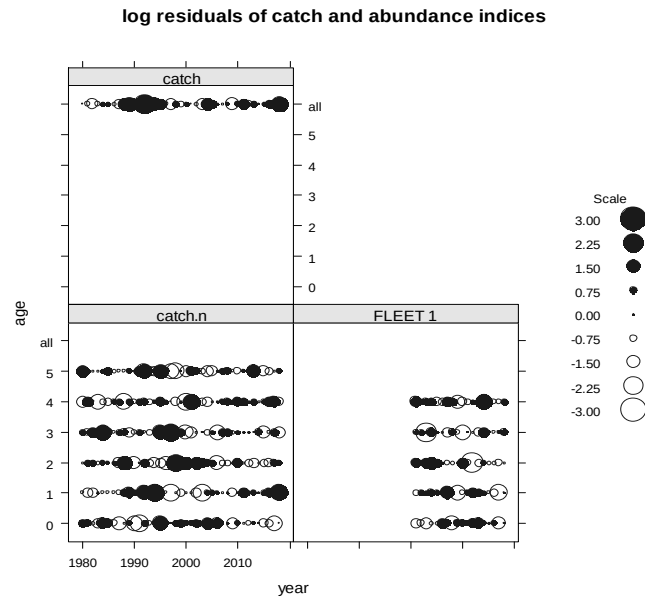
Model residuals for the assessment of GSAs 1-5-6-7 have some minor cohort and year effect patterns.



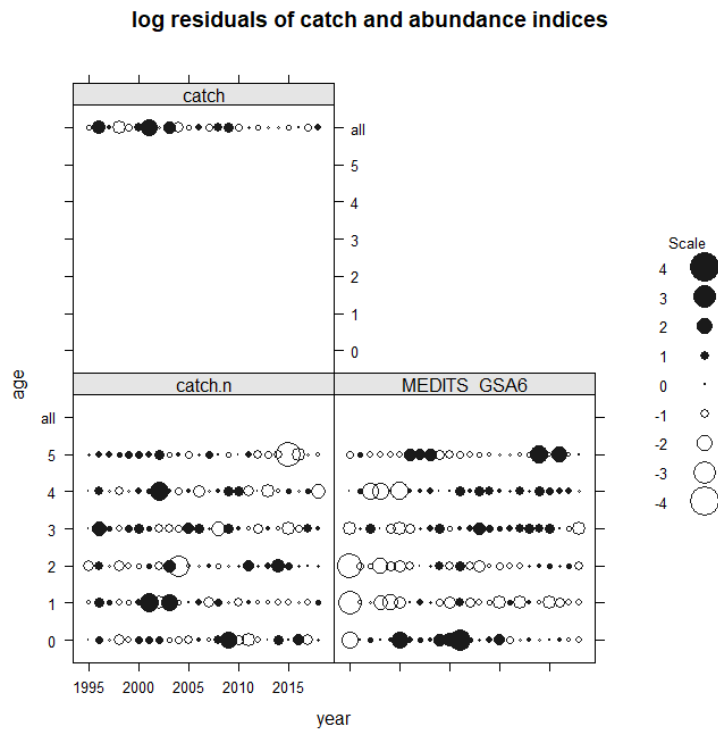
Model residuals for the assessment of GSAs 1-3 have some minor cohort and year effect patterns.



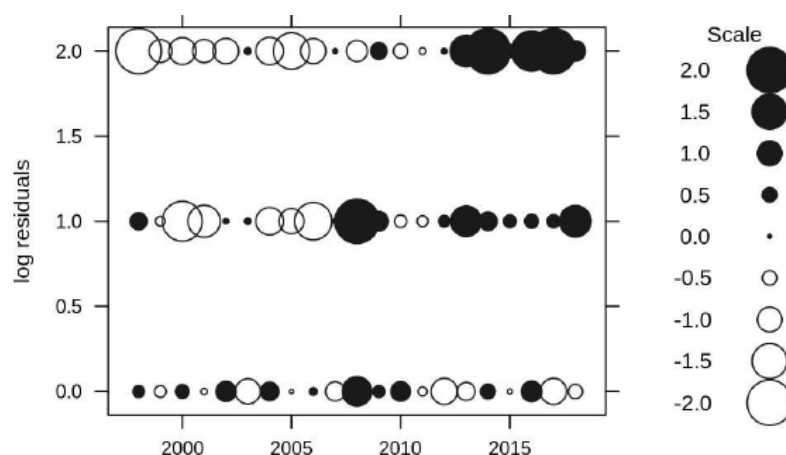
Model residuals for the assessment of GSA 5 have some minor patterns.



Model residuals for the assessment of GSA 6 have some minor patterns.



Model residuals for the assessment of GSA 7 have a major residual pattern in which all residuals for ages 1-2 and 2012–2018 are positive. These patterns persist for several alternative model configurations and could only be resolved by allowing survey catchability to change.



Some results from separate GSA assessments are difficult to understand and may not be realistic. The assessment of European hake in GSA 6 produces unrealistic estimates of selectivity. The current fishing mortality and $F_{0.1}$ in each assessment indicate overexploitation. However, the assessment of European hake in GSA 7 indicates an exploitation status ($F_{\text{current}}/F_{0.1}=18$) that may be unrealistic.

Table 3.2.1.1. Exploitation status (based on fishing mortality on ages 0-2) of European hake in GSAs 1-7

GSAs	F_{current}	$F_{0.1}$	$F/F_{0.1}$
1-3	1.20	0.17	7.1
5	1.40	0.31	4.5
6	1.20	0.11	11.2
7	2.70	0.15	18.0
1-5-6-7	1.40	0.25	5.6

Note that estimates of current F and $F_{0.1}$ are not directly comparable, because current F refers to either the terminal year or the average of the last three years and each assessment has different estimates of selectivity.

Based on these evaluations, the external reviewers recommend that **advice should be based on the assessment of European hake in GSAs 1, 5, 6, 7, and the assessment of European hake in GSA 5, GSA 6 and GSA 7 should be considered as sensitivity analyses and supplemental spatial information.** The greatest concern about grouping GSAs 1-5-6-7 is that there is a biological boundary on at the Almeria-Oran front, and European hake in GSA 1 should not be grouped with those in GSAs 5-6-7. Therefore, assessing European hake in GSAs 5-6-7 may be another option.

The assessments attempted are reported below, and the final advice provided, on the basis of the analysis carried out and taking into account the recommendations above, is available in Appendix 3.

3.2.2. Assessment unit: GSAs 1, 5, 6, 7

3.2.2.1. Method a4a

A. Model assumptions

The assessment of European Hake carried out during the STECF EWG 19-10 and presented during the GFCM benchmark considered the stock shared by GSAs 1, 5, 6 and 7. According to the assessment for all initiative (a4a) method (Jardim *et al.*, 2015) a statistical catch-at-age assessment was used. The a4a method utilizes catch-at-age data to derive estimates of historical population size and fishing mortality.

The assessment was carried out in terms of time between 2007 and 2018 as survey indices data were available only from 2007 for GSA 5 (Balearic Islands). Available catch numbers at length and index number at length were sliced using the a4a age slicing routine in FLR (I2a). The analyses were carried out for ages 0 to 5+.

According to the resulting selection pattern ages classes 1-3 were chosen to compute the current level of fishing mortality.

B. Input data and parameters

As information by sex were not available for the GSAs considered, a sex combined a4a model was applied. All the parameters used were the same as in the previous assessment for European hake in this combined area.

Growth parameters used were those estimated by Mellon-Duval *et al.* (2010) from tagging experiments in the Gulf of Lion (Table 3.2.2.1).

Table 3.2.2.1. Growth parameters and length-weight relationship parameters for European hake in GSAs 1, 5, 6 and 7.

Linf	K	t0	a	b
110	0.178	-0.005	0.00677	3.0351

The maturity vector was taken from García-Rodríguez and Esteban (1995). The natural mortality vector was estimated as an average of different methods (Gislason; Prodbiom revised version with unique solution; Chen and Watanabe; Brodziak [2011 and 2012]; Lorenz and Gulland), consistently with the approach used in the GFCM benchmark assessment of European hake in the Adriatic Sea in 2019 (Table 3.2.2.2).

Table 3.2.2.2. Maturity and natural mortality vectors used in the assessment of European hake in GSAs 1, 5, 6 and 7

Age	Maturity	M
0	0.00	1.63
1	0.15	0.68
2	0.82	0.41
3	0.98	0.31
4	1.00	0.25
5+	1.00	0.22

Landings data were reported to STECF EWG 19-10 through the DCF. European hake is largely exploited in GSAs 1 and 6, mainly by trawlers on the shelf and slope, but also by small-scale fisheries using long lines, gillnets and trammel nets. In GSA 5, European hake catches come exclusively from bottom trawlers. They show important oscillations along the data series, between 50 and 200 tonnes. In the Gulf of Lion (GSA 7), European hake is exploited by French trawlers, French gillnetters, Spanish trawlers and Spanish longliners. Anyway, contribution of set nets and longlines to the total landing is quite low (~4 percent). In Figure 3.2.2.1 total landings for the western Mediterranean area (excluding Italy) provided during the GFCM European hake benchmark are showed.

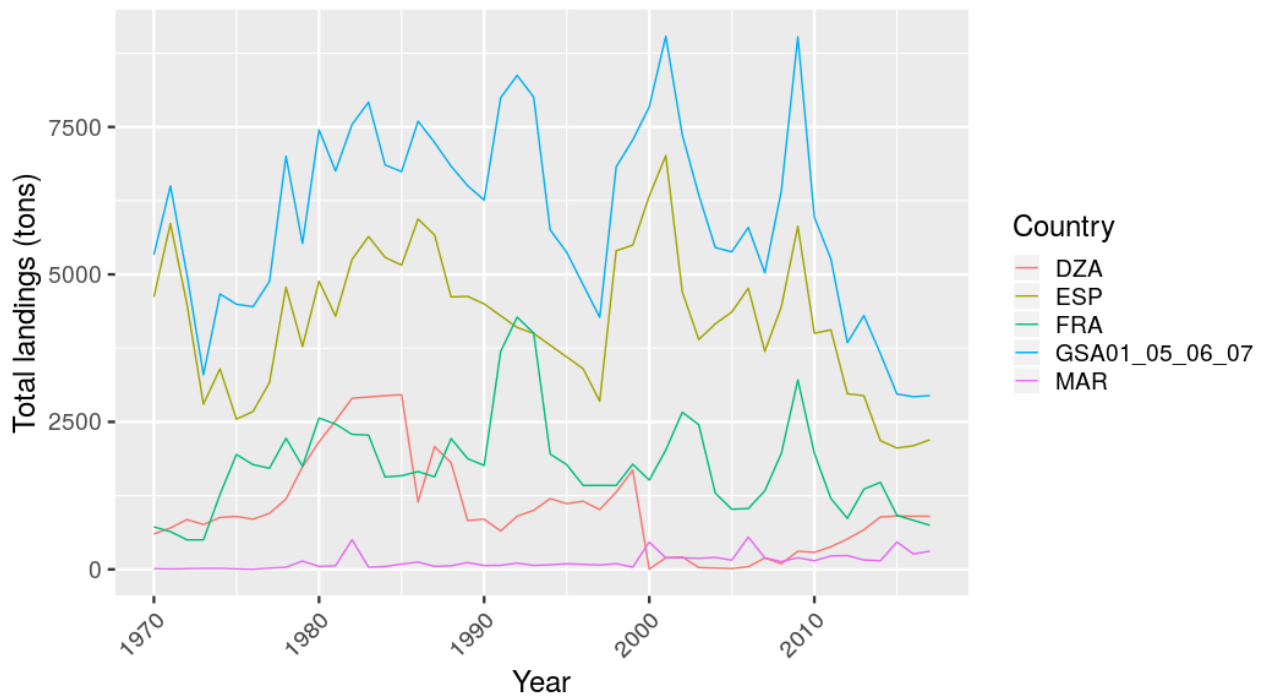
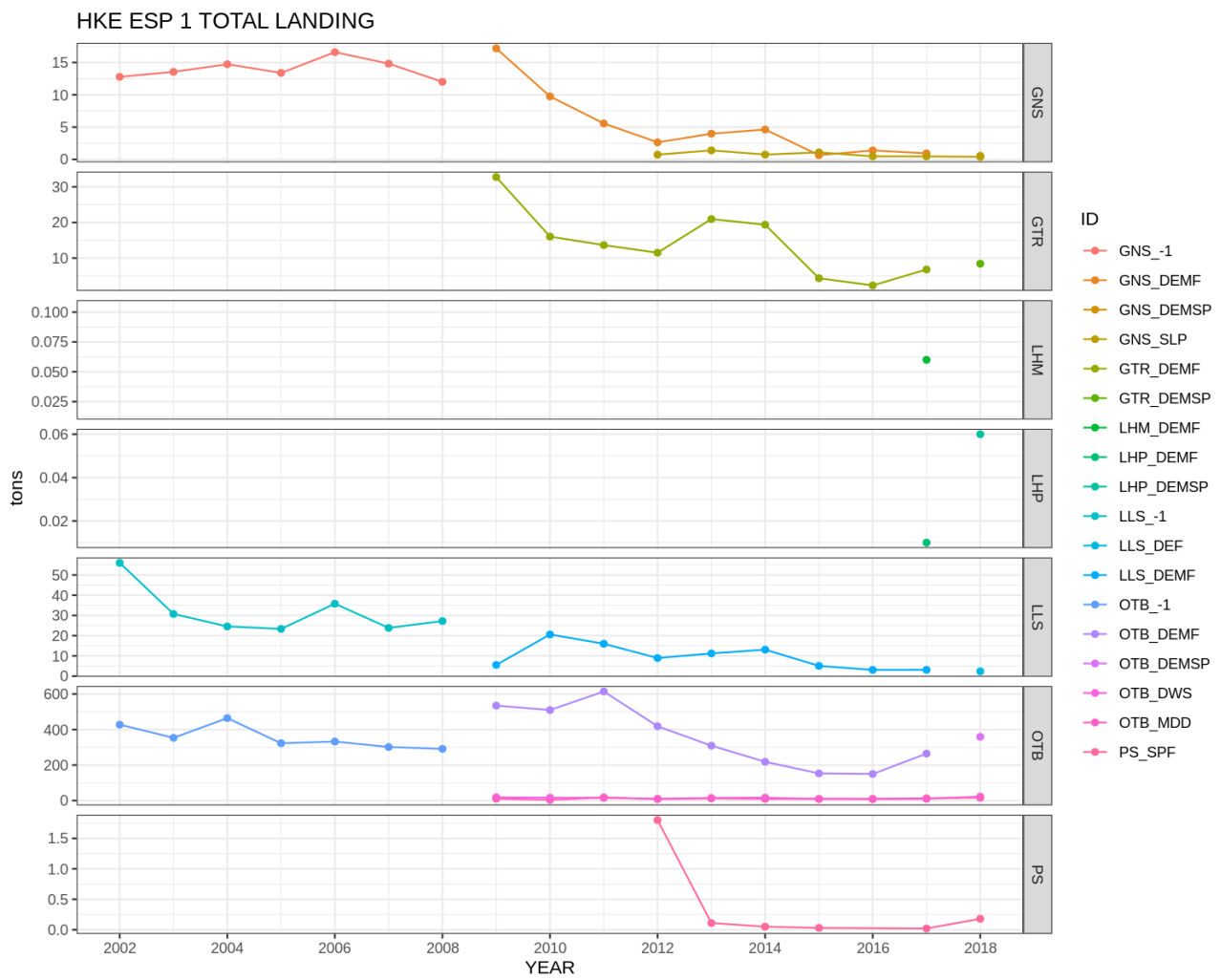
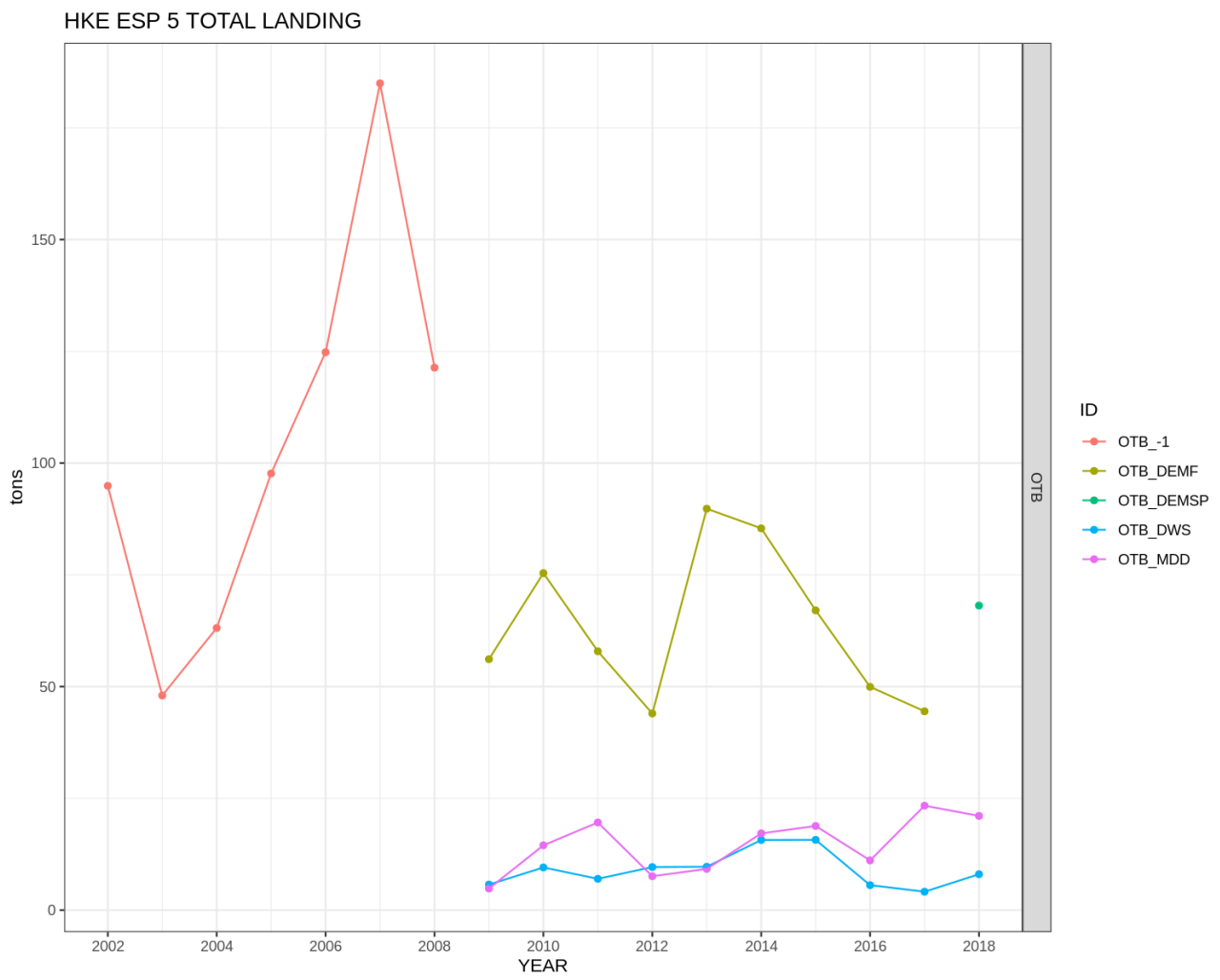
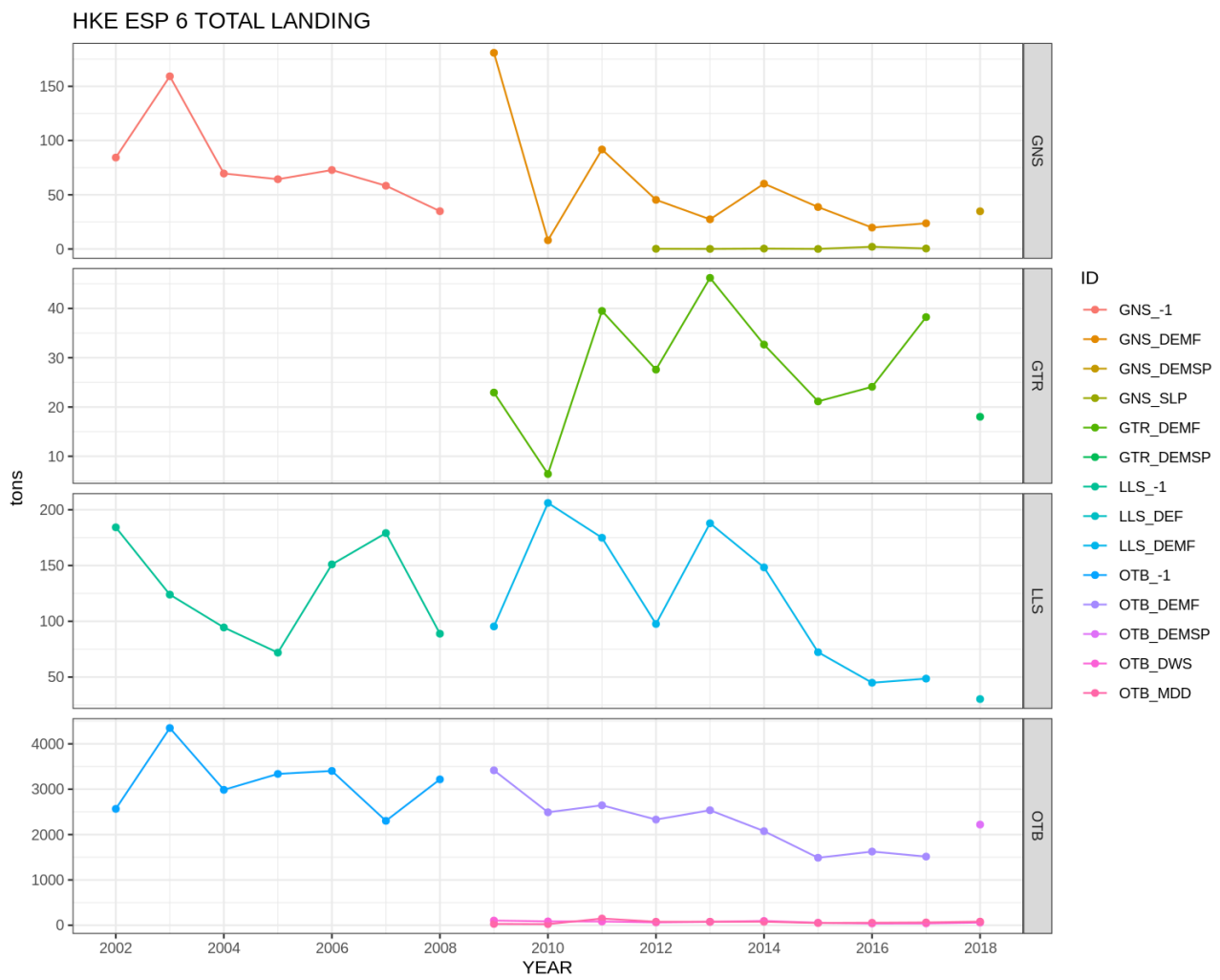


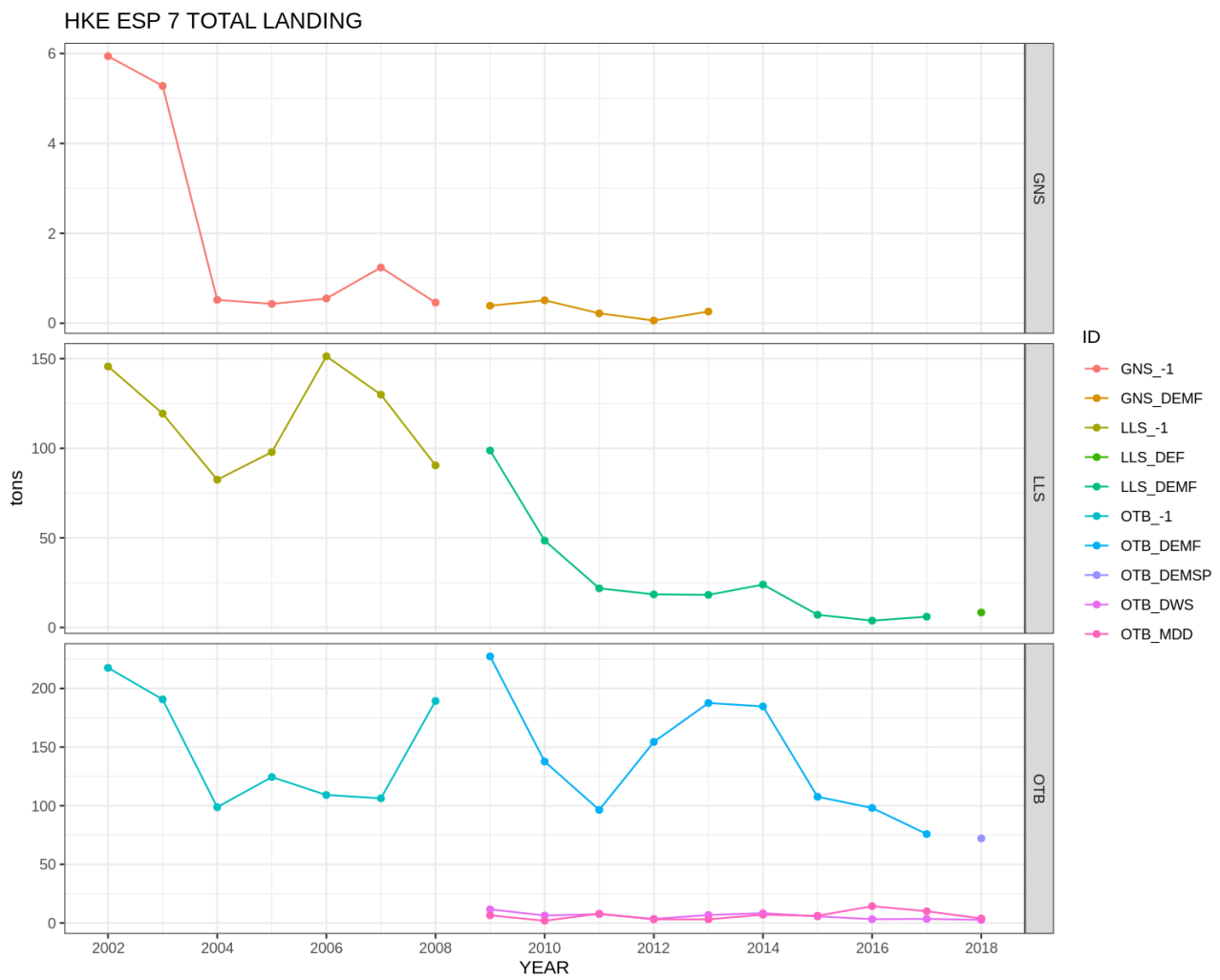
Figure 3.2.2.1. Total landings in tonnes provided during the GFCM European hake benchmark in GSAs 1, 5, 6 and 7. (Algeria, Spain, France and Morocco)

Landings data by year and fleet provided through the EU Data Call are presented in Figure 3.2.2.1 and total landings by year are presented in Table 3.2.2.3. For metier code, refer to Annex 1 of EU Official Data Call (<https://datacollection.jrc.ec.europa.eu/dc/medbs>).









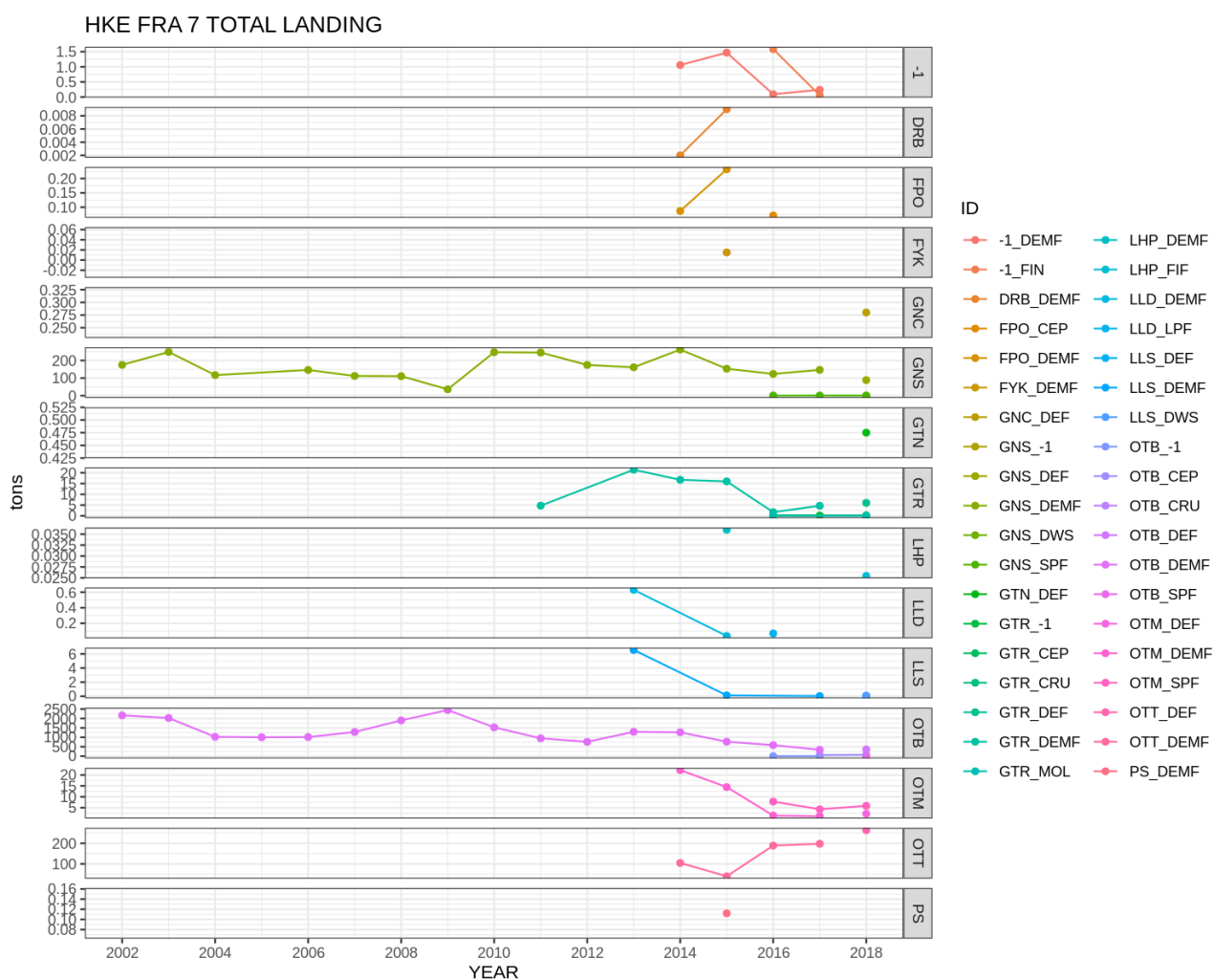
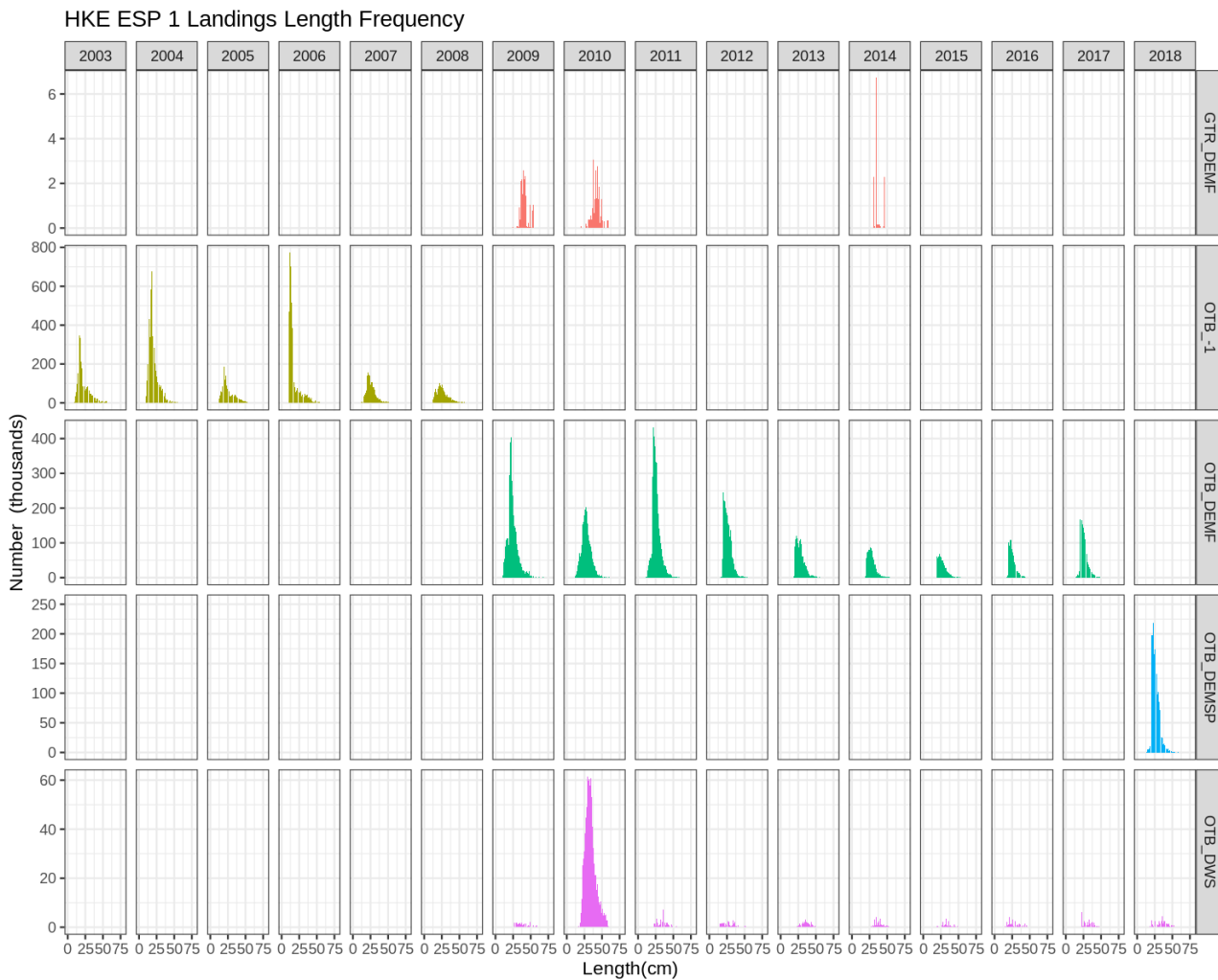


Figure 3.2.2.2. Landings data in tonnes by year and fleet for European hake in GSAs 1, 5, 6 and 7

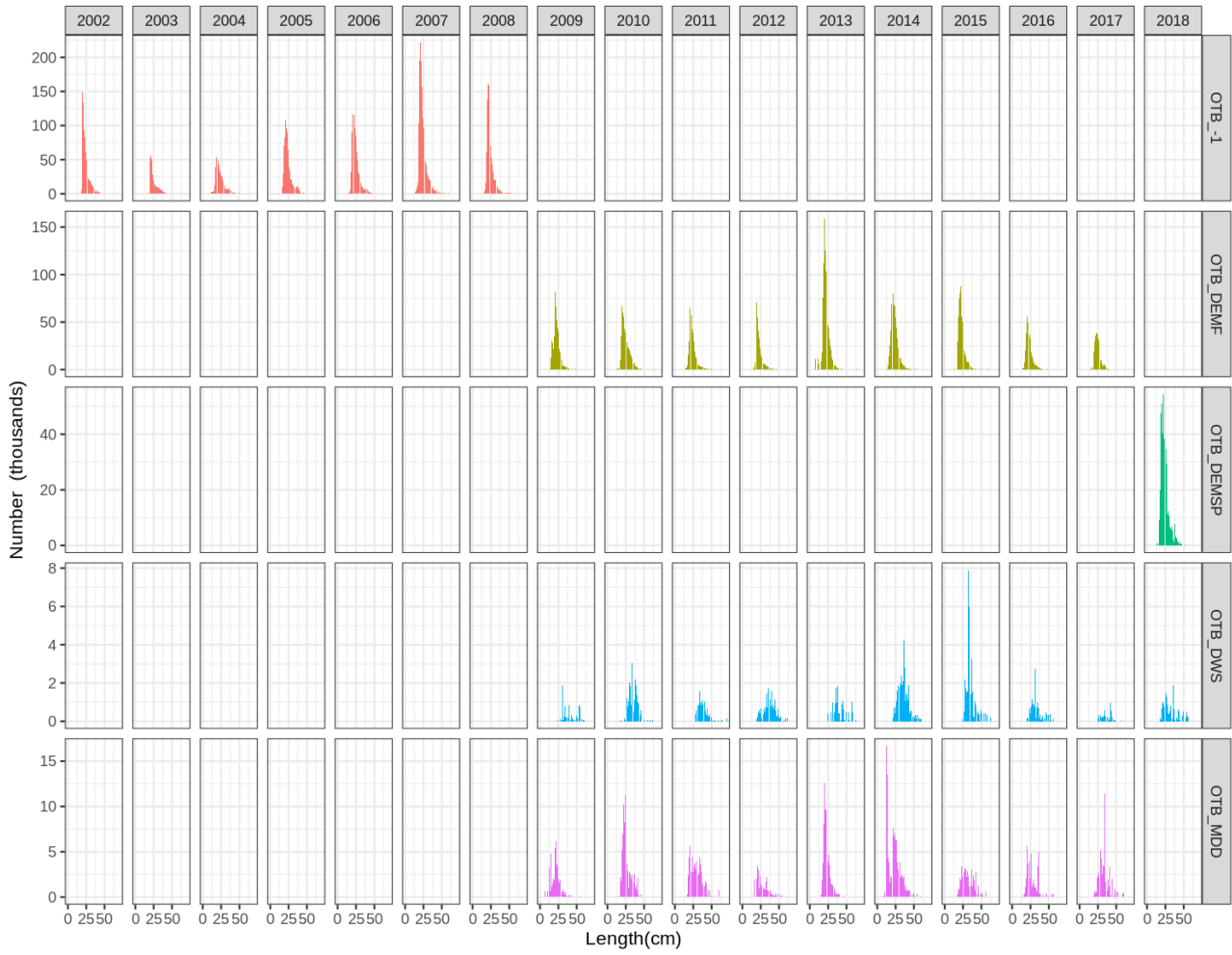
Table 3.2.2.3. Landings data in tonnes by year for European hake in GSAs 1, 5, 6 and 7

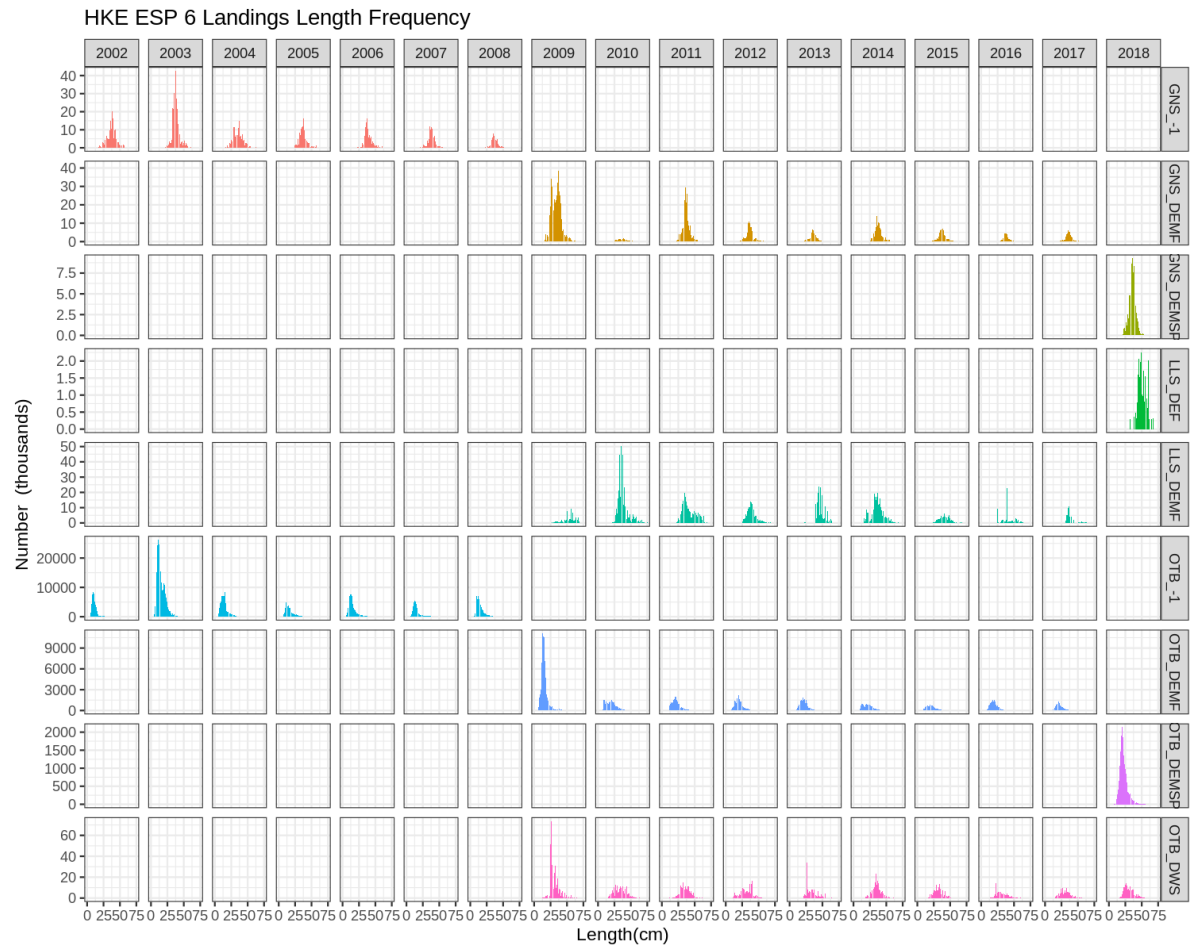
Year	Total landing (tonnes)
2002	6 138
2003	7 666
2004	5 039
2005	5 156
2006	5 558
2007	4 697
2008	6 082
2009	7 362
2010	5 466
2011	5 279
2012	4 278
2013	5 131
2014	4 786
2015	3 129
2016	3 083
2017	2 946
2018	3 831

Length frequency distribution of the landings by year and gear or fleet from the DCF database are presented in Figure 3.2.2.3.



HKE ESP 5 Landings Length Frequency





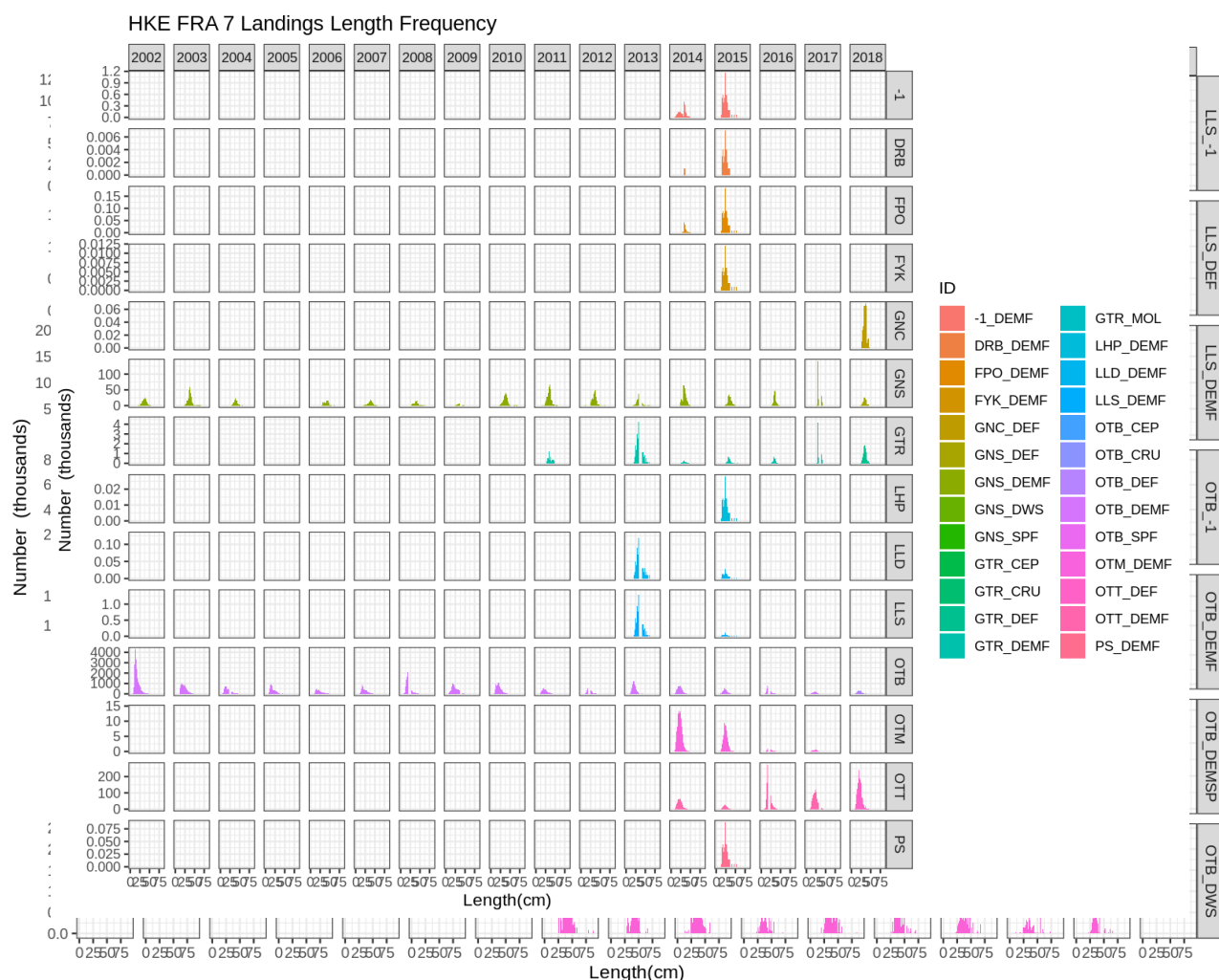


Figure 3.2.2.3. Length frequency distribution of the landings by year and gear or fleet for European hake in GSAs 1, 5, 6 and 7

Discards data by year and fleet provided through the EU Data Call were included in the stock assessment. For the years in which discards data were missing, they were estimated on the basis of the discard ratio (discard/landing) of the available years and the landing time series.

The highest discard rates were represented by the bottom trawl fishery; for the other types of gear, the discards were negligible. Total discard by year for the bottom trawl fishery is presented in Table 3.2.2.4.

Table 3.2.2.4. OTB discards data in tonnes by GSA for European hake in GSAs 1, 5, 6 and 7.

Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
GSA 1	19.3	24.2	19.1	13.2	20.8	14.9	5.8	20.8	10.4	30.5	23.5	24.9	21.4	27.6
GSA 5	12.2	11.9	9.4	7.1	16.2	19.2	6.5	6.5	13.1	5.6	0.6	9.8	4.1	46.3
GSA 6	0.1	98.4	77.8	0.5	0.3	0.8	141.6	194.3	156.6	151.8	50.3	70.8	69.0	139.2
GSA 7	1.4	14.4	11.4	186.4	9.6	1.5	3.6	10.4	46.2	46.8	20.4	20.8	4.8	33.4
Total discard (tonnes)	33.1	148.8	117.6	207.1	46.8	36.4	157.4	231.9	226.2	234.7	94.7	126.2	99.2	246.4

Length and age frequency distributions of discards were available from DCF data only for France in GSA 7 while for Spain only the last two years in GSAs 1 and 6, and the last year in GSA 5 were available.

Total catches and catch numbers at age from the single GSAs were used as input data. SOP correction was applied to catch numbers at age (Table 3.2.2.5).

Table 3.2.2.5. SOP correction vector for European hake in GSAs 1, 5, 6 and 7

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
SOP	1.05	1.10	1.01	0.92	1.05	1.14	1.12	1.12	1.11	1.16	1.10	1.02

Table 3.2.2.6 lists the input data for the a4a model, namely catches, catch number at age, weight at age, maturity at age, natural mortality at age, and the tuning series at age.

Table 3.2.2.6. Input data for the a4a model for European hake in GSAs 1, 5, 6 and 7

Catches (tonnes)

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
4 814.5	6 288.8	7 409.2	5 502.2	5 436.3	4 510.3	5 338.6	5 018	3 208.7	3 209.2	3 045.1	4 077.3

Catch numbers at age (thousands)

Year/Age	0	1	2	3	4	5+
2007	42 048.58	18 325.41	3 528.93	525.86	96.14	23.66
2008	70 082.19	38 842.29	2 855.38	299.18	102.96	18.10
2009	71 066.10	32 161.29	5 396.14	528.76	125.60	13.56
2010	15 980.27	26 182.47	4 767.19	374.10	91.19	10.36
2011	9 228.88	28 730.84	4 527.02	348.89	64.12	9.21
2012	11 167.71	29 624.35	2 970.79	248.99	44.38	3.80
2013	12 600.23	33 062.28	3 514.35	324.34	37.77	5.97
2014	14 220.58	25 491.95	4 066.91	257.69	28.14	4.83
2015	7 916.29	17 277.83	2 473.69	187.57	27.49	2.37
2016	14 929.19	22 093.15	1 880.76	113.95	20.97	1.72
2017	10 174.79	18 059.08	2 274.76	121.04	17.68	4.19
2018	15 280.85	40 337.49	2 097.47	176.92	12.43	1.41

Weights at age (Kg)

Year/Age	0	1	2	3	4	5+
2007	0.018	0.105	0.404	0.945	1.599	2.764
2008	0.017	0.088	0.398	0.955	1.615	2.665
2009	0.020	0.095	0.409	0.946	1.516	2.792
2010	0.018	0.106	0.402	0.933	1.627	2.419
2011	0.024	0.104	0.390	0.923	1.628	2.507
2012	0.024	0.093	0.394	0.906	1.622	2.451
2013	0.024	0.100	0.386	0.916	1.606	2.721
2014	0.020	0.112	0.388	0.919	1.562	2.616
2015	0.019	0.109	0.387	0.914	1.580	2.695
2016	0.023	0.091	0.378	0.942	1.578	2.631
2017	0.019	0.103	0.370	0.922	1.529	2.741
2018	0.020	0.067	0.388	0.917	1.589	2.465

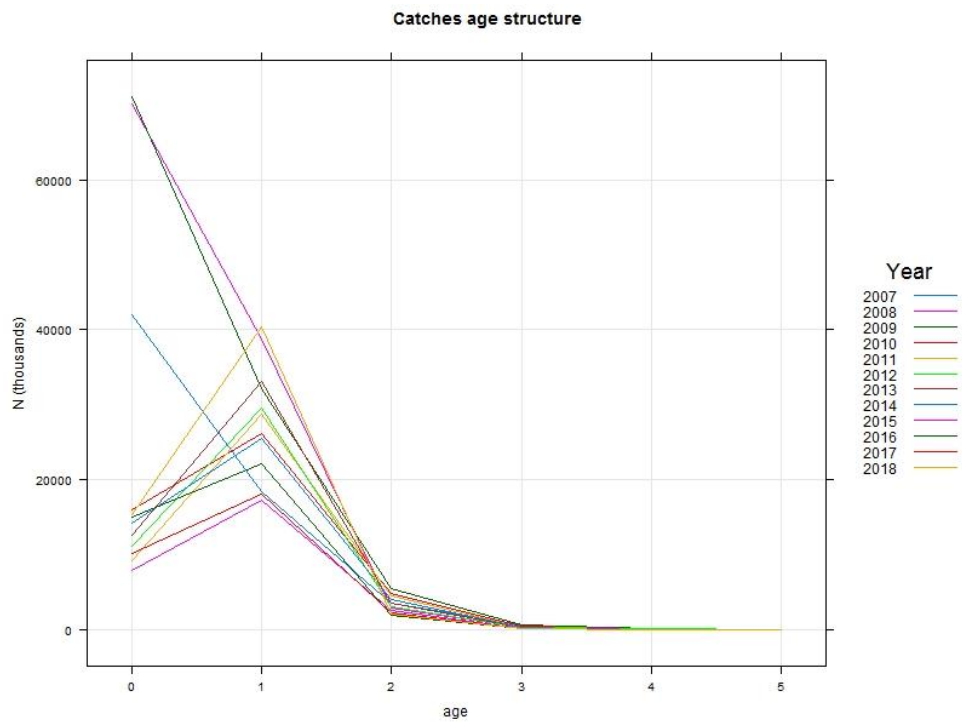
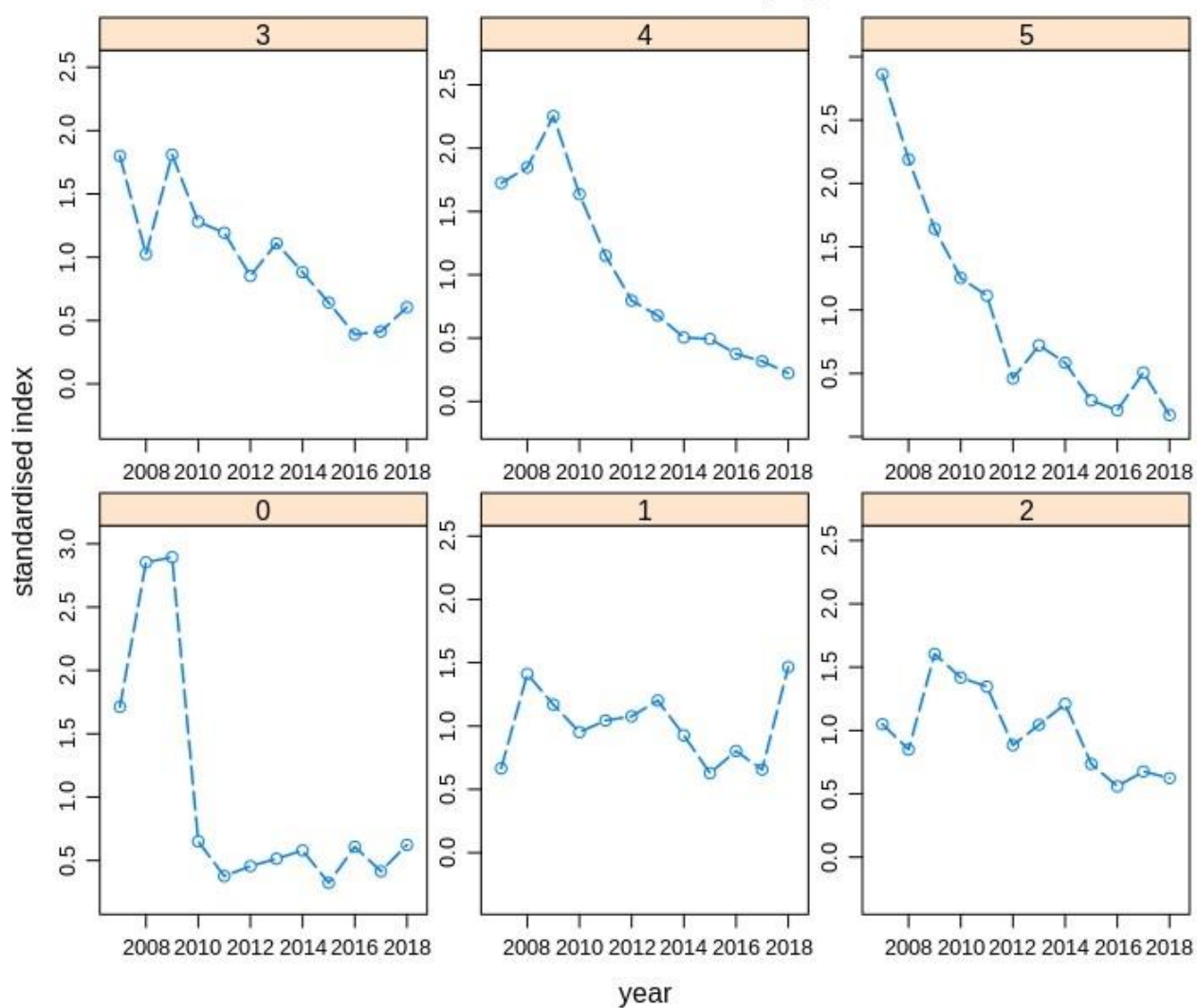


Figure 3.2.2.4. Catch at age input data for European hake in GSAs 1, 5, 6 and 7

abundance in the catch by age



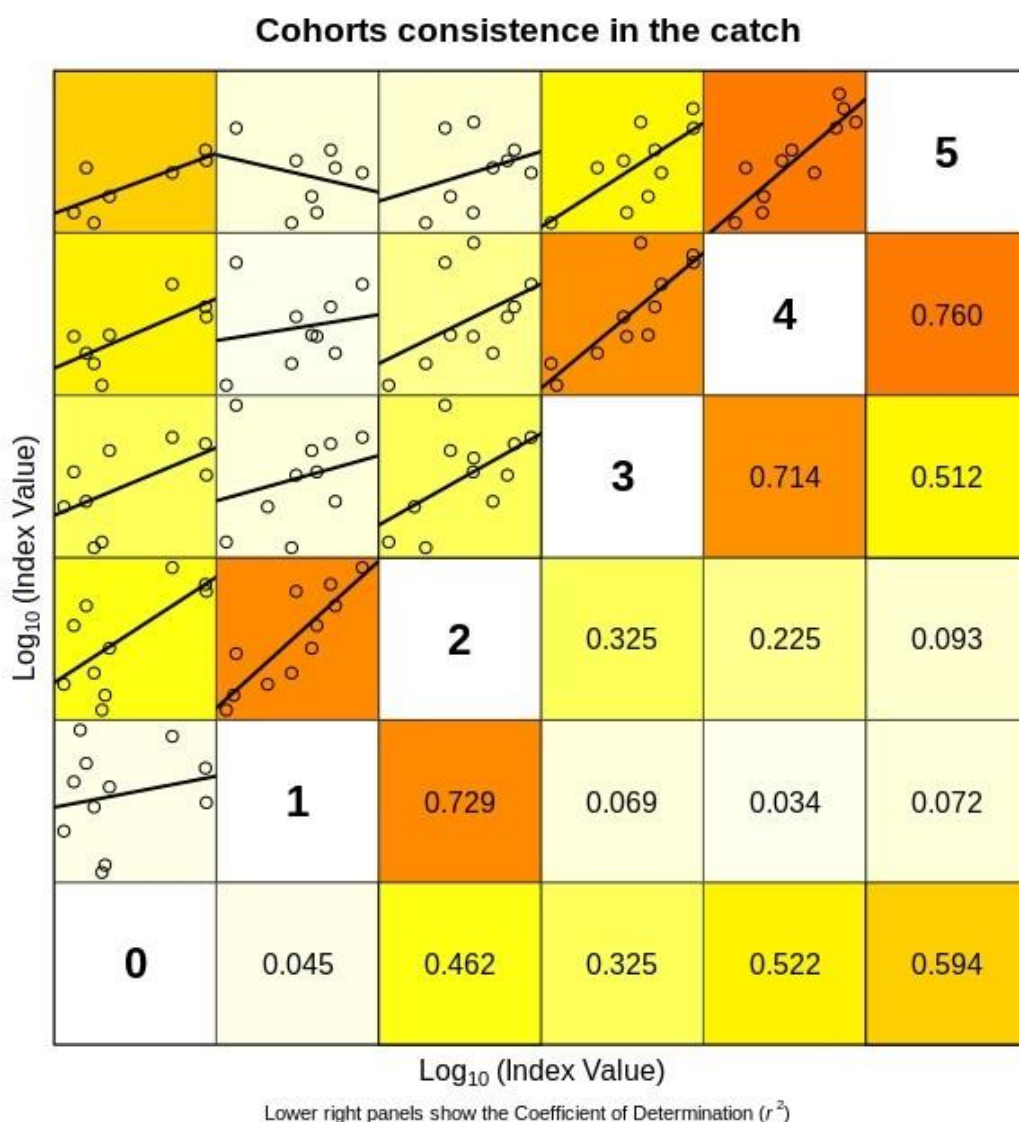
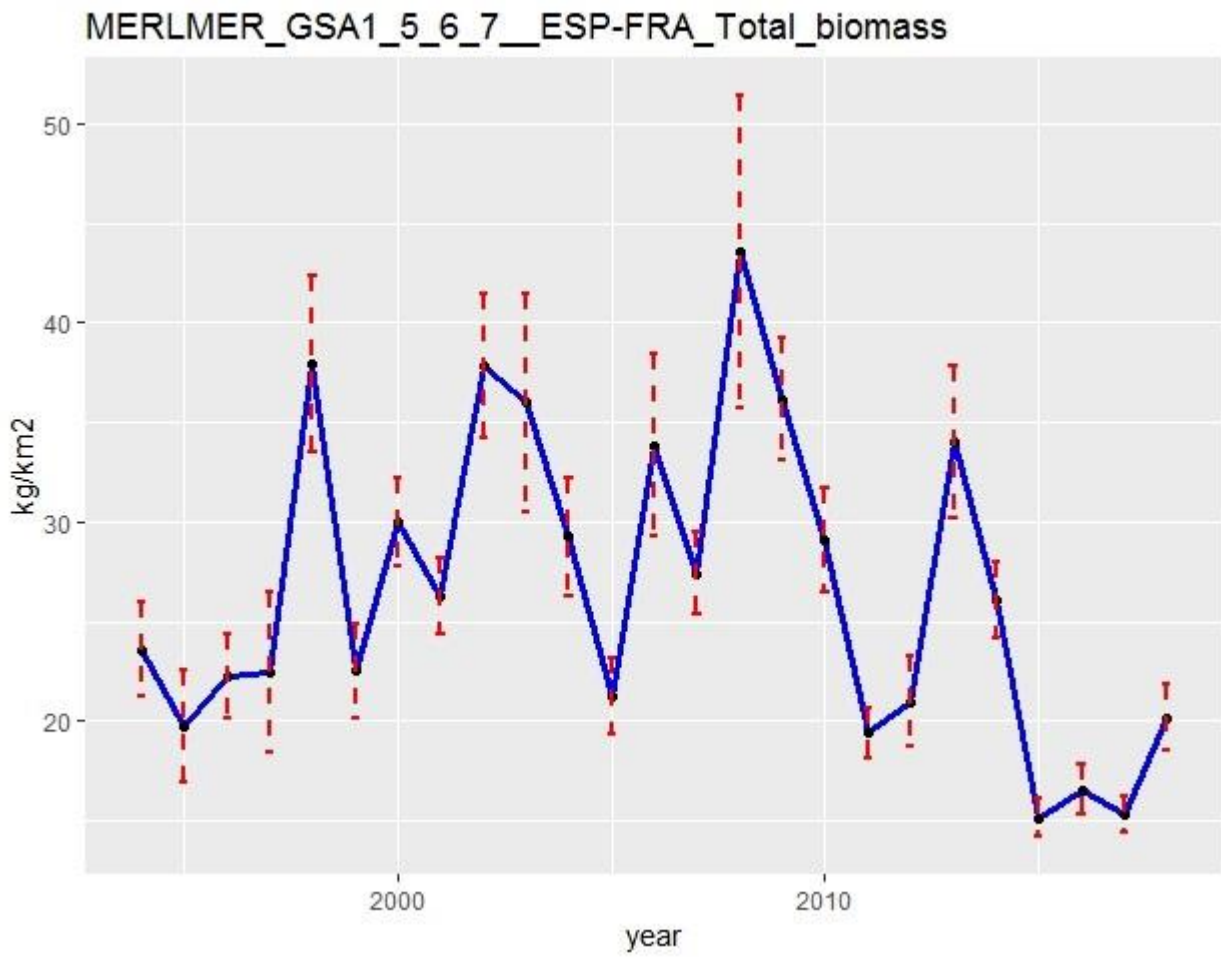


Figure 3.2.2.5. Catch at age input data (abundance by age and year and cohort consistency) for European hake in GSAs 1, 5, 6 and 7

Since 1994, the Mediterranean International Trawl Survey (MEDITS) surveys have been regularly carried out each year during the spring season. In the current assessment combined MEDITS data for GSAs 1-5-6-7 from 2007 onwards were used, as in GSA 5 the survey has been carried out consistently only from that year. The Balearic Islands, in fact, were partially covered by the MEDITS survey in 1994–2006, with a very low number of hauls by year, covering only a small part of the area (Ibiza channel). Thus, only the information collected from 2007, when the sampling was extended, was considered reliable for the analysis.

The combined MEDITS indexes were calculated using the script provided by the JRC expert (Figure 3.2.2.6).



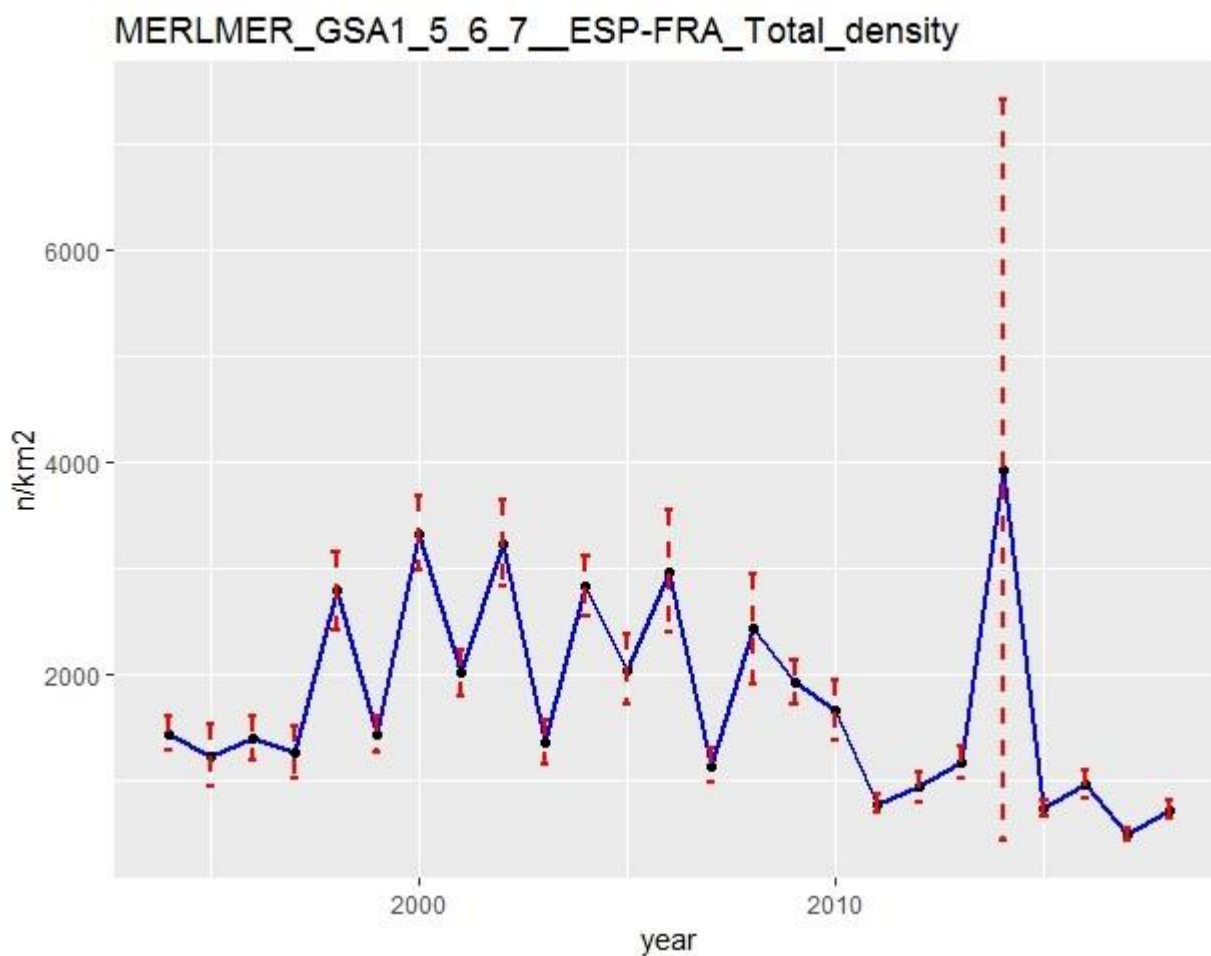


Figure 3.2.2.6. Estimated biomass indices (kg/km²) and density (n/km²) from the MEDITS survey for the European hake in GSAs 1, 5, 6 and 7

Both estimated abundance and biomass indices show similar trends, with strong fluctuations throughout the time series and a slight increase in the last year.

Size structure indices are shown in Figure 3.2.2.7. Table 3.2.2.7 and Figure 3.2.2.8 showed numbers at age derived from the survey. Figure 3.2.2.9 shows abundance by age and year, and cohort consistency from the survey.

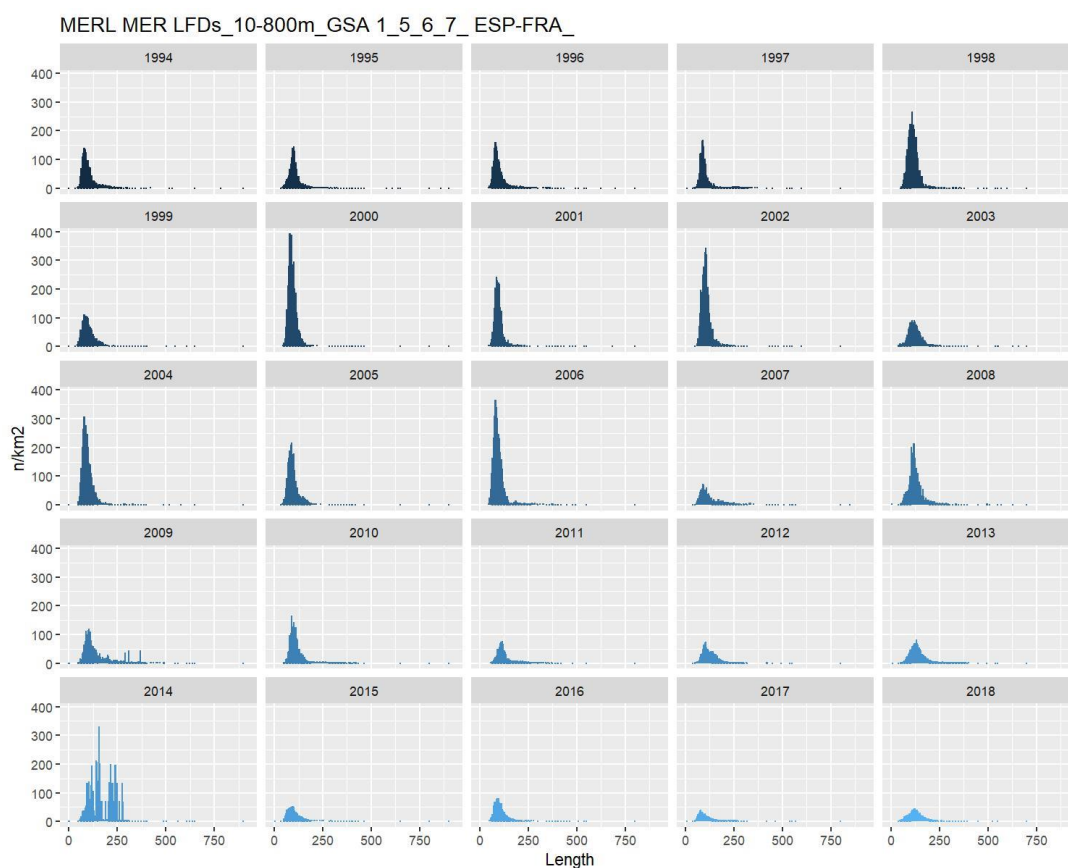


Figure 3.2.2.7. Length frequency distribution by year from the MEDITS survey for European hake in GSAs 1, 5, 6 and 7

Table 3.2.2.7. Input data for the a4a model (MEDITS numbers at age [n/km^2]) for European hake in GSAs 1, 5, 6 and 7

Year/Age	0	1	2	3	4
2007	752.35	135.03	22.02	1.98	0.91
2008	2 042.50	181.64	10.72	3.96	0.68
2009	1 241.50	222.98	23.13	2.73	0.42
2010	1 377.80	75.23	12.11	0.91	0.07
2011	686.32	85.75	7.02	0.60	0.01
2012	818.95	68.29	4.05	0.61	0.12
2013	932.74	128.49	8.36	0.31	0.11
2014	820.23	101.32	11.28	1.47	0.34
2015	672.74	49.77	7.03	0.75	0.18
2016	901.94	54.32	4.83	0.45	0.13
2017	408.95	67.95	8.36	0.48	0.22
2018	623.98	92.18	4.59	0.37	0.08

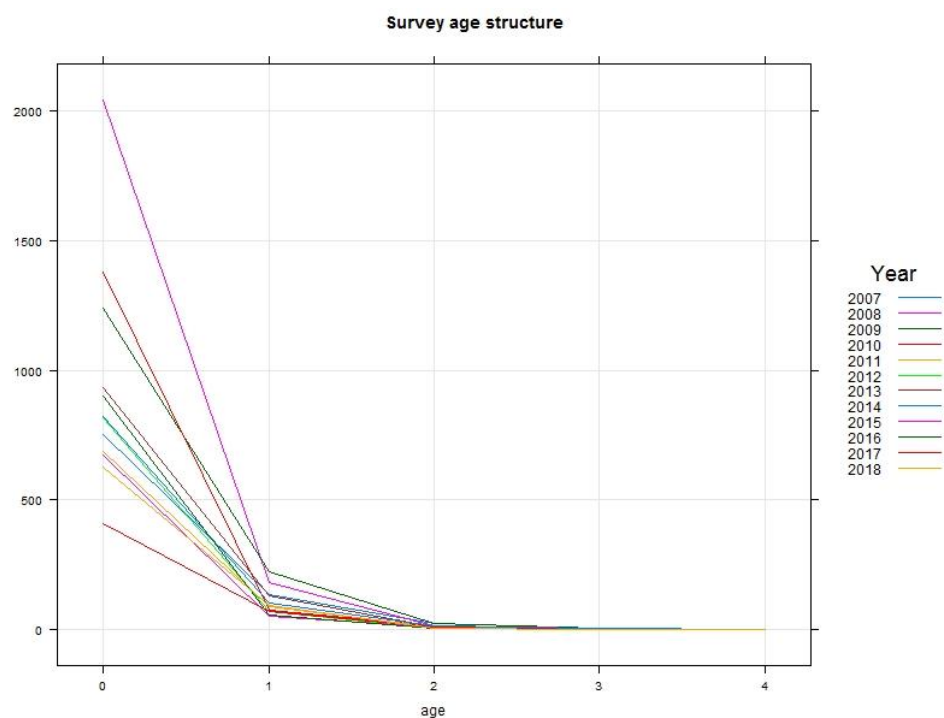


Figure 3.2.2.8. Age structure of the index for European hake in GSAs 1, 5, 6 and 7

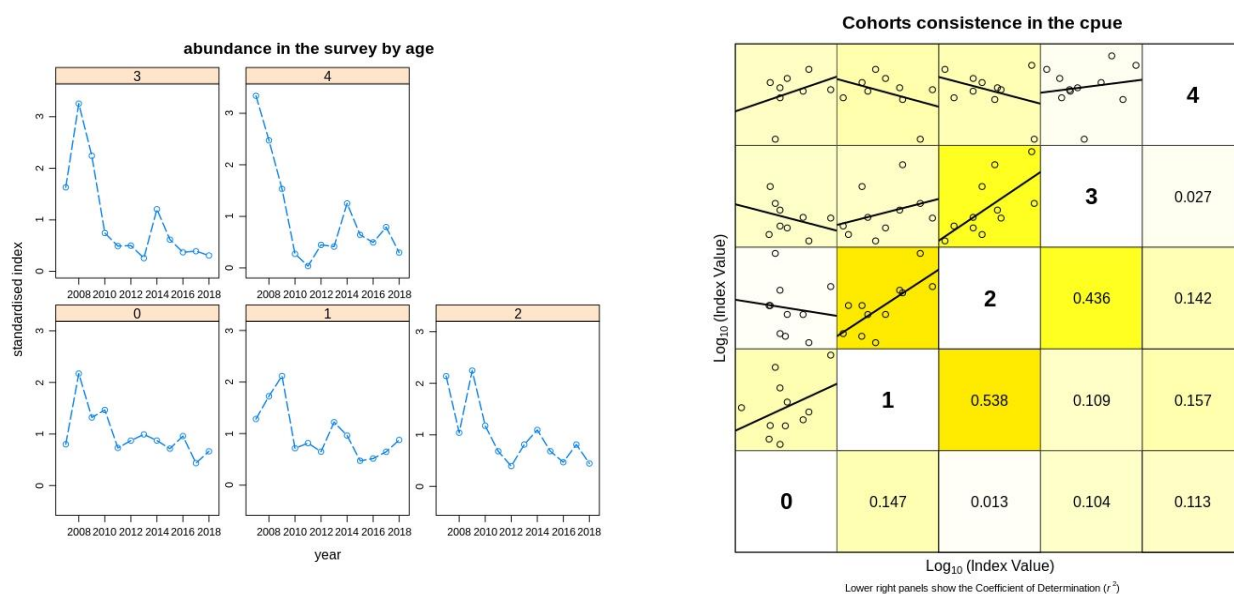


Figure 3.2.2.9. Index at age input data (abundance by age and year, and cohort consistency) for European hake in GSAs 1, 5, 6 and 7

C. Results

Different a4a models were performed (combination of different f , q and sr). The best model (according to diagnostics) was:

a4a model fit for: HKE_1_5_6_7

Submodels:

fmodel: $\sim s(\text{age}, k = 4) + s(\text{year}, k = 6) +$
 $s(\text{year}, k = 6, \text{by} = \text{as.numeric}(\text{age} == 0)) +$

$s(\text{year}, k = 6, \text{by} = \text{as.numeric}(\text{age} == 4))$

$\text{srmodel}: \sim \text{factor}(\text{year})$

$\text{n1model}: \sim s(\text{age}, k = 3)$

$\text{qmodel}: \sim I(1/(1 + \exp(-\text{age})))$

$\text{vmmodel:catch}: \sim s(\text{age}, k = 3) \text{ and } \text{Index}: \sim 1$

The use of additional parameters on age 0 and age 4 in the fishery model were included to allow the model to fit better to the first few years of the data, which show higher catches particularly at age 0. These extra terms also improved the retrospective performance, suggesting the early years are indeed different from the recent years fishery.

Results are shown in Figures 3.2.2.10 and 3.2.2.11 and Tables 3.2.2.8 to 3.2.2.10.

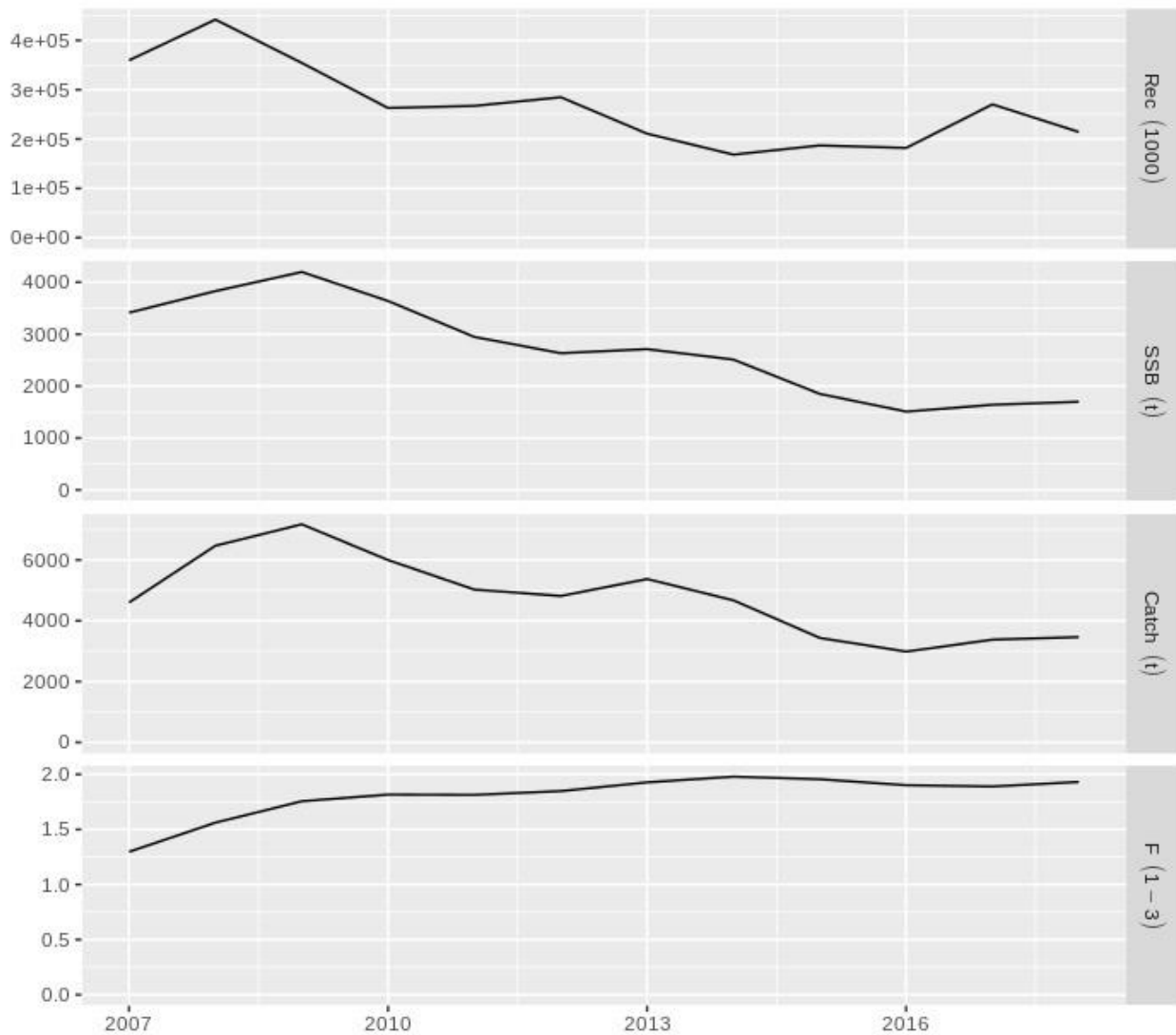


Figure 3.2.2.10. Final a4a model stock summary for European hake in GSAs 1, 5, 6 and 7

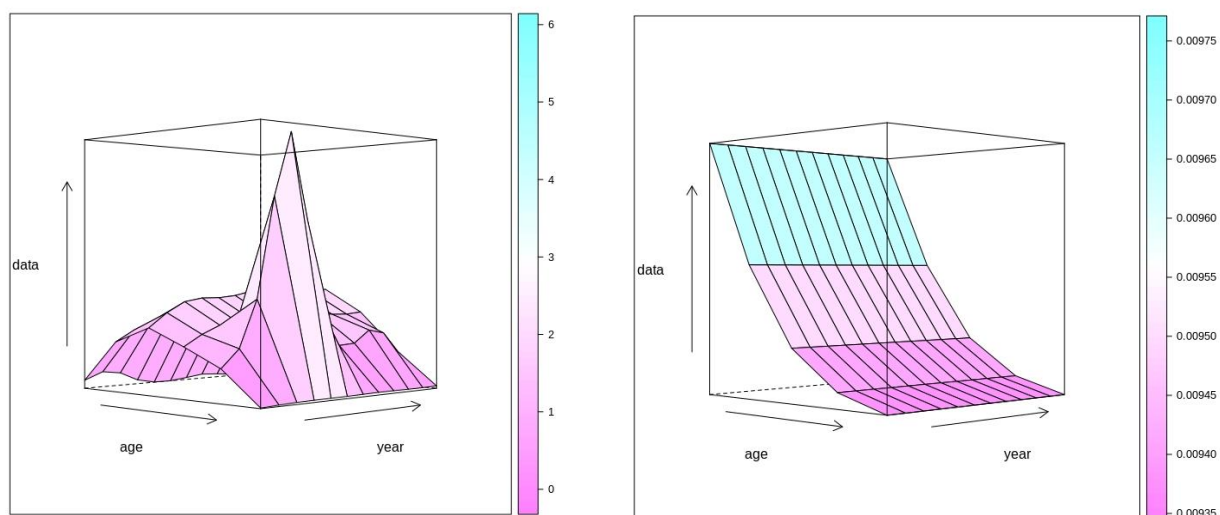


Figure 3.2.2.11. 3D contour plot of estimated fishing mortality (left) and 3D contour plot of estimated survey catchability (right) at age and year for European hake in GSAs 1, 5, 6 and 7

In the following tables, the population estimates obtained by the a4a model are provided.

Table 3.2.2.8. Stock numbers at age (thousands) as estimated by a4a for European hake in GSAs 1, 5, 6 and 7

Year/Age	0	1	2	3	4	5+
2007	359 645	35 449	4 402	790	238	104
2008	442 154	54 589	5 509	631	179	161
2009	354 294	56 996	6 668	578	112	160
2010	262 833	48 407	5 831	556	86	124
2011	267 185	43 766	4 689	453	78	90
2012	284 771	48 439	4 248	365	64	64
2013	210 794	51 860	4 557	317	50	47
2014	168 339	36 690	4 540	310	41	39
2015	187 015	27 862	3 064	291	38	38
2016	181 905	31 701	2 377	202	36	37
2017	270 249	32 186	2 841	167	26	33
2018	214 245	47 919	2 915	202	22	29

Table 3.2.2.9. A4a summary results for European hake in GSAs 1, 5, 6 and 7

Year	Fbar (1-3)	Recruitment (thousands)	SSB (t)	TB (t)	Catch (t)
2007	1.297	359 645	3 414	13 360	4 598
2008	1.562	442 154	3 829	16 062	6 467
2009	1.756	354 294	4 198	16 418	7 172
2010	1.816	262 833	3 638	13 271	5 995
2011	1.814	267 185	2 946	13 666	5 024
2012	1.848	284 771	2 634	13 608	4 814
2013	1.927	210 794	2 712	12 572	5 373
2014	1.979	168 339	2 510	9 642	4 671
2015	1.956	187 015	1 850	8 260	3 435

2016	1.902	181 905	1 510	8 299	2 984
2017	1.890	270 249	1 641	9 786	3 379
2018	1.931	214 245	1 699	8 828	3 463

Table 3.2.2.10. A4a F at age for European hake in GSAs 1, 5, 6 and 7

Year/Age	F at age					
	0	1	2	3	4	5+
2007	0.255	1.182	1.533	1.177	0.786	0.085
2008	0.419	1.423	1.845	1.417	1.168	0.102
2009	0.360	1.600	2.075	1.594	2.176	0.115
2010	0.163	1.655	2.146	1.648	4.346	0.119
2011	0.078	1.652	2.143	1.646	5.745	0.119
2012	0.073	1.684	2.184	1.677	3.848	0.121
2013	0.118	1.756	2.277	1.749	1.802	0.126
2014	0.169	1.803	2.339	1.796	1.092	0.130
2015	0.145	1.781	2.311	1.775	1.119	0.128
2016	0.102	1.732	2.247	1.726	1.397	0.124
2017	0.100	1.722	2.233	1.715	1.312	0.124
2018	0.147	1.759	2.282	1.752	0.865	0.126

Based on the a4a results, the European hake SSB shows a decreasing trend from 2009 to 2016 (from 4 198 to 1 510 tonnes), with a slight increase in the last two years (1 699 tonnes in 2018). The assessment shows a decreasing trend in the number of recruits in the time series. The recruitment (age 0) reached a minimum of 168 339 thousands individuals in 2014, which had an increase up to 2017 (270 249 thousands). F_{bar} (1-3) shows a quite stable trend in the time series from 2010 although increasing from a value of 1.816 to a value of 1.931 in 2018. A maximum peak of 1.979 was reached in 2014.

D. Retrospective analysis, comparison between model runs, sensitivity analysis

Retrospective

The retrospective analysis was applied up only to three years back, due to the short time series. Models results were quite stable in terms of catch and SSB estimations. Fishing mortality value removing only one year was a bit different but remain quite similar for the previous years. Recruitment was quite different removing two years, although not an issue considering the really short time series used (Figure 3.2.2.12).

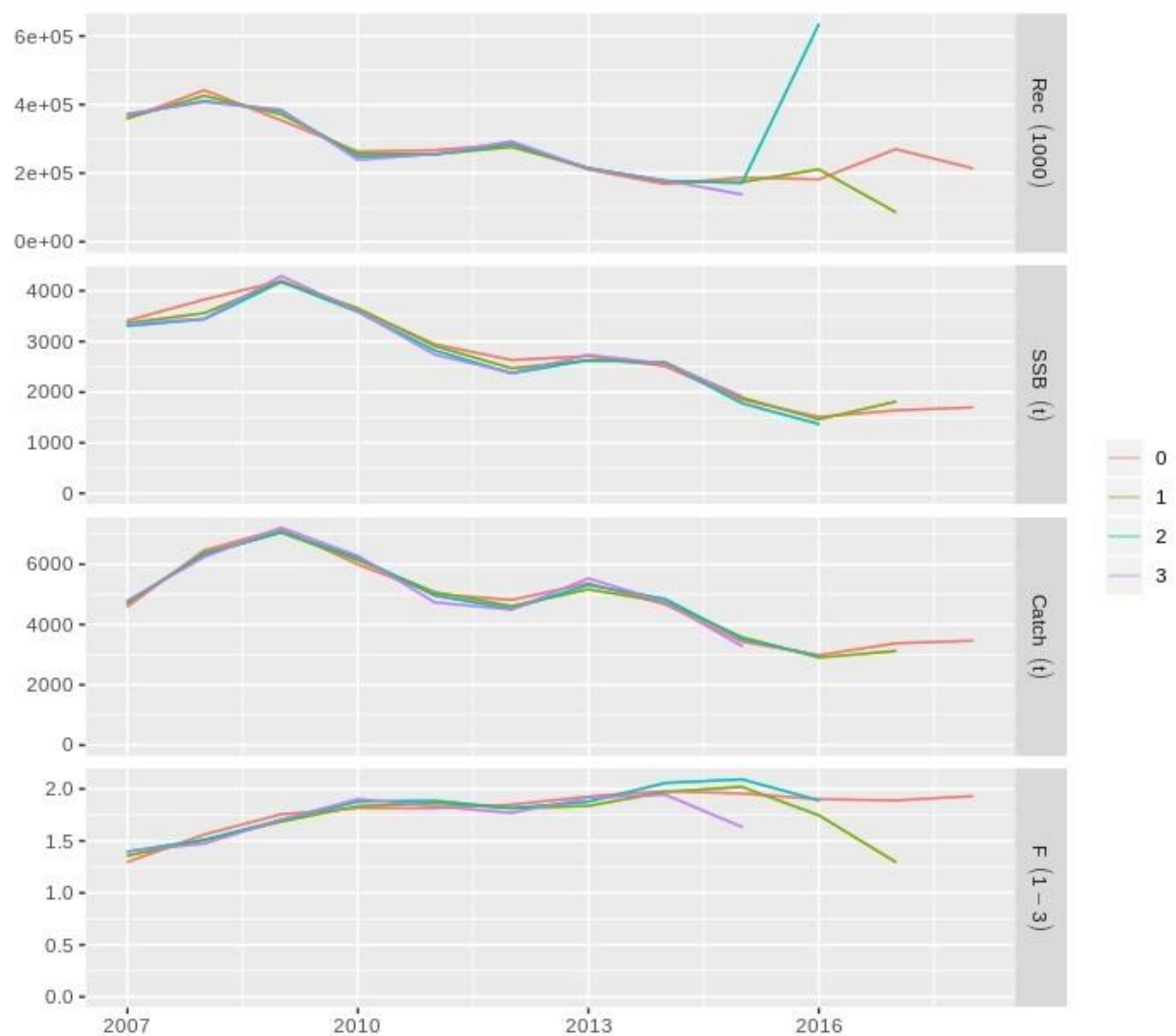
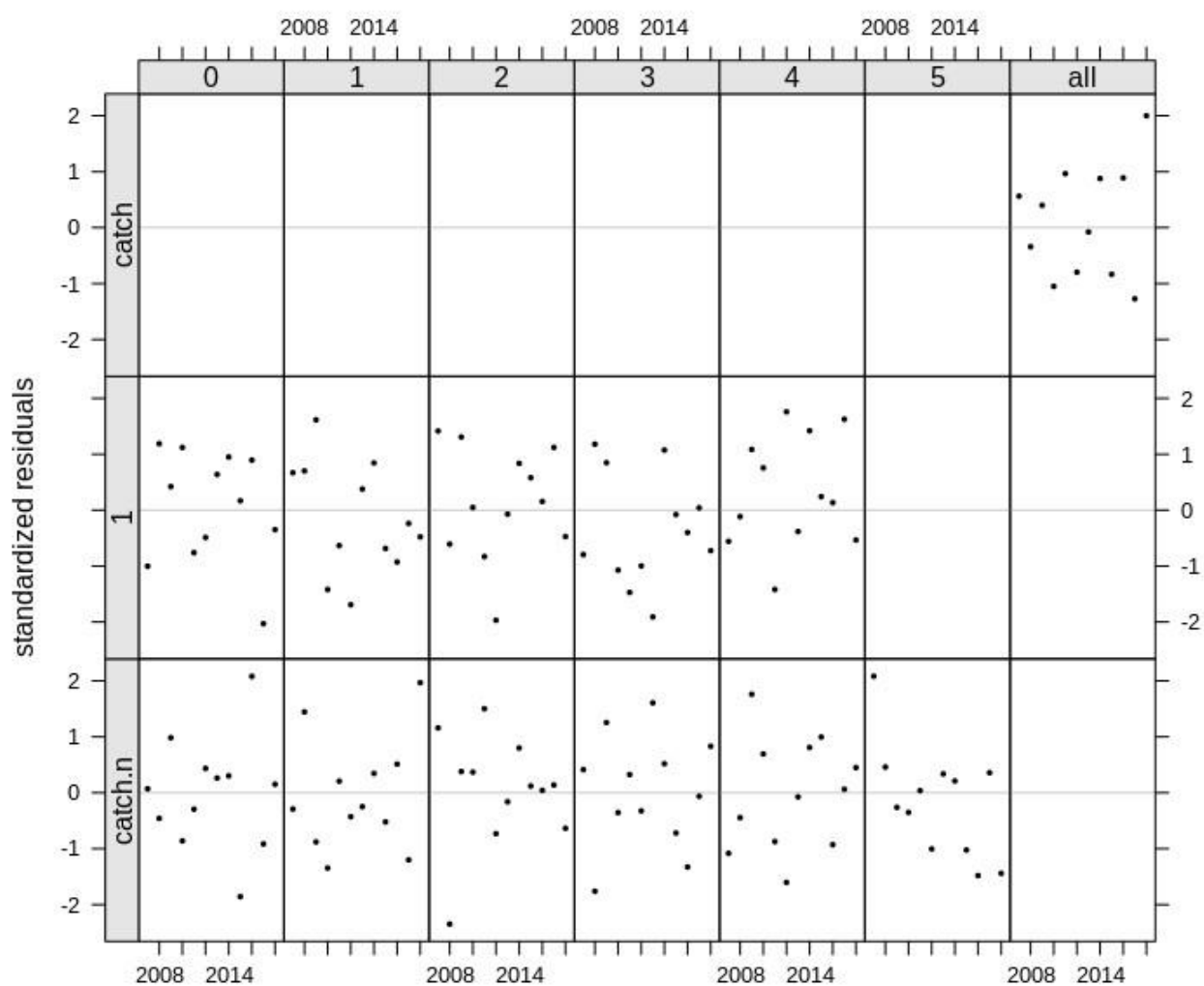


Figure 3.2.2.12. Retrospective analysis for European hake in GSAs 1, 5, 6 and 7

log residuals of catch and abundance indices by age



log residuals of catch and abundance indices

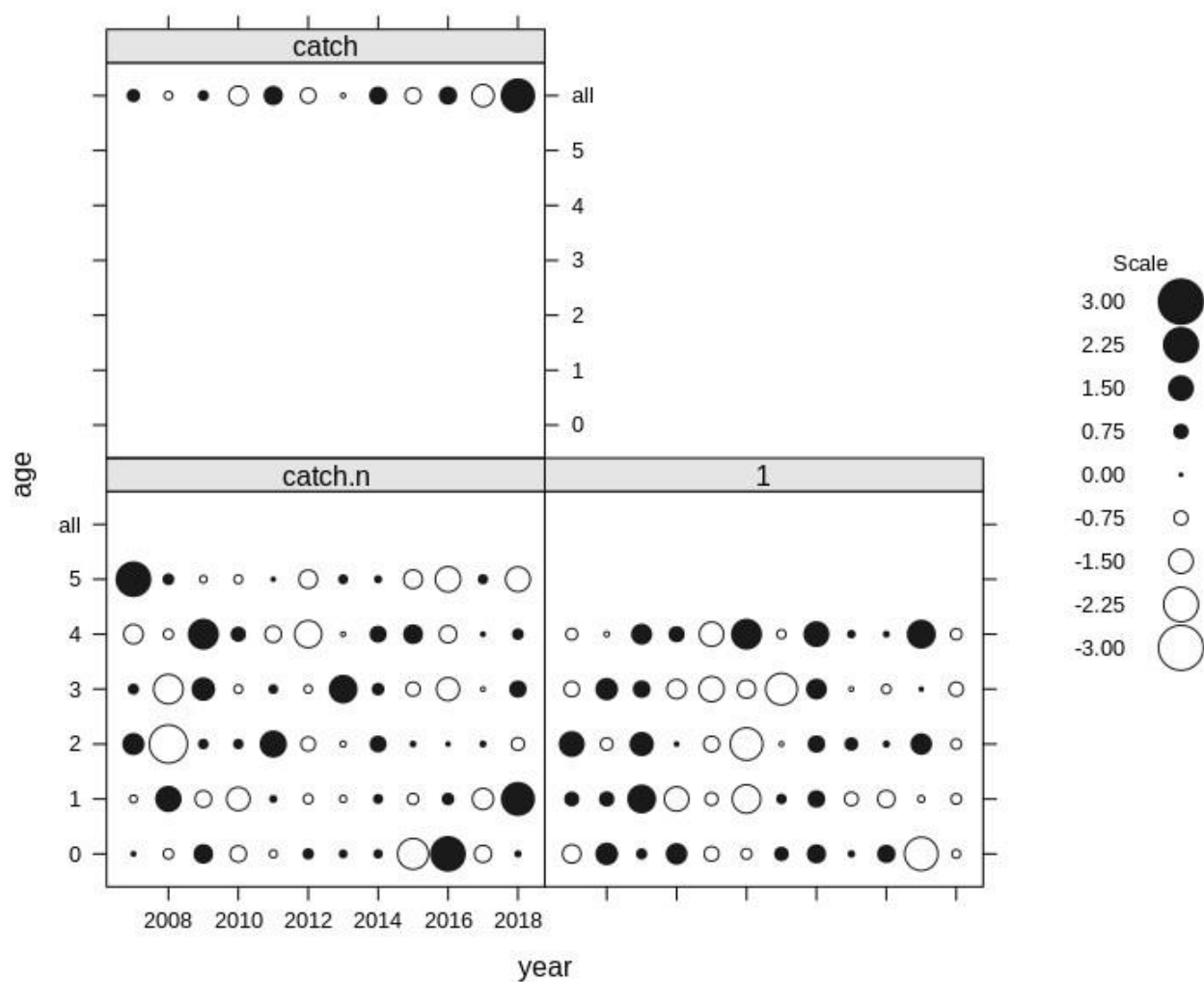
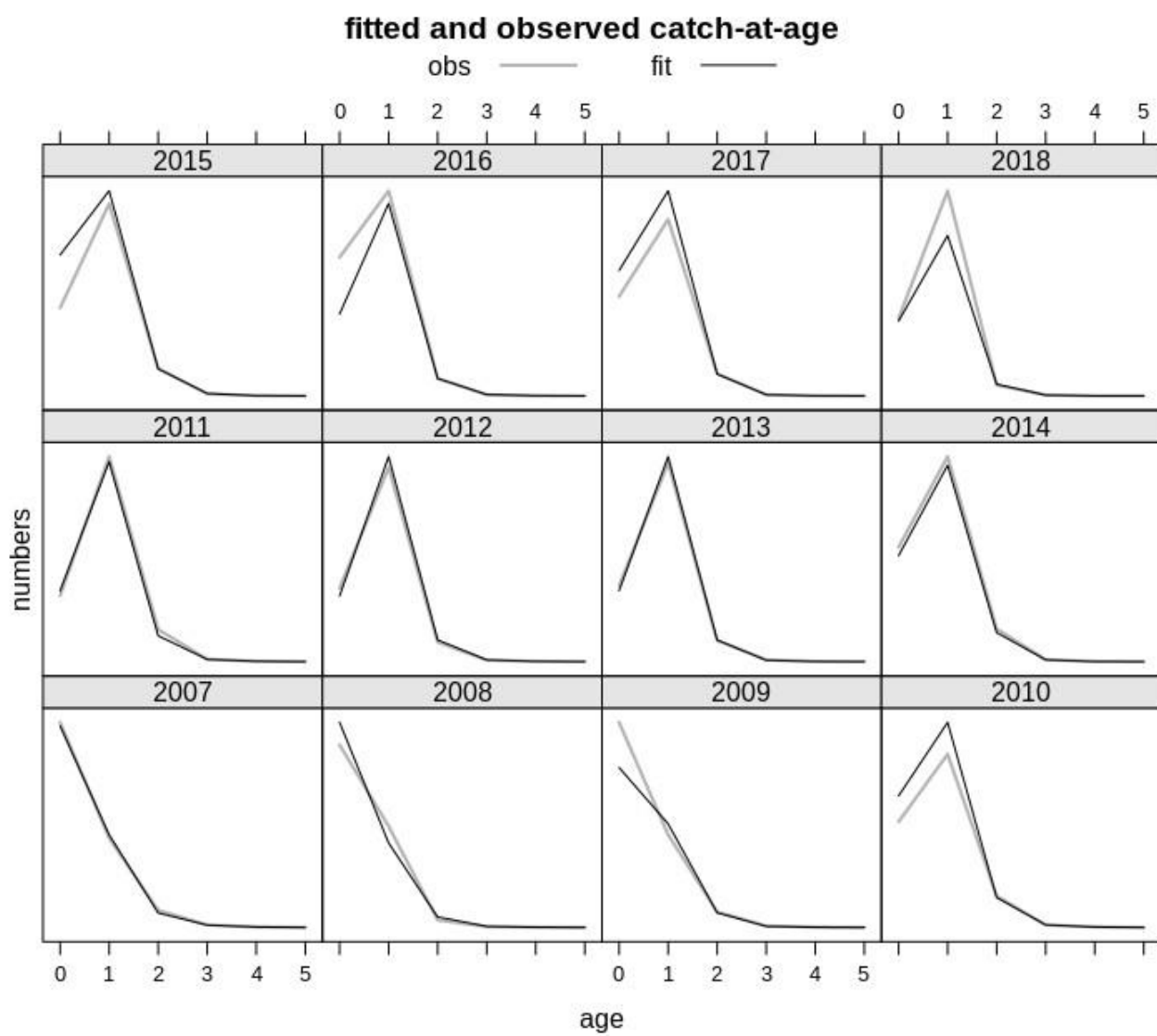


Figure 3.2.2.13. Standardized residuals for abundance indices (1 referring to MEDITS survey), catch numbers and total catch for European hake in GSAs 1, 5, 6 and 7



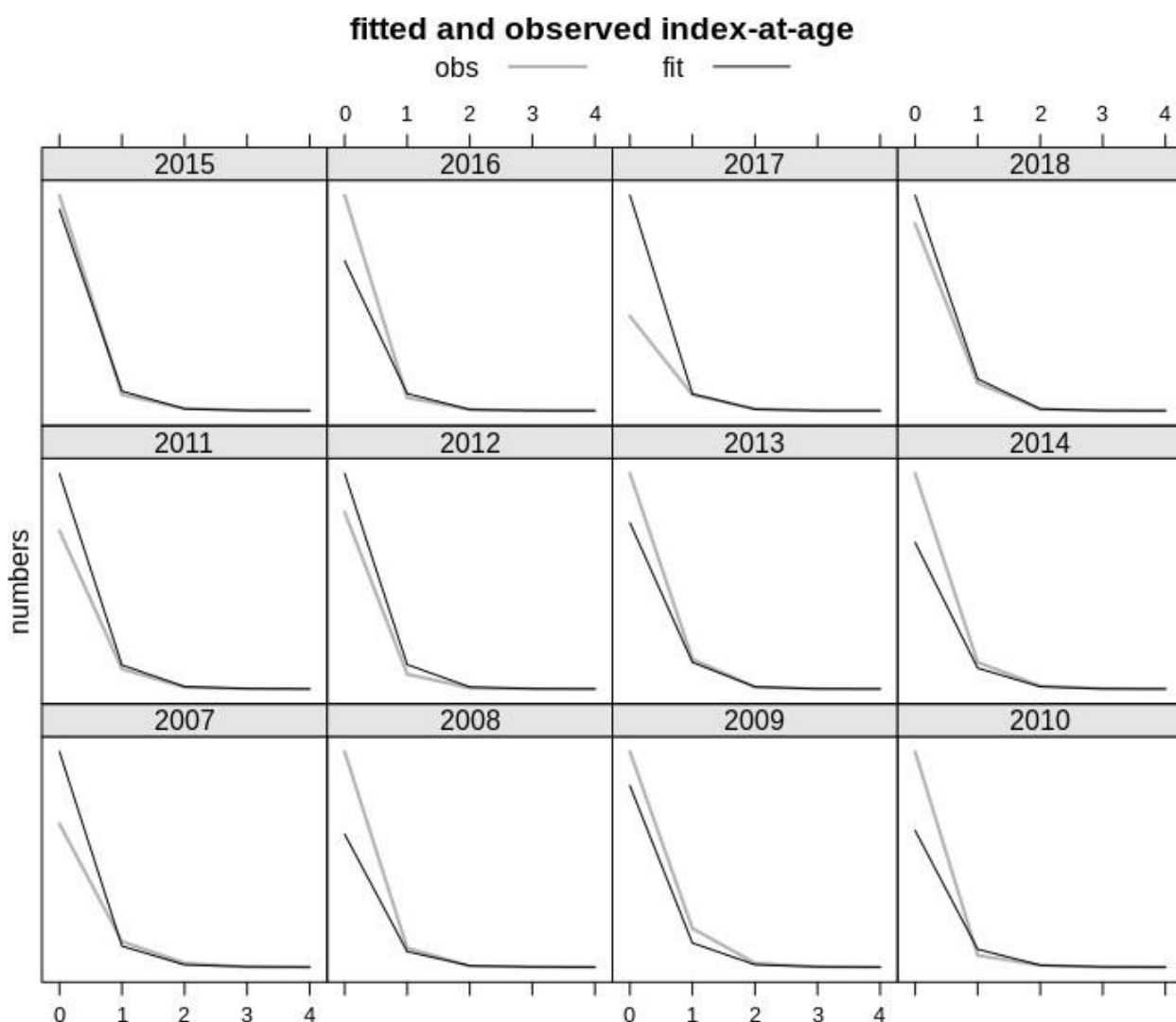


Figure 3.2.2.14. Fitted and observed catch at age and index at age for European hake in GSAs 1, 5, 6 and 7

E. Reference points

The time series being too short to fit a stock recruitment relationship, reference points are based on equilibrium methods, and $F_{0.1}$ was considered as a proxy of F_{MSY} . The library FLBRP available in FLR was used to estimate $F_{0.1}$ from the stock object resulting from the outputs of the a4a assessment.

Both F in the last year (1.931) and F as mean of the last three years (1.902) are higher than the estimated $F_{0.1}$ (0.346) which indicates that European hake stock in GSAs 1, 5, 6 and 7 is highly over-exploited, suggesting the need for a strong reduction in the fishing mortality towards the reference point, progressively reducing the fishing effort.

Slot "refpts":

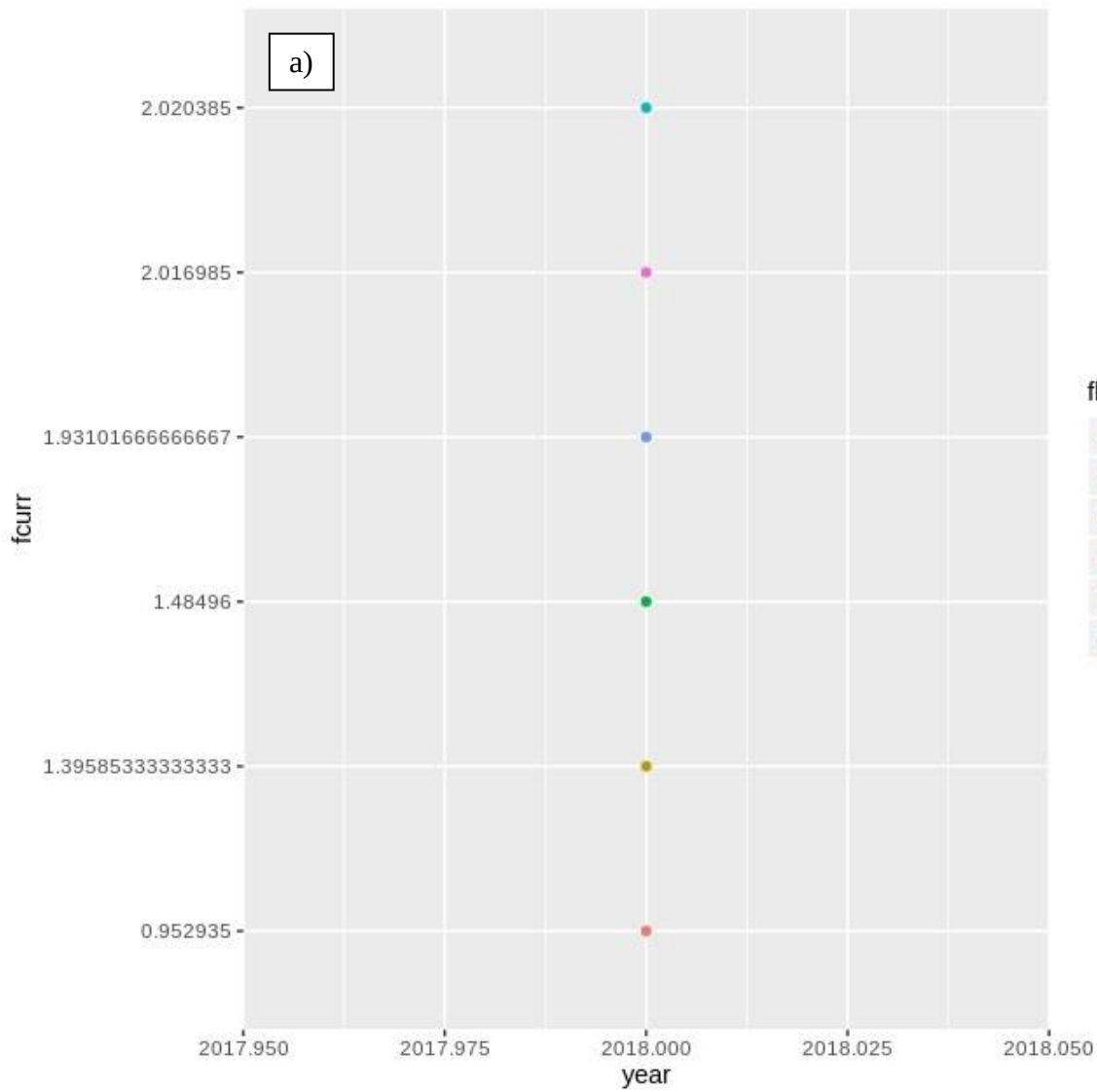
An object of class "FLPar"

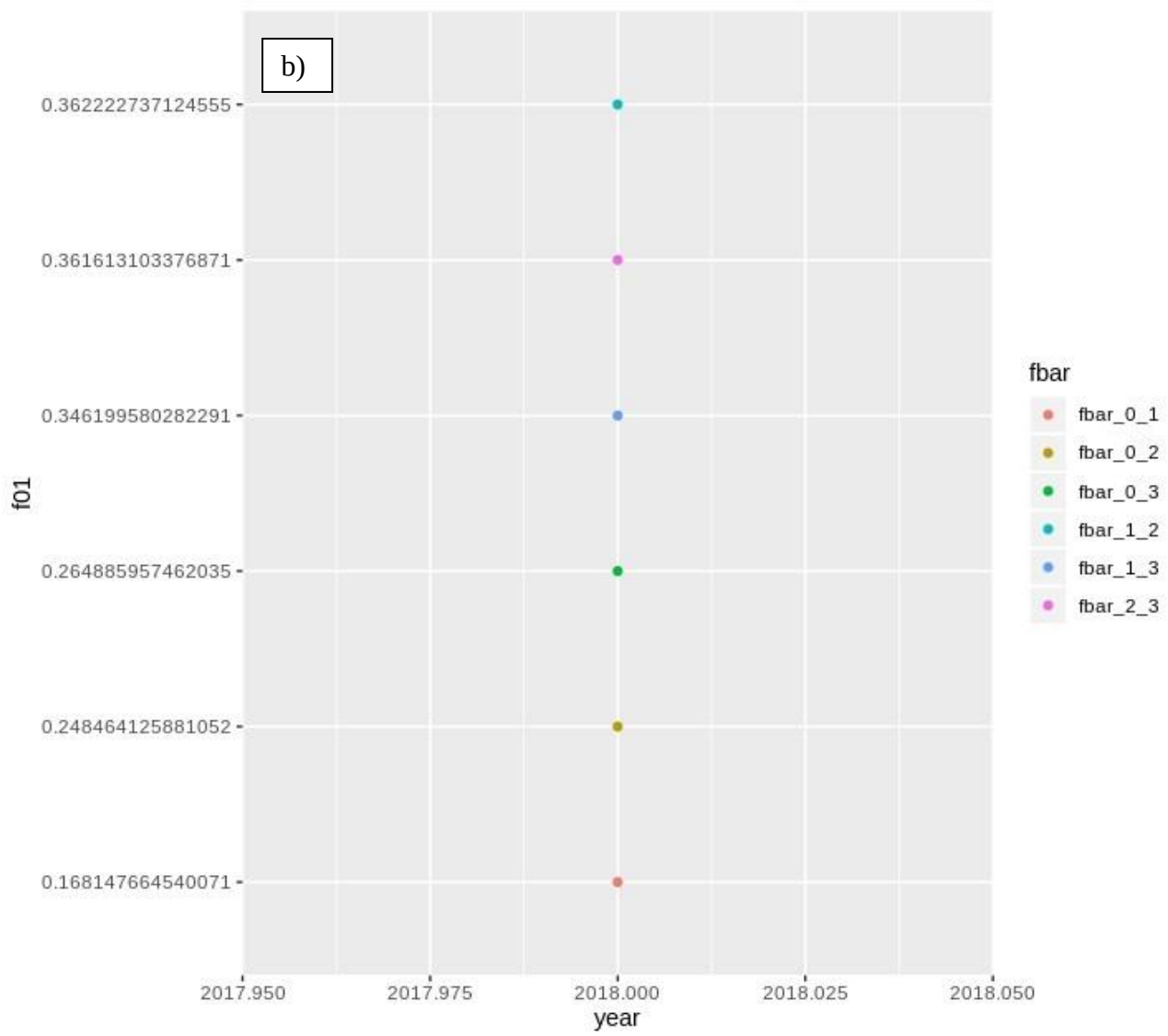
quant

refpt	harvest	yield	rec	ssb	biomass
virgin	0.00e+00	0.00e+00	1.00e+00	6.67e-01	7.10e-01
msy	4.93e-01	2.60e-02	1.00e+00	1.31e-01	1.70e-01
crash	1.05e+02	1.63e-02	1.00e+00	4.39e-06	2.05e-02
$f_{0.1}$	3.46e-01	2.49e-02	1.00e+00	2.06e-01	2.47e-01
f_{max}	4.93e-01	2.60e-02	1.00e+00	1.31e-01	1.70e-01

spr.30 3.56e-01 2.51e-02 1.00e+00 2.00e-01 2.40e-01

A sensitive analysis was carried out according to different Fbar ranges. In the following figures, estimated values of Fcurrent, F0.1 and FF0.1 are shown.





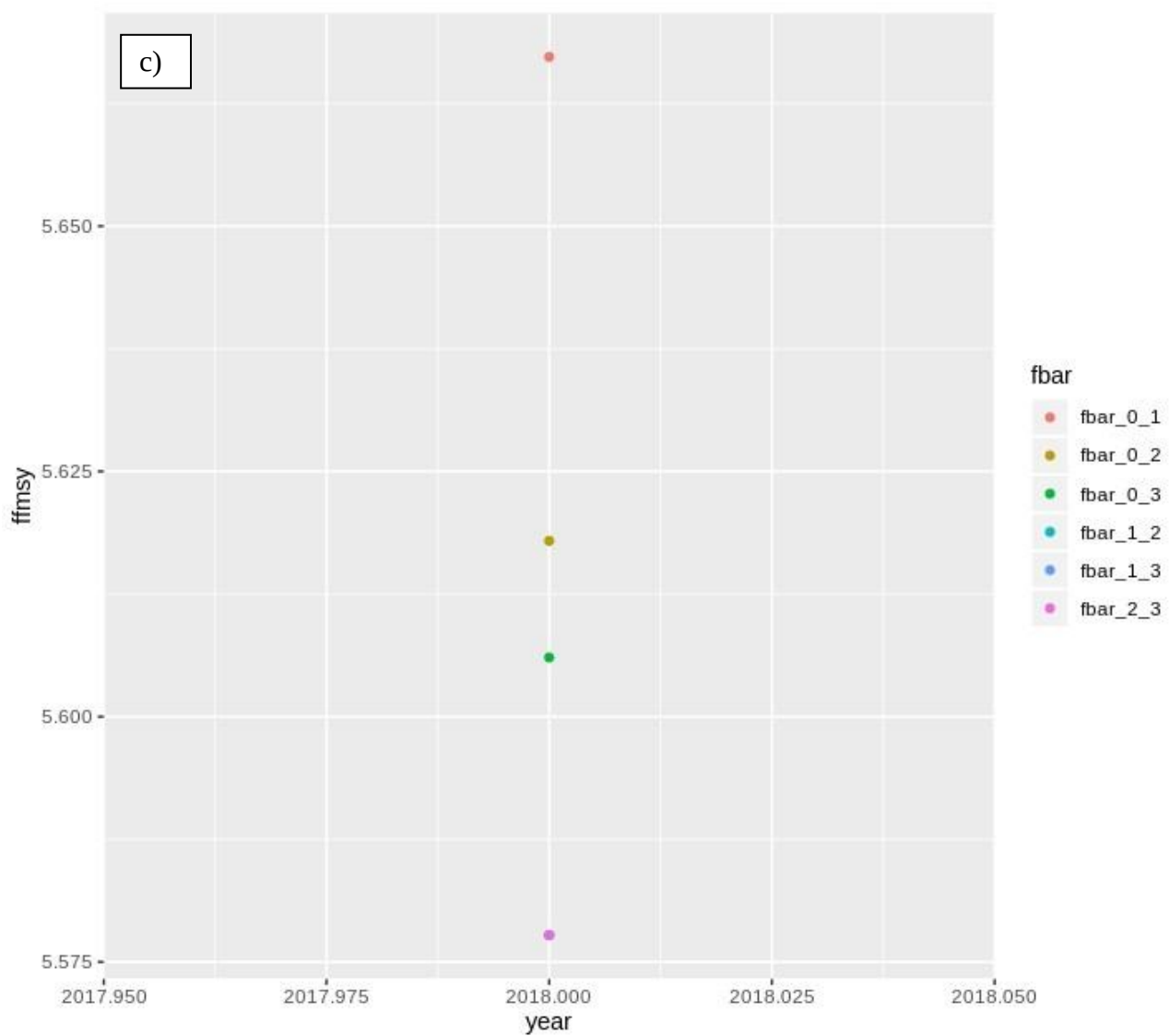


Figure 3.2.2.15. $F_{current}$ (a), $F_{0.1}$ (b) and $FF_{0.1}$ (c) ratio with different $Fbar$ ranges for European hake in GSAs 1, 5, 6 and 7

In the following histograms, simulated values according to variance covariance matrix (iter 500) of estimated $F_{current}$, $F_{0.1}$ and $FF_{0.1}$ values ($Fbar$ ages 1-3) are shown.

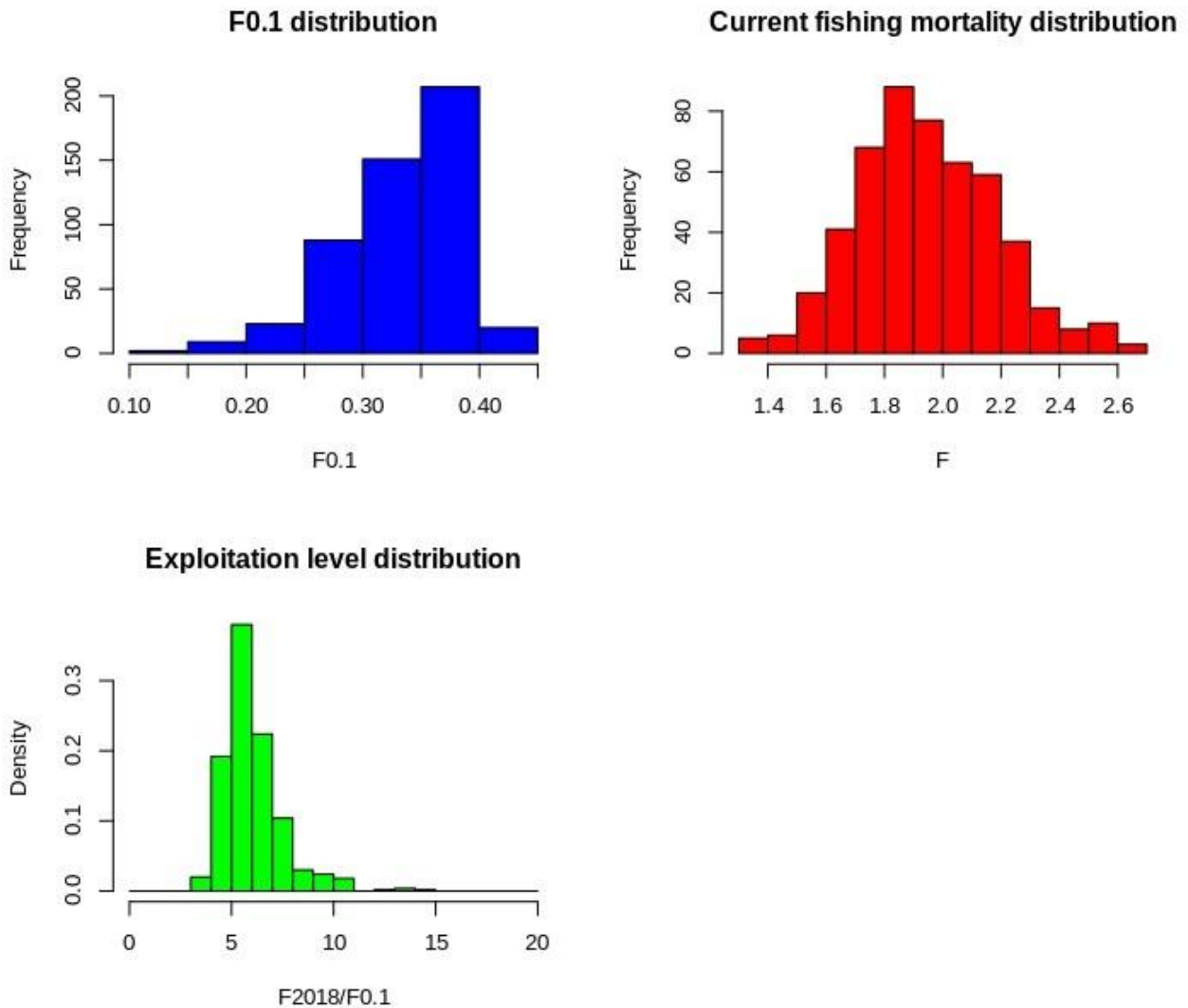


Figure 3.2.2.16. Distribution of 500 simulated iterations of $F_{current}$, $F_{0.1}$ and $F/F_{0.1}$ ratio for European hake in GSAs 1, 5, 6 and 7.

F. Short-term forecast

A deterministic short-term prediction for the period 2019 to 2021 was performed using the FLR libraries and scripts, and based on the results of the a4a stock assessment.

An average of the last three years was used for weight at age and maturity at age, while the $F_{bar}=1.908$ (average of the last three years' F from the a4a assessment) was used for F in 2019. As recruitment, in 2019 the mean of the last three years (222133) was used.

Table 3.2.2.11. Short term forecast in different F scenarios for European hake in GSAs 1, 5, 6 and 7

Rationale	Ffactor	Fbar	Recruitment2019	Fsq2019	Catch2018	Catch2020	SSB2019	SSB2021	SSB_change_2019-2021(%)	Catch_change_2018-2020(%)
High long term yield (F0.1)	0.18	0.346	222133	1.908	3462	1134	2064	6639	221.6	-67.3
Fupper	0.25	0.475	222133	1.908	3462	1477	2064	5929	187.2	-57.3
F lower	0.12	0.232	222133	1.908	3462	795	2064	7351	256.1	-77.0
Zero catch	0.00	0.000	222133	1.908	3462	0	2064	9057	338.8	-100.0
Status quo	1.00	1.908	222133	1.908	3462	3653	2064	1906	-7.7	5.5
Different Scenarios	0.10	0.191	222133	1.908	3462	666	2064	7624	269.4	-80.8
	0.20	0.382	222133	1.908	3462	1232	2064	6436	211.8	-64.4
	0.30	0.572	222133	1.908	3462	1714	2064	5449	164.0	-50.5
	0.40	0.763	222133	1.908	3462	2126	2064	4628	124.2	-38.6
	0.50	0.954	222133	1.908	3462	2479	2064	3946	91.2	-28.4
	0.60	1.145	222133	1.908	3462	2784	2064	3378	63.6	-19.6
	0.70	1.335	222133	1.908	3462	3048	2064	2905	40.7	-12.0
	0.80	1.526	222133	1.908	3462	3277	2064	2510	21.6	-5.4
	0.90	1.717	222133	1.908	3462	3477	2064	2181	5.7	0.4
	1.10	2.098	222133	1.908	3462	3808	2064	1676	-18.8	10.0
	1.20	2.289	222133	1.908	3462	3946	2064	1483	-28.1	14.0
	1.30	2.480	222133	1.908	3462	4069	2064	1322	-36.0	17.5
	1.40	2.671	222133	1.908	3462	4179	2064	1186	-42.5	20.7
	1.50	2.861	222133	1.908	3462	4278	2064	1072	-48.1	23.6
	1.60	3.052	222133	1.908	3462	4368	2064	976	-52.7	26.2
	1.70	3.243	222133	1.908	3462	4450	2064	895	-56.7	28.5
	1.80	3.434	222133	1.908	3462	4525	2064	826	-60.0	30.7
	1.90	3.624	222133	1.908	3462	4595	2064	767	-62.8	32.7
	2.00	3.815	222133	1.908	3462	4659	2064	718	-65.2	34.6

G. Fishing mortality by fleet

Total fishing mortality at age was splitted into F at age for the main fleet in the different GSAs. According to catches data, the main fleet is bottom otter trawl (OTB).

Table 3.2.2.12. F by ages and GSA for for European hake caught with OTB nets in GSAs 1, 5, 6 and 7

Age	GSA1_ESP	GSA5_ESP	GSA6_ESP	GSA7_ESP	GSA7_FRA
0	0.009	0.003	0.096	0.000	0.039
1	0.138	0.051	1.139	0.018	0.414
2	0.274	0.056	1.410	0.061	0.481
3	0.215	0.036	1.203	0.101	0.197
4	0.095	0.028	0.580	0.084	0.079
5+	0.000	0.018	0.065	0.025	0.019
Fbar(1-3)	0.209	0.048	1.251	0.060	0.364

3.2.3.Assessment unit: GSAs 1 and 3

European hake in GSA 1 is mainly caught by trawlers on the shelf and slope (97 percent landings), but also by small-scale fisheries using gillnets and trammel nets (3 percent) (average percents estimated in 2018). The trawler fleet (118 boats in 2018) is the largest in landings (398 tonnes in 2018). The main ports in landings in GSA 1 were: Almería (73 tonnes), Vélez-Málaga (55 tonnes), Cartagena (48 tonnes), Garrucha (41 tonnes), Águilas (31tonnes), Fuengirola (27 tonnes) and Adra (27 tonnes) (2018 period).

The trawl fishing fleet in Moroccan GSA 3 is heterogeneous. 83 trawlers are operating in GSA 3. European hake in GSA 3 is found at depths ranging from 50 to 510 m. In the period 2016–2018, the mean annual European hake production was 125 tonnes.

Landings are made at four fishing ports: Beni Nsar (Nador), Al Hoceima, M'diq and El Jebha. The port of Nador is the most important in terms of European hake production (94 percent) and with regard to the fishing effort (91 percent). In 2018, there were 81 trawlers targeting European hake in GSA 3 with an average engine power of 400 HP and a mean GRT of 60 Tx (Table 3.2.3.1). Long liners are not found in Moroccan GSA 3.

Table 3.2.3.1. Segment fleet characteristics in Moroccan GSA 3

Ports	Number of trawlers	Mean HP	Mean GRT
Nador	49	418	67
Al Hoceima	13	366	54
M'diq	29	378	54
Total	81	-	-

3.2.3.1. XSA

A. Model assumptions

An extended survivor analysis (XSA) tuned with MEDITS survey data (2007–2018) and Moroccan Mediterranean survey data (2010–2018) was carried out for the trawl fleet data, considering age classes from 0 to 4+. The XSA assessments were performed using the Lowestoft VPA *Suite stock assessment* software package (Darby and Flatman, 1994) and the open-source framework FLR (Fisheries Library for R) (Kett *et al.*, 2007). Their results were analyzed and compared. FLR packages were also used to perform exploratory data analysis, sensitivity analysis, retrospective analysis, reference points estimation and short term projections.

- Input Parameters
 - Catch time series 2007–2018 (official landings and discard data) from trawl fleet.
 - Length distributions 2007–2018 (monthly onboard and port sampling).
 - Catch-at-length data converted into catch-at-age data using cohort slicing.
 - Growth parameters from Mellon *et al.* (2010) and DCF-Spain (2012).
 - Biological sampling 2007–2018 for maturity and length-weight relationships.
 - M vector by age using median of many models.
 - Tuning data 2007–2018 from MEDITS survey and commercial fleet, and (2010–2018) from Moroccan survey.
- Main Settings
 - Ages 0 to 4+ (Age 4 is a Plus Group).
 - Fbar 0-3.
 - Catchability independent of age for ages older than 2.
 - Survivor estimates shrunk towards the mean F of the final three years or the two oldest ages.
 - S.E. of the mean to which the estimates are shrunk = 1.
 - Minimum standard error for population estimates derived from each fleet = 0.3.

B. Input data and parameters

Growth and maturity

Table 3.2.3.2. Maximum size, size at first maturity, and size at recruitment

Somatic magnitude measured	Total length (LT)	Units	cm
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(LT, LC, etc)					
Sex	Female	Male	Combined	Reproduction season	All year: February and June
Maximum size observed	90	61	90	Recruitment season	All year (higher peaks in winter and spring)
Size at first maturity			26	Spawning area	Shelf and upper slope
Recruitment size to the fishery			14.5	Nursery area	Continental shelf

Table 3.2.3.3. M vector and proportion of matures by size or age (males and females combined)

Age	Natural mortality **	Proportion of matures
0	1.90	0.000
1	0.70	0.296
2	0.39	0.98
3	0.29	0.99
4	0.23	1
5+	0.20	1

**Natural mortality vector, PROBIOM: Abella, A.; Caddy, J.F.; and Serena, F. (1999)

Table 3.2.3.4. Growth and length weight model parameters

		Sex			
	Units	Female	Male	Combined	Years
Growth model	L_{∞}			108*	
	K			0.21*	
	t_0			-0.115	
	Data source	*García <i>et al.</i> (2002) **DCF-EU (Spain, 2012)			
Length weight relationship	A			0.00677**	
	B			3.035097**	
	M (scalar)			0.4 (Vector average)	
	sex ratio (% females/total)	0.36			

Landings have shown important oscillations along the period of the data series. However, in the last eight years from 2011 onwards, a decreasing trend in landings is observed with the minimum values in the time series data (280 tonnes), and in the last two years, landings increase to reach 526 tonnes.

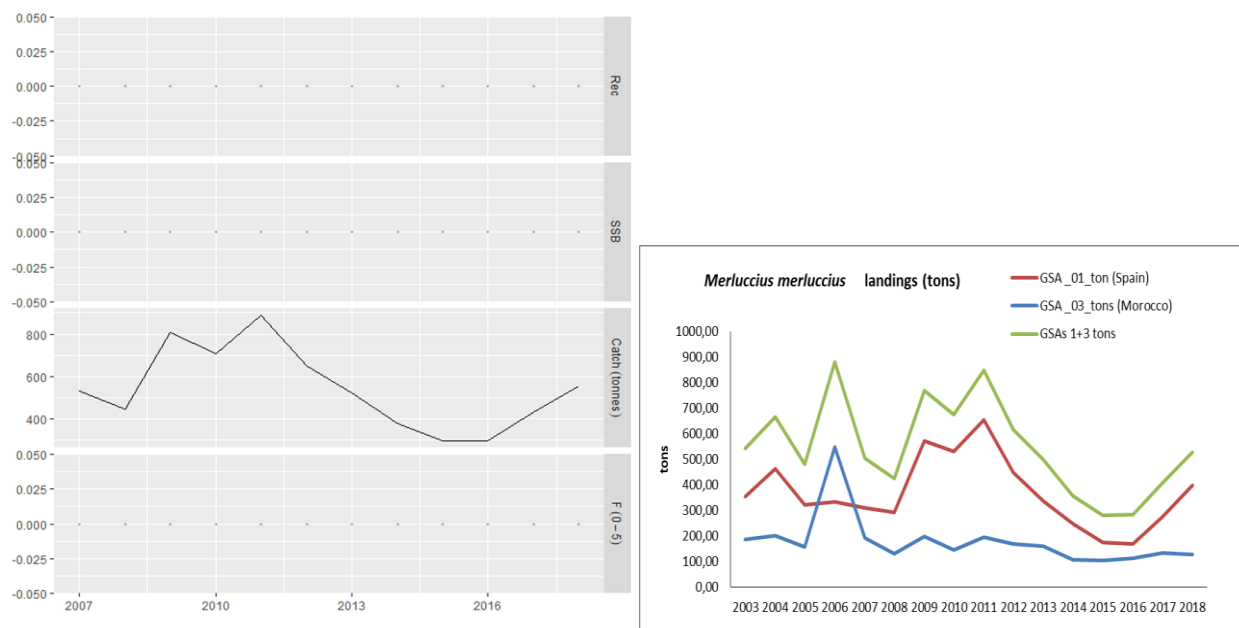


Figure 3.2.3.1. (Right) Historical trend of European hake landings by GSA and for GSAs 1 and 3
(Left) Total landings used in the assessment (2007–2018) for GSAs 1 and 3

Table 3.2.3.5. Catches from GSA 1 and GSA 3 combined (i.e. summed up) for 2003–2017 (only 2007–2017 were used in the assessment)

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Catch (t)*	540	666	479	880	503	426	769.1	676	848	616	497	357	280	282	407	526
Landings(t)																
Minimum size*	5	7	5	6	6	6	5	5	5	5	5	4	4	5	8	11
Average size					24.32	27.30	24.51	28.89	26.09	25.93	29.56	29.01	27.71	27.71	27.71	27.71
Maximum size**					67	76	70	76	76	78	74	76	76	76	62	74
Fleet:OTB (GSA 1)					182	184	188	154	149	139	129	124	121	110		
Fleet:OTB (GSA 3)					80		100	85	158	112	95	115	71	72	83	81

*Including discard fraction for GSA 1

** Trawl

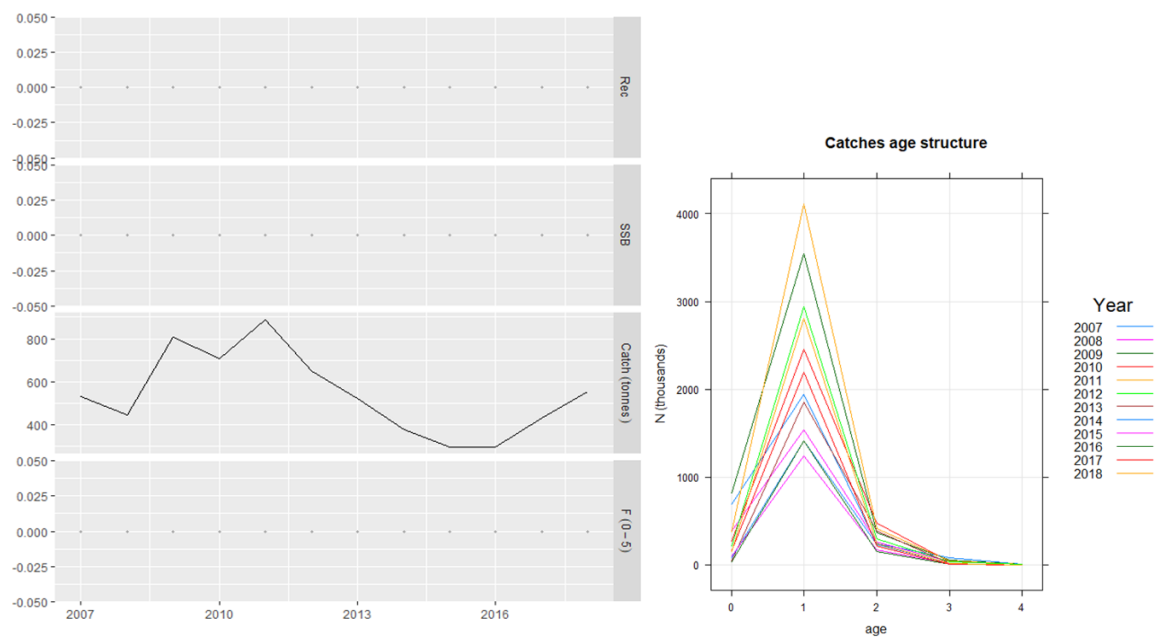


Figure 3.2.3.2. Catch matrix (total landings by age and year) and length frequency distribution (total length) of trawl catches in GSA 1 for the period 2007–2018

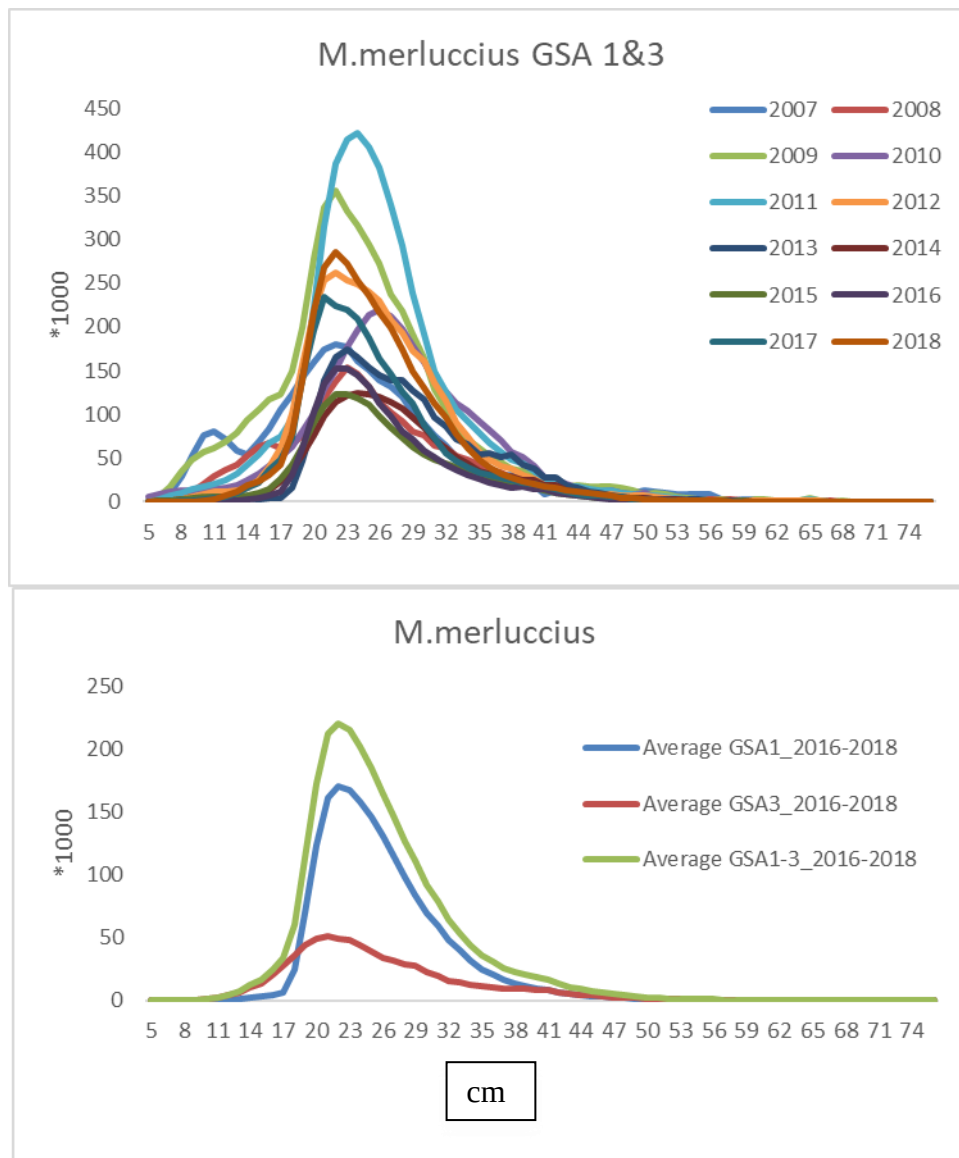


Figure 3.2.3.3. Length frequency distribution (total length) of trawl catches in GSAs 1 and 3 for the period 2007–2018 and average size compositions by GSA (2016–2018)

3.2.3.2. Fishery-independent information

Trawl Survey in GSA01. MEDITS_ES

The Spanish Institute of Oceanography carries out two scientific surveys under the DCR: MEDITS and MEDIAS. Both are international coordinated surveys. MEDITS is an international bottom trawl survey, the Spanish Institute of Oceanography is involved in it from 1994. The survey takes place in all European Mediterranean countries and the main target species are the demersal species. The Spanish Medits survey carries out about 170 to 180 hauls in the spring. It samples four GSAs, including the Balearic Islands, and the sampling procedure is based on the common methodology included in the MEDITS instruction manual. The GSAs sampled are: GSA 1, GSA 2, GSA 5 and GSA 6.

Table 3.2.3.6. Medits trawl survey sampling area and number of hauls

Stratum	Total surface (km ²)	Trawlable surface (km ²)	Swept area (km ²)	Number of hauls
A (-50m)		510		4
B (50-100m)		1 951		16
C (100-200m)		1 086		7
D (200-500 m)		3 461		14
E (500-800m)		4 912		14
Total (km²)		2 384		55

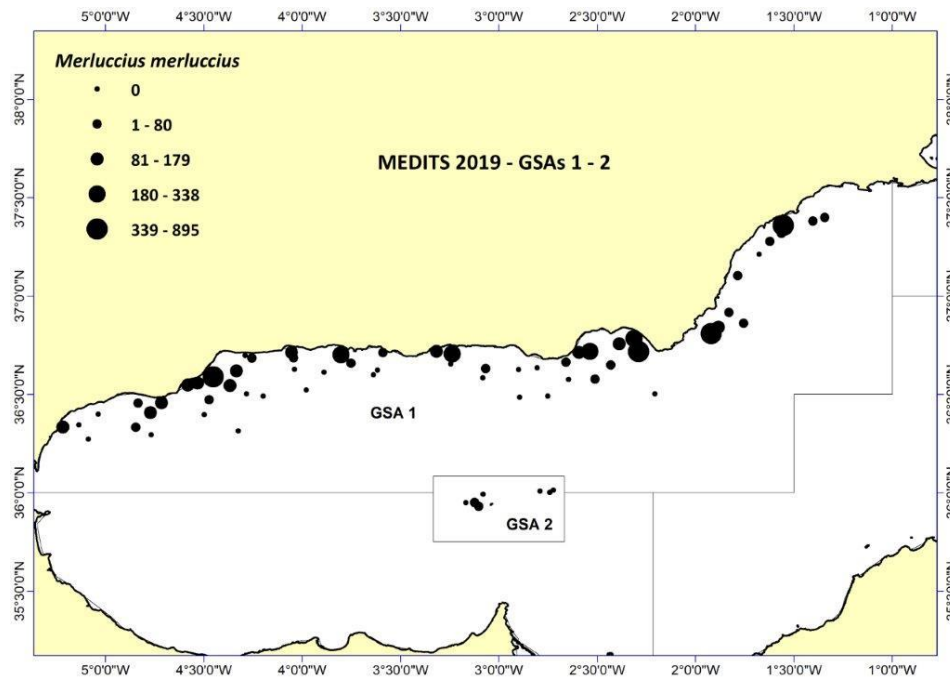


Figure 3.2.3.4. European hake spatial distribution of estimated abundances (N/Km2) in theMEDITS trawl survey (2018)

A. Trawl survey in GSA 3

Trawl surveys are using the Moroccan research boat (Institut national de recherche halieutique), using a stratified random sampling.

Table 3.2.3.7. Trawl survey sampling area and number of hauls

Stratum	Total surface (km ²)	Trawlable surface (km ²)	Swept area (km ²)	Number of hauls
	2 surveys a year			63
Total (km²)				

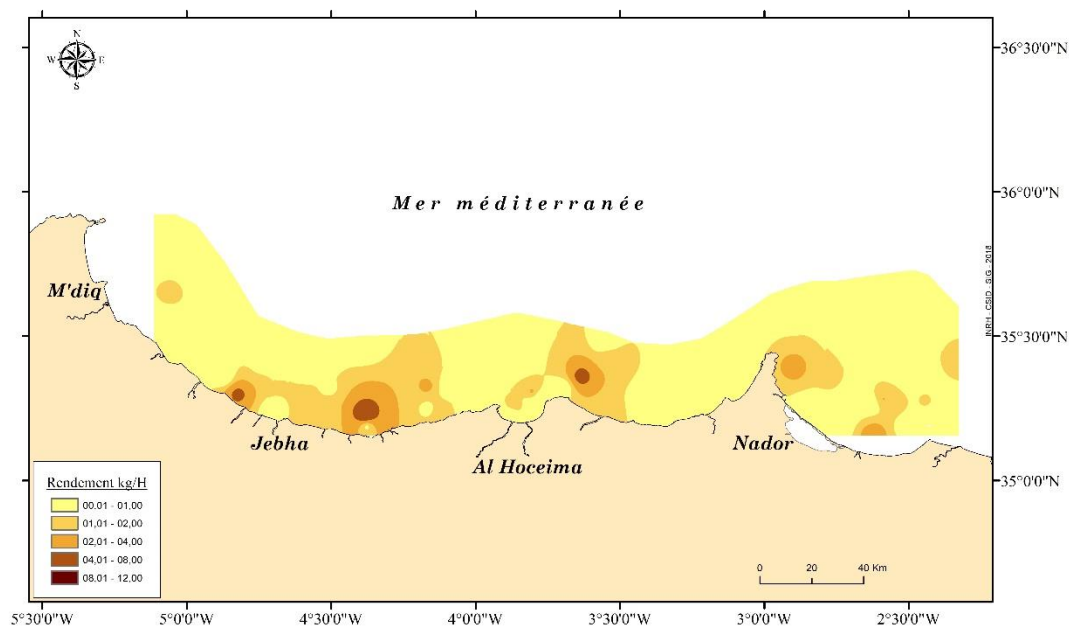


Figure 3.2.3.5. GSA3 European hake trawl survey spatial distribution of estimated abundances in 2018

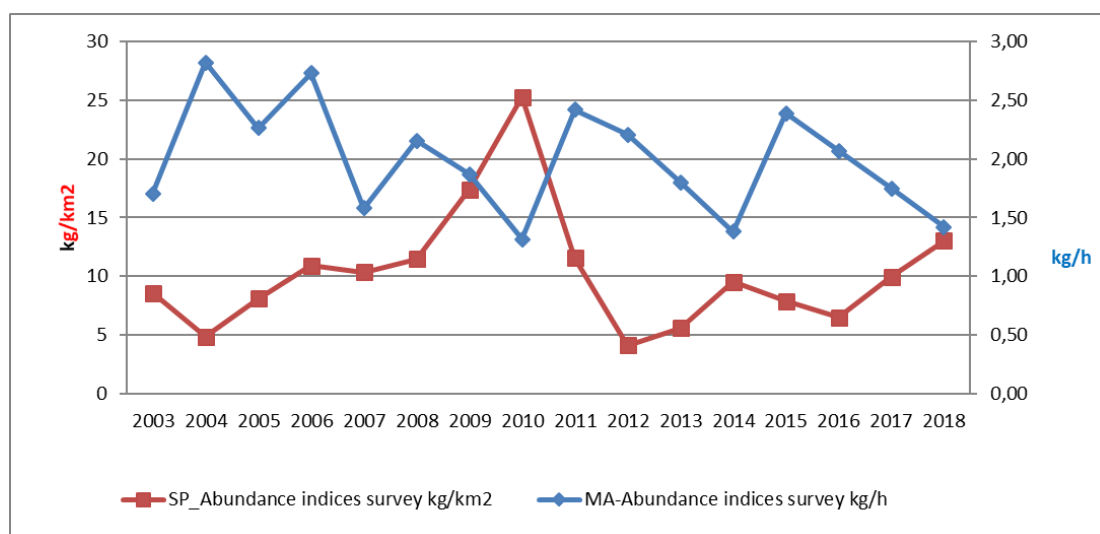


Figure 3.2.3.6. Trends in abundance indices (Kg/km²) for GSA 1 and kg/hour for GSA 3

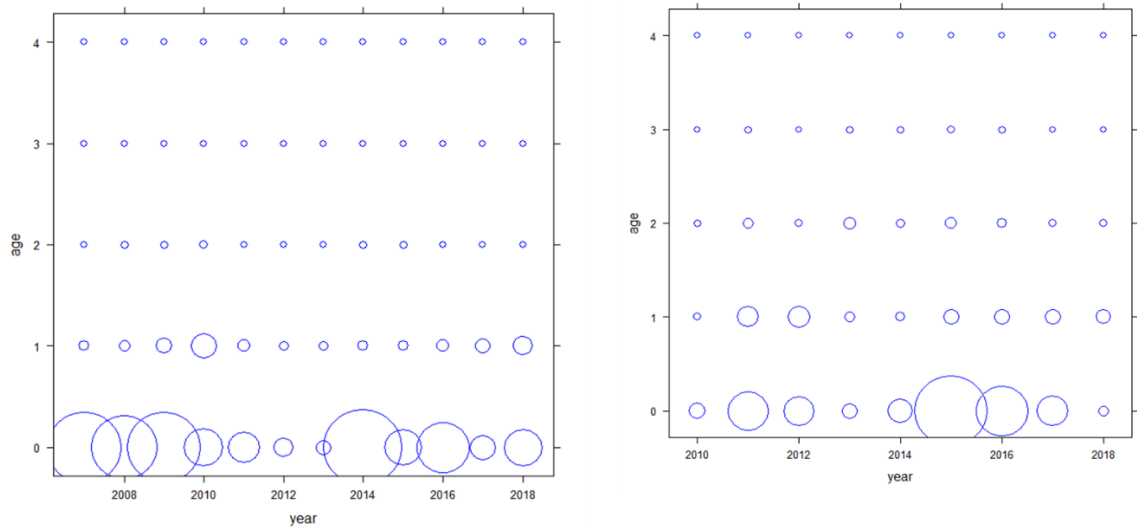


Figure 3.2.3.7. Surveys indices age structure for GSA 3 (right) and GSA 1 (left)

B. Results

XSA results show that SSB and yield show a decreasing trend from 2011 to 2016 and an increase in the last two years. Recruitment showed fluctuations over all series, increasing in the two last years.

Fishing mortality (F_{bar0-2}) showed a decrease from 2012 to 2014 then stays stable.

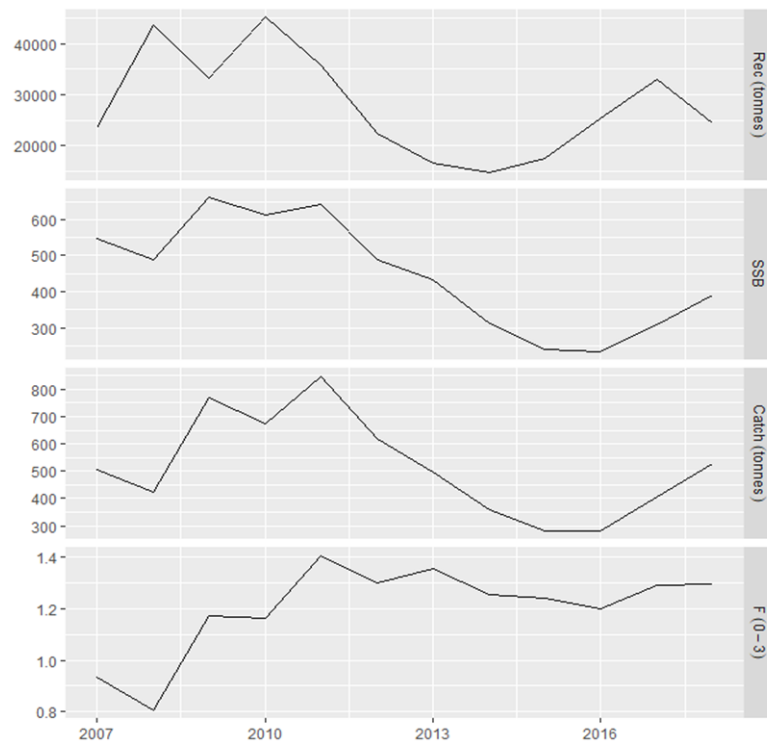


Figure 3.2.3.7. XSA results

Table 3.2.3.8. XSA results

	F	catch	B	R	SSB
2007	0,93281	504	1 412,55559	23 577	546,07
2008	0,80419	425,8	1 950,88808	43 555	488,58
2009	1,1711	769,1	2 059,30871	33 133	663,64
2010	1,16147	675,8	2 224,28866	45 137	613,48
2011	1,4059	848,2	2 268,0941	35 734	643,85
2012	1,30125	615,9	1 706,12785	22 515	489,02
2013	1,35633	497,1	1 159,00918	16 721	433,64
2014	1,25508	357,3	1 019,10957	14 791	310,45
2015	1,23832	280,1	961,325586	17 526	239,29
2016	1,1971	282,5	1 420,8041	25 439	232,48
2017	1,29084	407,2	1 745,15923	33 020	309,1
2018	1,2947	526,6	1 667,59558	24 495	389,85
33rd	1,18748	418,918	1 417,75215	23 184,06	360,472
66th	1,2918436	549,818	1 798,64873	33 049,38	503,853

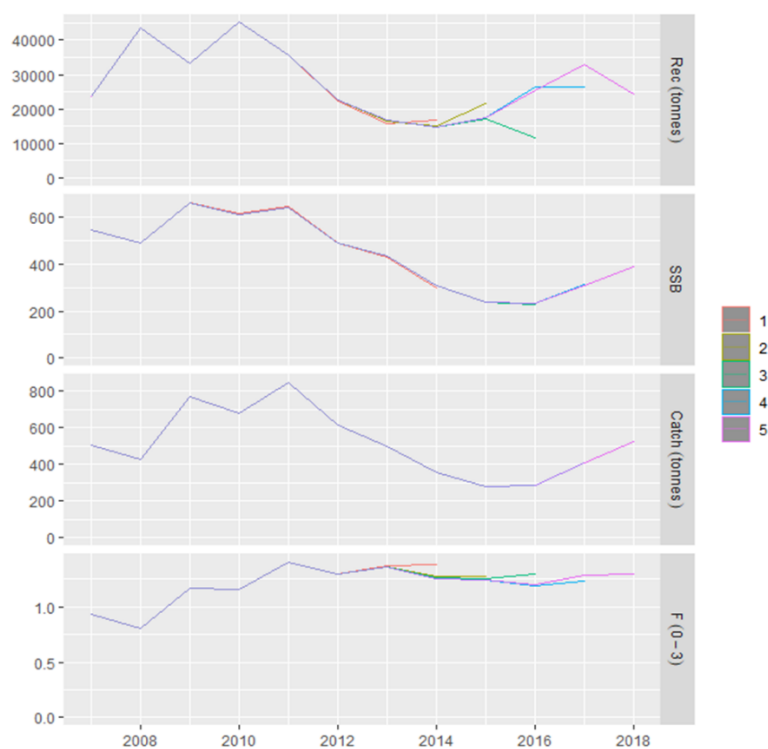
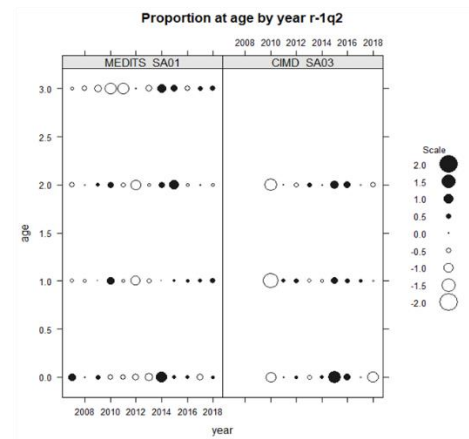
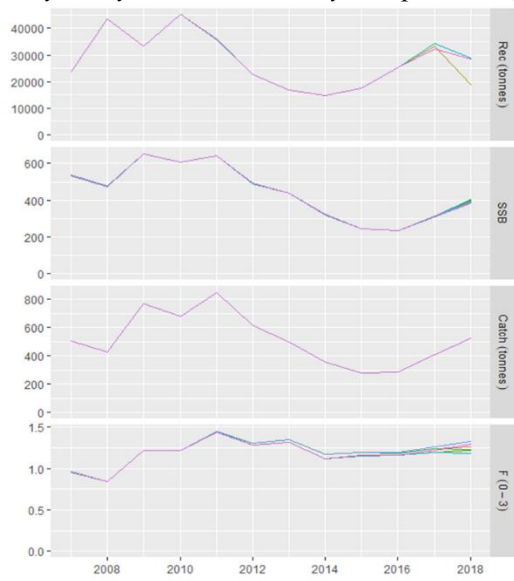


Figure 3.2.3.9. Retrospective analysis applied in the XSA model for European hake in GSAs 1-3 for the period 2013–2017 up to 5 years backward

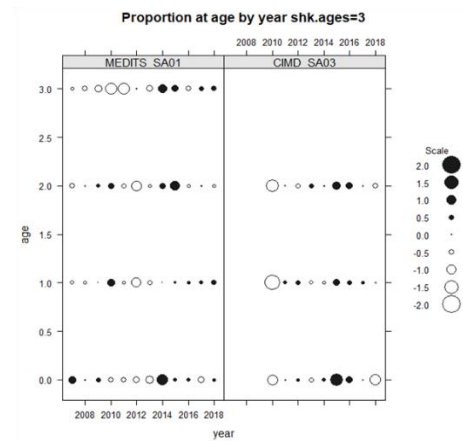
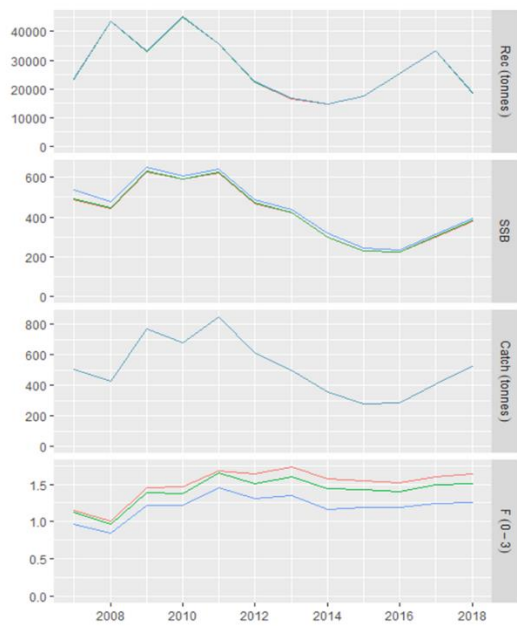
Results show no particular retrospective bias.

C. Sensitivity analysis

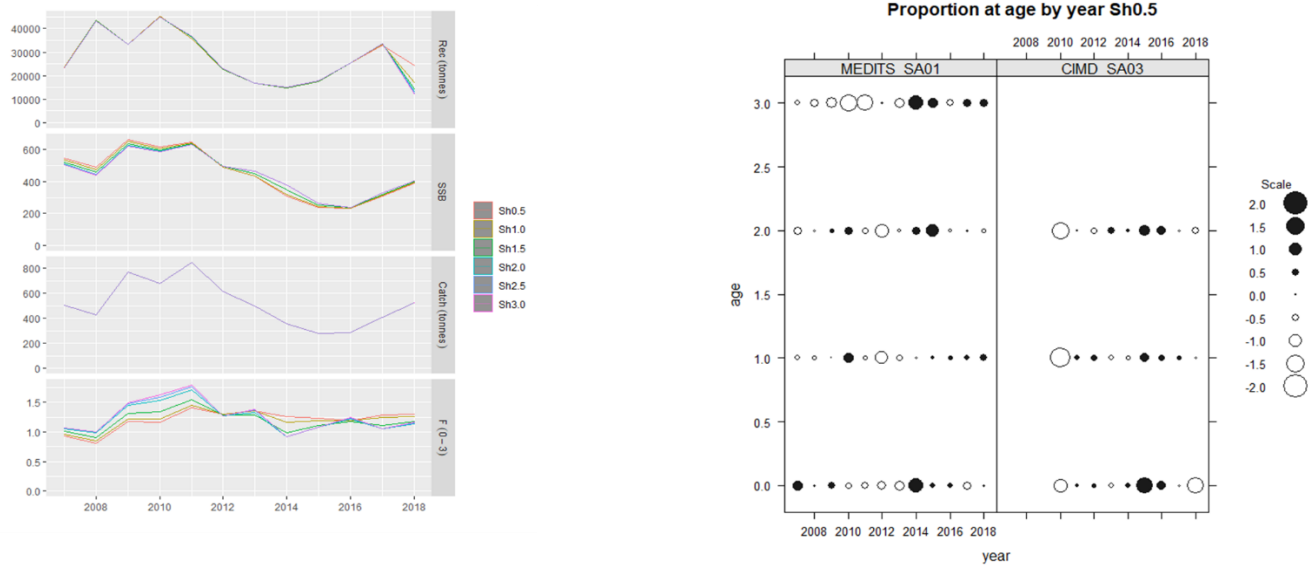
Sensitivity analysis on catchability independent of age “qage”



Sensitivity analysis on shrinkage ages “shk.ages”



Sensitivity analysis on shrinkage years



D. Assessment quality

Tuning data analysis

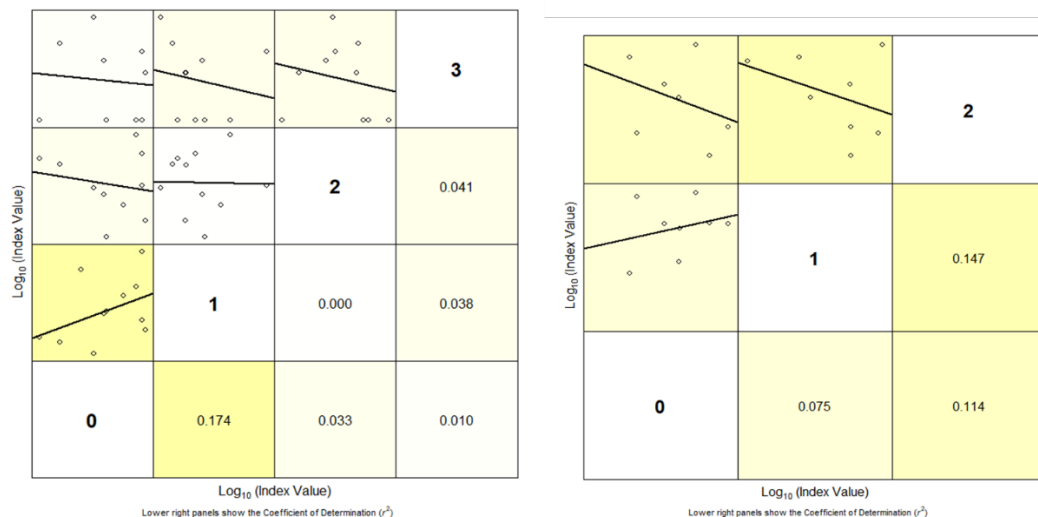


Figure 3.2.3.10. Catchability residuals plots by fleet (GSA 1 and GSA 3 surveys)

E. Yield per recruit analysis

Yield per recruit analyses were conducted based on the exploitation pattern resulting from the XSA model and population parameters. Minimum and maximum ages for the analysis were considered to be age group 0 and 4. Stock weight at age, catch weight at age and maturity ogive were estimated as mean values between 2007 and 2018. Natural mortality vector values were applied per age group using mean of many models. Fishing mortalities were the mean exploitation pattern F between 2016 and 2018. Reference F was considered to be mean F for ages 0 to 3 during the last three years (2016–2018).

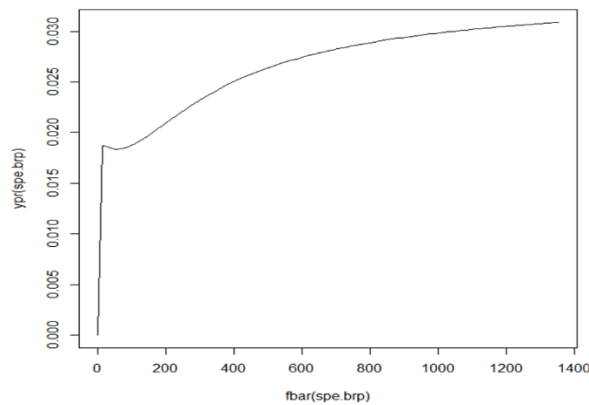


Figure 3.2.3.11. Yield per recruit curve, including the corresponding yield reference point ($F_{0.1} = 0.17$, $F_{max}=0.34$, $F_{status\ quo} = 1.36$)

Current F ($F_{ref} = F_{BAR\ 0-3}$) was estimated to be 1.2. F_{ref} exceeds $F_{0.1}$ reference point (0.17) indicating that the stock is subjected to over-fishing (or overexploitation) from a precautionary point of view.

3.2.4. Assessment unit: GSA 4

3.2.4.1. Pseudocohorte analysis (Vpa_Vit)

A pseudocohorte analysis was carried out for this stock, using Vit software (ILeonard et Slat., 2004). Cohort analysis (Gulland, 1965; Murphy, 1965) uses catch-at-age data, growth parameters and mortality by age classes to estimate instantaneous rates of fishing mortality (F) that have affected the stock over time, and historical population size.

The application of cohort analysis requires the knowledge of the catch demographic structure for several years. In case of poor data or time series, these are rarely available. Pseudo-cohort analysis can then be conducted with a few year data or even only one (Cassot *et al.*, 2008).

A. Model assumptions

The assessment was carried out using commercial data sampled between 2015–2018 in the western part of GSA 4 (Alboran Sea). This data and national landings of European hake were used to build LFD data of the whole GSA 4. Catch data in numbers at length were sliced using the length at age slicing routine in FLR, using GSA 4 growth parameters. The analyses were carried out for the ages 0 to 5+ with sensitivity test using several F terminal values ranged from 0 to 1.5. Concerning the F_{bar} , the age range used was 1-3 age groups.

B. Input data and parameters

European hake is one of the main target species in terms of landings, incomes and vessel involved in the area. In Algeria (GSA 4), it is mainly exploited by trawlers on the shelf and slope, but also as bycatch in small-scale fisheries using set gillnets, trammel nets and bottom long-lines targeting other species.

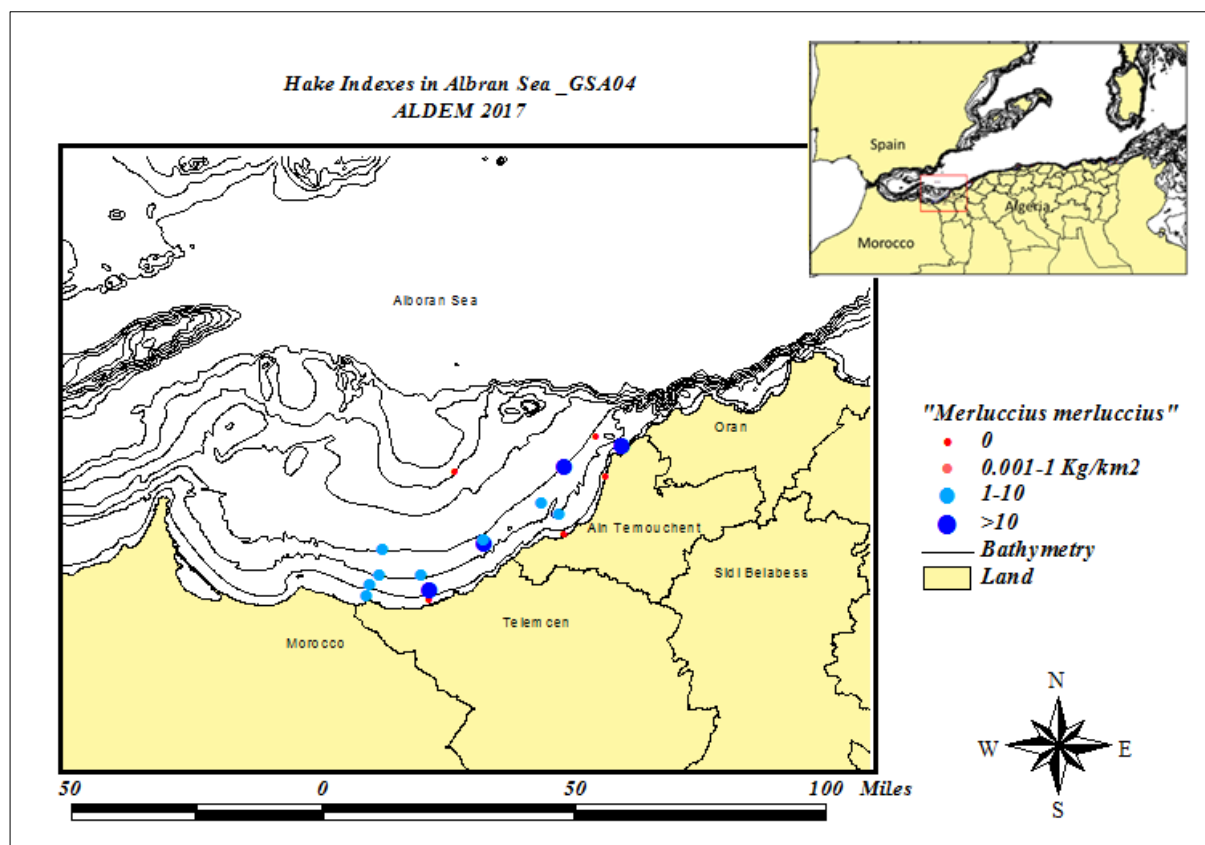


Figure 3.2.4.1. Biomass indexes observed in the western part of GSA 4, Algerian demersal survey (ALDEM 2017_CNRDPA, 2017)

This species represented 13 percent of national demersal fish landings and 14 percent of Osteichthyes demersal fish landed by commercial fleets in 2018 (Official statistics_DGPA, 2018). It is largely targeted by bottom trawlers (94 percent of national landings) in the average of landings from 2005 to 2018, but also small-scale fisheries using gillnets and trammel nets (CNRDPA, 2019). In 2017, the statistical office (DGPA) gave a number of 463 active trawlers in GSA 4 with an average engine power of 463 HP and a mean GRT of 70.91 TX.

Algerian demersal surveys (ALDEMs) were carried out from 2012 to 2017 with the Algerian scientific ship BELKACEM GRINE (40m) using the Medits protocol.

Spatial distribution of European hake in the Alboran part of GSA 4 in 2017 are presented in kg/km² (Fig. 35). The survey data analysis (ALDEM, 2017) using ATrIS v.2.1 (FAO, 2007) shows a maximum biomass index (>10kg/km²) of European hake in the stratum ranged between 50-200m in depth.

The data used in the benchmark meeting for European hake come from the official statistical office. Discards are not included in the catch because no information is available. Monthly samples were used to reconstruct length frequency data from 2015 to 2018. The plot (Fig. 35) emphasized a decrease in the catches from 2005. The minimum production was observed in 2010.

Landing data by year for tOTB are presented in Figure 3.2.4.2, while length classes density coming from catches and surveys from 2015–2017 and their average were compared and presented in Figure 3.2.4.3. Lengths density from the 2012–2017 surveys show a peak before 16 cm (Figure 3.2.4.4).

Table 3.2.4.1. European hake landings in GSA 4 (tonnes)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Landings	2 041	1 648	912	909	723	540	693	816	841	1 025	975	892	941	796

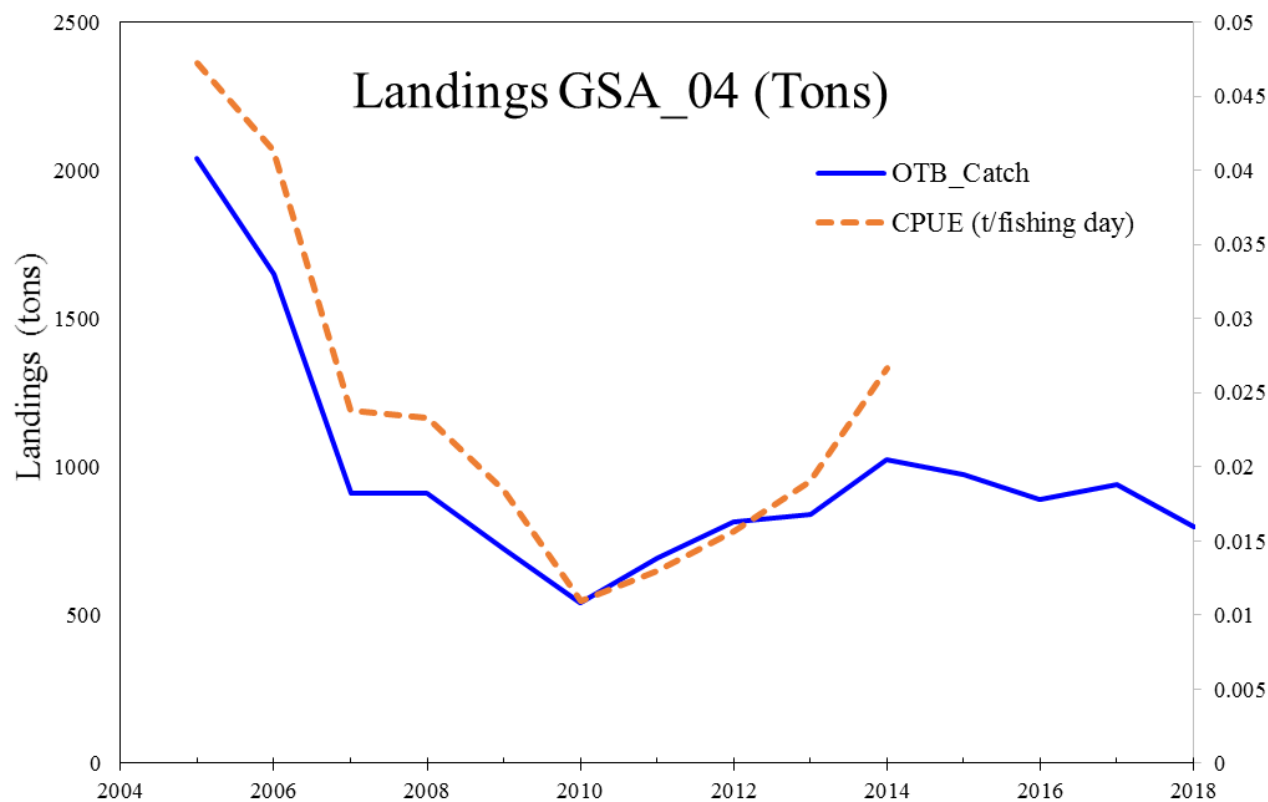


Figure 3.2.4.2. Trend of landings and CPUE (t/fishing day) in all GSA 4

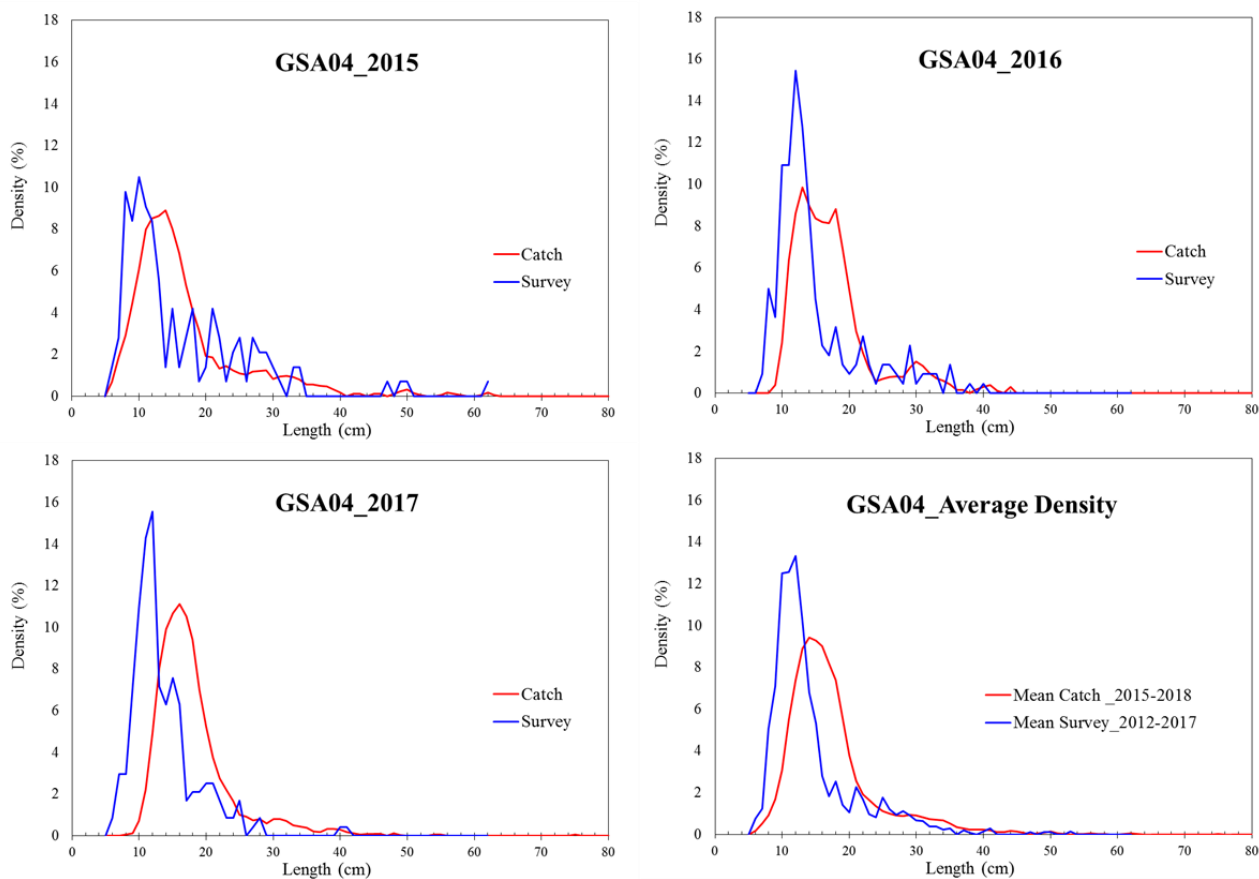


Figure 3.2.4.3. Landings and survey density indices for European hake in GSA 4 from the Algerian demersal survey (ALDEM 2017_CNRDPA, 2017)

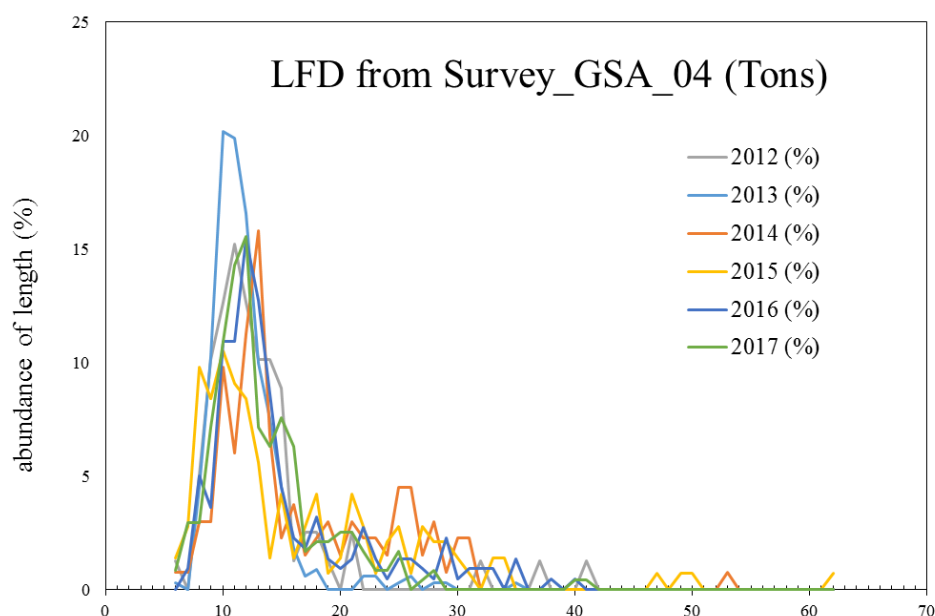


Figure 3.2.4.4. LFD of European hake in GSA 4 from the Algerian demersal survey (ALDEM 2012–2017)

For biological parameters, VBGF and length weight relationship parameters estimated by Filali and Hemida (2014) in GSA 4 using the routine Elefan available in the software FiSAT II were used in this approach (Table 3.2.4.2).

Table 3.2.4.2. VBGF and length-weight relationship parameters used in the assessment

GSA	L_{∞}	K (an ⁻¹)	t_0 (an)	a	b
04	85.5	0.18	-0.71	0.0039	3.1387

Using these VBGF parameters, length frequency data were converted into numbers by age classes. Six age classes (from 0 to 5+) were obtained after carrying out a slicing using FLR package in R (Fig. 39).

The four years data were converted separately, after that, assessment of European hake in the western part of GSA 4 was carried out merging three (2015–2017) and four (2015–2018) years of sampling.

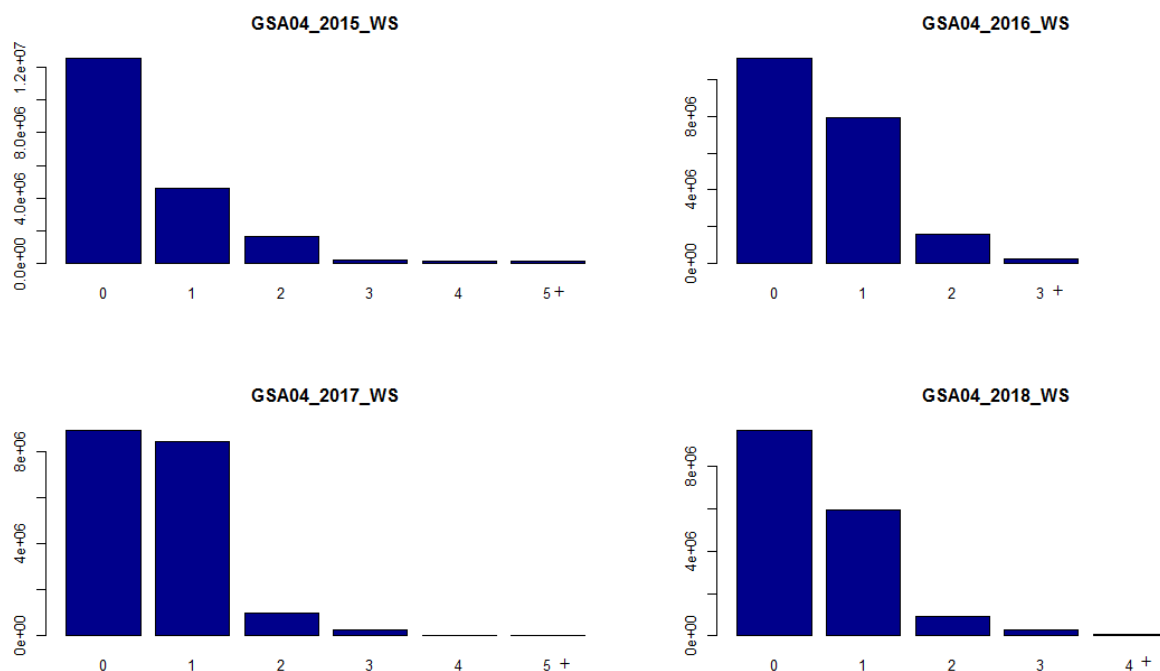


Figure 3.2.4.5. European hake population structure in the Alboran area of GSA 4

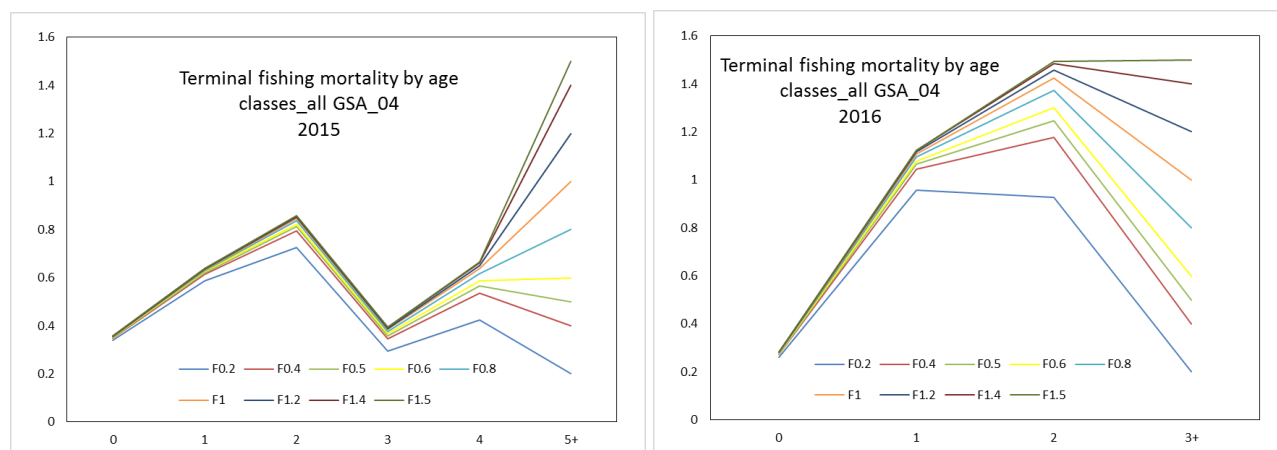
The selected VBGF and LW relationship parameters were used to estimate a range of natural mortality (M) vectors using different models and empirical formulas, as agreed during the benchmark meeting. Combined M vector and maturity used in the benchmark assessment is shown in Table 3.2.4.3.

Table 3.2.4.3. M vector and proportion of matures by size or age (males and females combined)

Age	0	1	2	3	4	5+
Average vector of M _GFCM	1.397	0.67865	0.47274	0.37848	0.32489	0.2092
Proportion of mature females	0.035	0.278	0.97	1	1	1

C. Results

After running several VPA using several values of terminal F, the fishing mortality curves (Fig. 40) of different terminal F are presented by age classes.



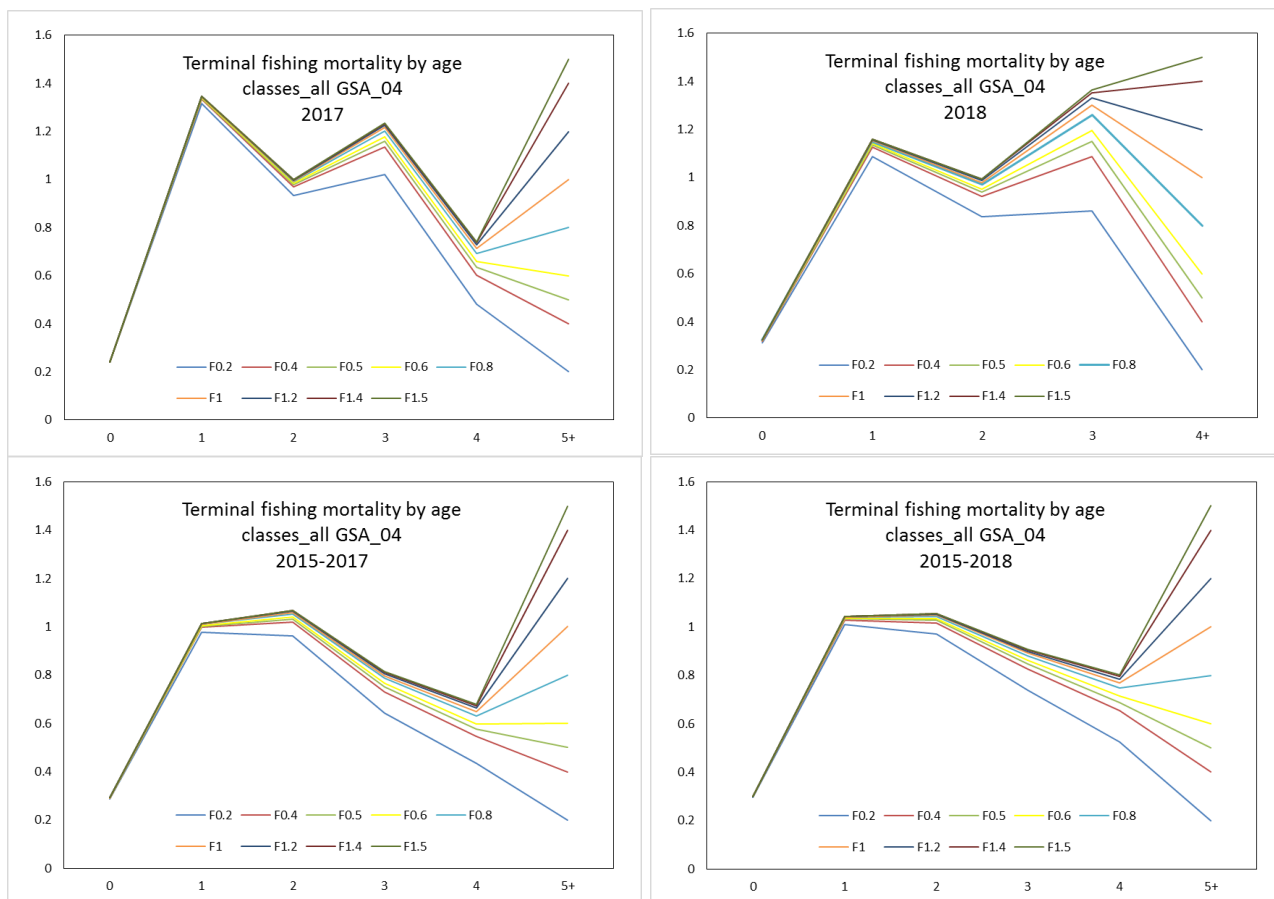
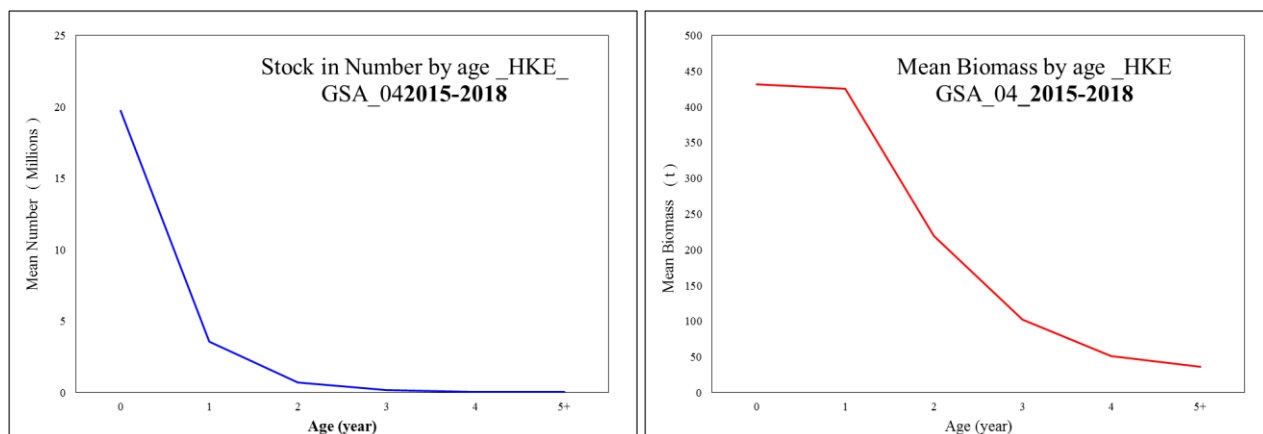


Figure 3.2.4.6. Fishing mortality by age classes using different values of terminal F from different pseudocohorte analysis

The study group agreed to take the VIT results for the terminal $F = 0.5$ as the best run to continue the Y/R analysis. Age classes ranged from 1 to 3 year (Figure 3.2.4.6) are the most exploited in GSA 4. Current F value ($F_{\text{current}} = 0.97 \text{ y}^{-1}$) corresponds to the average mortality of the most exploited age classes ranging from 0 to 3 years (Table 3.2.4.4).



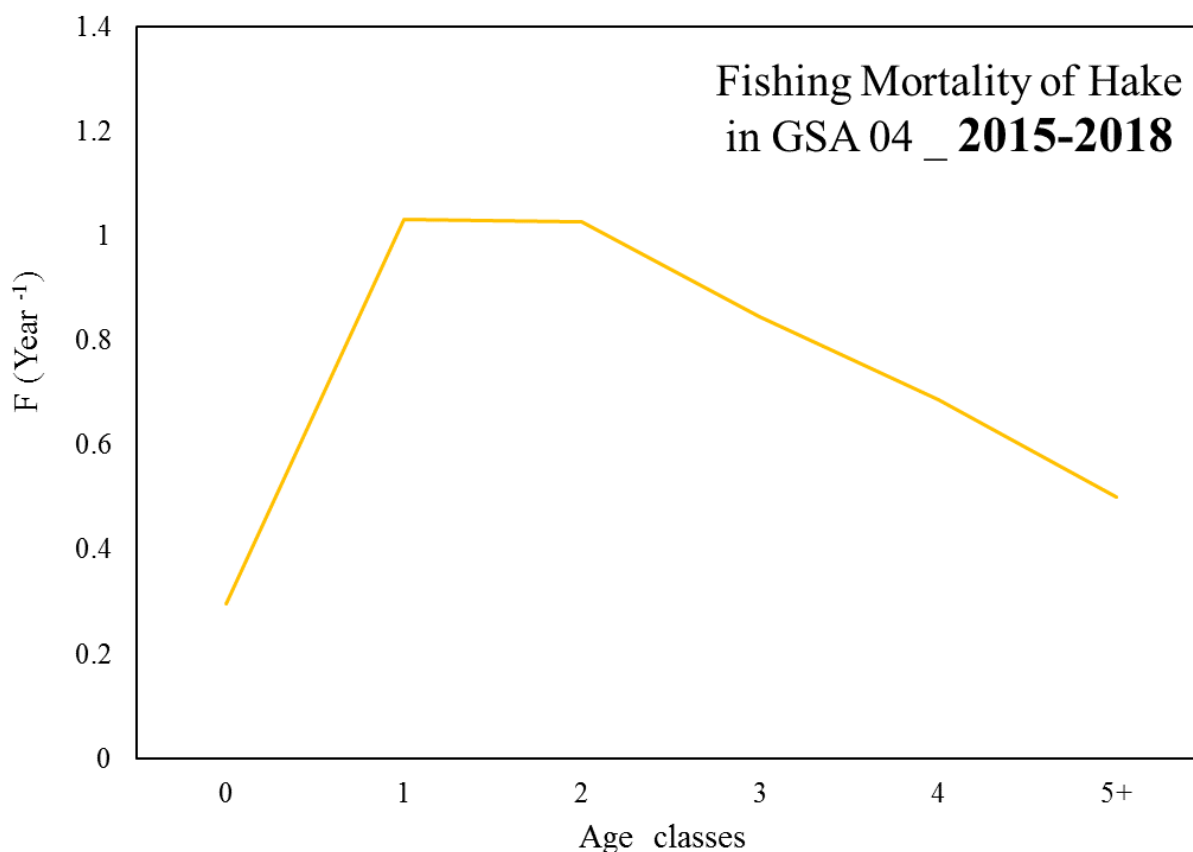


Figure 3.2.4.7. Fishing mortality, biomass and population of pseudocohort analysis in GSA 4 (2015–2018) using F terminal equal to 0.5

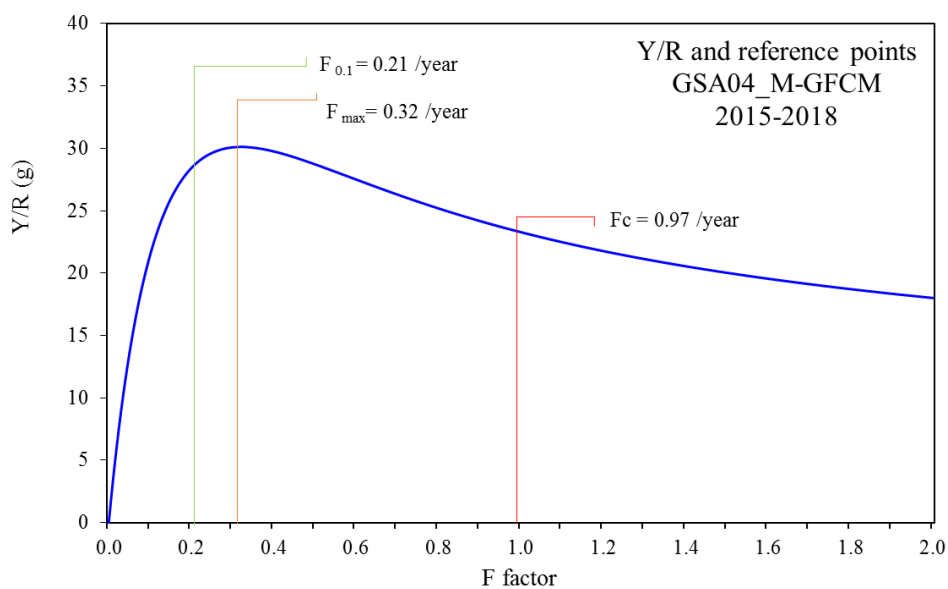


Figure 3.2.4.8. Yield per recruit curve and reference points of the European hake stock in GSA 4

D. Reference points

The yield per recruit curve (Y/R) and biological reference points $F_{0.1}$ FMSY (fig. 42) show that the actual level of fishing mortality ($F_{current} = 0.97$) is higher than the values calculated for the FMSY proxy ($F_{0.1} = 0.22$), which indicates that the current European hake stock is in high overfishing status.

The comparison of European hake stock reference points in GSA 4 among the different pseudocohort analysis of four years and merged data (Tab. 27) show a high over exploited stock of European hake in GSA 4.

Table 3.2.4.4. Comparison of outcomes of the assessment in GSA 04 using different years/aggregated years

GSA	Points	F_2015	F_2016	F_2017	F_2018	F_15-17	F_15-18
GSA 04	F_cur	0.72	0.94	1.16	1.07	0.93	0.97
	F0.1	0.19	0.31	0.24	0.29	0.21	0.21
	F_msy	0.28	0.45	0.36	0.43	0.32	0.32
	M_GFCM	3.8	3.0	4.8	3.7	4.3	4.5
vector	SSB						574
	Biomass						1305
	R (Thousands)						40942

3.2.5. Assessment unit: GSA 5

3.2.5.1. Fisheries information

In the Balearic Islands (western Mediterranean), commercial trawlers develop up to four different fishing tactics, which are associated with the shallow shelf, deep shelf, upper slope and middle slope (Guijarro and Massutí, 2006; Ordines *et al.*, 2006), mainly targeting: i) picarel (*Spicara smaris*), surmullet (*Mullus surmuletus*), common octopus (*Octopus vulgaris*) and a mixed fish category on the shallow shelf (50-80 m); ii) European hake (*Merluccius merluccius*), mullets (*Mullus* spp.), John dory (*Zeus faber*) and a mixed fish category on the deep shelf (80-250 m); iii) Norway lobster (*Nephrops norvegicus*), but with an important bycatch of big European hake, Megrims nei (*Lepidorhombus* spp.), Monkfishes nei (*Lophius* spp.) and Blue whiting (*Micromesistius poutassou*) on the upper slope (350-600 m); and iv) Blue and red shrimp (*Aristeus antennatus*) on the middle slope (600-750 m). The European hake is one of the target species from the deep shelf, although it is also an important bycatch in the upper slope and, in a lower level, in the middle slope.

Catches show important oscillations along the data series, although the maximum values reached before 1995 have never been observed again (Figure 3.2.5.1). These oscillations have been related to the influence of environmental conditions related to meso-scale (IDEA, Monserrat *et al.*, 2008) and large-scale (NAO) indices (Massutí *et al.*, 2008). The IDEA index is used as a proxy for two oceanographic scenarios for the regional circulation around the Balearic Islands, while the NAO index should have an impact on the climatic conditions on the areas where western intermediate waters (WIW) are formed. The bathymetric range of these water masses coincides with those of the European hake population. Periods of low NAO and IDEA indices could produce an oceanographic scenario that increases productivity in the area, because of the major presence of cold intermediate WIW in the channels. In addition to its effect of reinforcement of the northern and Balearic currents (Pinot *et al.*, 2002; López-Jurado *et al.*, 2008), it must also be considered that WIW has originated in a more productive area (Estrada, 1996) and during periods of high hydro-climatic dynamism (e.g. rainfall and increased wind strength, causing increasing river runoff and wind mixing; Lloret *et al.*, 2001). These same authors have demonstrated that cold years (generally coincident with low NAO index) tend to be more productive in the western Mediterranean, partly because winter mixing may reach greater depths and in part because the formation of deep water in the Gulf of Lion may flow over a large area (Estrada *et al.*, 1985). Also, periods of low NAO index result in favorable conditions for the productivity of exploited stocks in the Gulf of Lion (Lloret *et al.*, 2001). These environmental conditions could benefit the recruitment of European hake in the Balearic Islands.

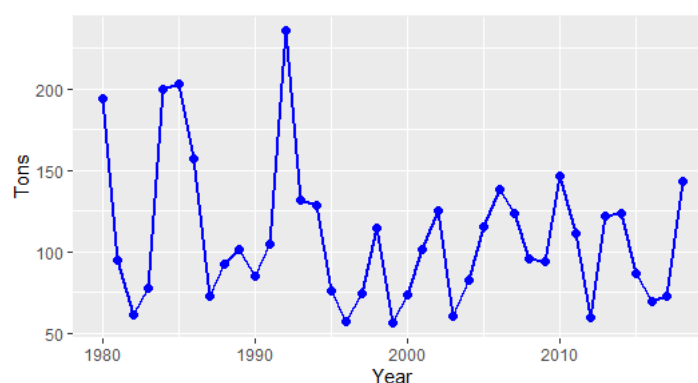


Figure 3.2.5.1. Catches of European hake from GSA 5

3.2.5.2. Input data and parameters

A. Biological parameters

		Units	Sex			Years
			Female	Male	Combined	
Growth model	L_{∞}	cm			110	
	K				0.178	
	t_0					
	Data source	Mellon-Duval <i>et al.</i> (2010)				
Length weight relationship	a				0.00677(*)	
	b				3.035097(*)	

(*) Spanish DCF

Natural mortality was obtained from the Excel spreadsheet provided during the meeting as an average of different M vectors.

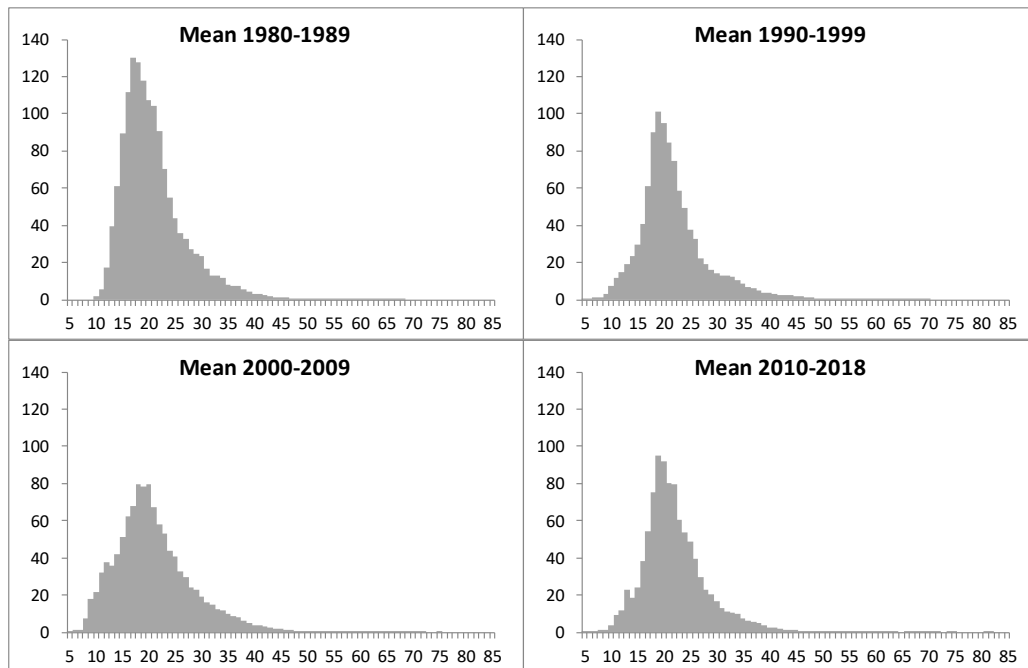
	0	1	2	3	4	5+
M	1.89	0.79	0.47	0.35	0.29	0.23

Maturity by age was obtained from Spanish DCF data.

	0	1	2	3	4	5+
M	0	0.297	0.986	0.990	1	1

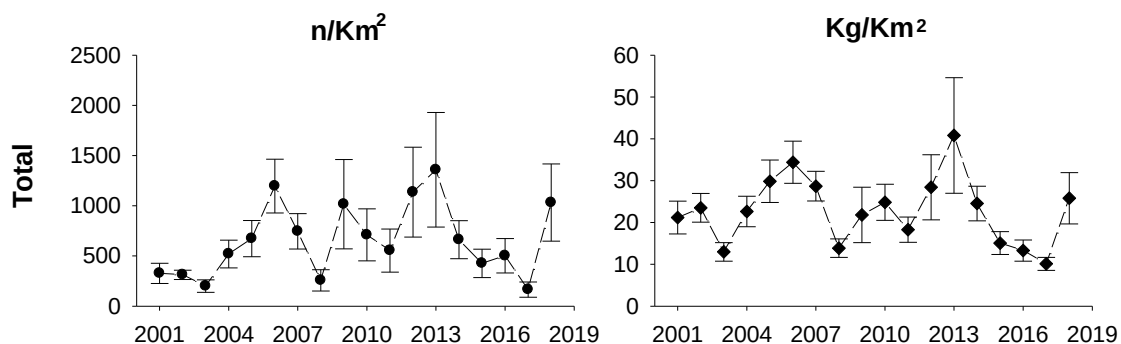
B. Size composition

Size composition was obtained from onboard and on port sampling, including discards. For the periods for which discards data were not available, they were estimated from nearby years.



C. Survey data

From 2001, the Spanish Institute of Oceanography has performed annual bottom trawl surveys following the same methodology and sampling gear described in the MEDITS protocol (BALAR surveys, Massutí and Reñones, 2005). Since 2007, this survey has been included in the MEDITS programme (Bertrand *et al.*, 2002). Mean stratified abundances and biomasses by km² have been computed using the methodology described by Grosslein and Laurec (1982). European hake is mainly distributed in the fishing grounds sited in the south of Mallorca and the Menorca channel, and its biomass and abundance indices show oscillations along the data series without a clear trend.



3.2.5.3. Model 1: XSA

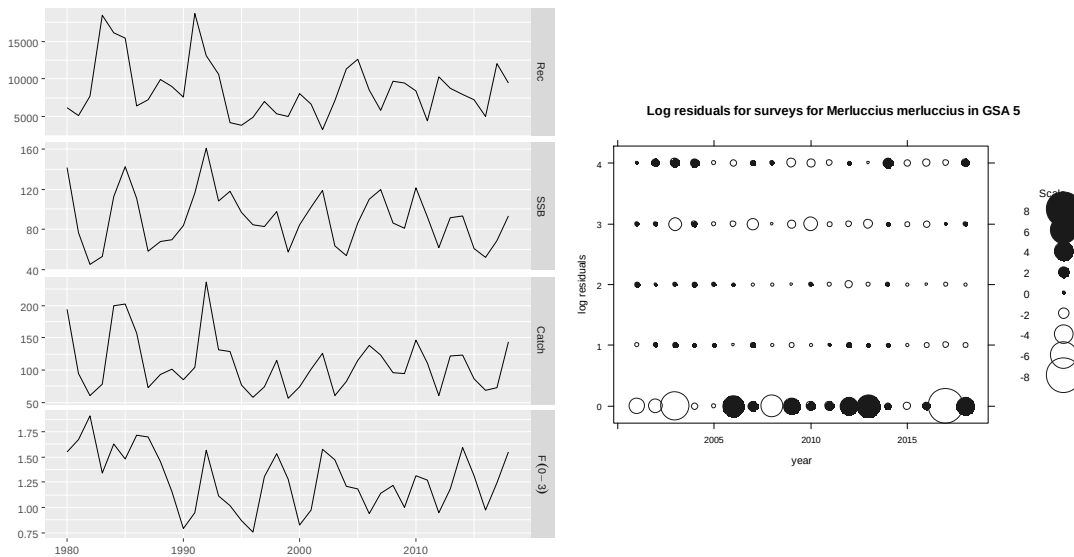
The stock assessment was performed over the period 1980–2018 using an XSA model over age classes ranging from 0 to 5+ and with MEDITS index as tuning fleet. The settings used were those of the previous years:

Fse	shk.yrs	shk.ages	rage	Qage
1.5	3	2	0	2

A. XSA results

XSA results show important oscillations along the data series. Neither recruitment nor SSB show any clear trend. Residuals from surveys by age and year were relatively low, except for age 0, which showed high values,

but without any clear temporal trend. The retrospective analysis did not show any pattern, so the assessment is considered to be robust.



3.2.5.4. Model 2: a4a

An a4a model was run using the same input parameters as for XSA, including tuning fleet. Several models were run with the following configurations:

	f	q	sr
1	$\sim \text{factor}(\text{age}) + \text{factor}(\text{year})$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim \text{factor}(\text{year})$
2	$\sim \text{factor}(\text{age}) + \text{s}(\text{year}, k=20)$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim \text{factor}(\text{year})$
3	$\sim \text{factor}(\text{age}) + \text{s}(\text{year}, k=39)$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim \text{factor}(\text{year})$
4	$\sim \text{s}(\text{age}, k=3) + \text{s}(\text{year}, k=39)$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim \text{factor}(\text{year})$
5	$\sim \text{s}(\text{age}, k=3) + \text{s}(\text{year}, k=10)$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim \text{factor}(\text{year})$
6	$\sim \text{factor}(\text{age}) + \text{s}(\text{year}, k=10)$	$\text{list}(\sim \text{factor}(\text{replace}(\text{age}, \text{age} > 3, 3)))$	$\sim \text{factor}(\text{year})$
7	$\sim \text{factor}(\text{age}) + \text{s}(\text{year}, k=20)$	$\text{list}(\sim \text{factor}(\text{replace}(\text{age}, \text{age} > 3, 3)))$	$\sim \text{factor}(\text{year})$

A4a results show important oscillations along the data series for recruitment and SSB (Figure 3.2.5.2). SSB shows a decreasing pattern, with a slight recovery in the last two years. Recruitment shows a peak for the last year considered. Residuals showed low values without a clear trend (Figure 3.2.5.3). Figure 3.2.5.4 shows the 3D contour plots of estimated fishing mortality and catchability at age and year. The final results with simulated and fitted data for 4a4 model are also included (Figure 3.2.5.5).

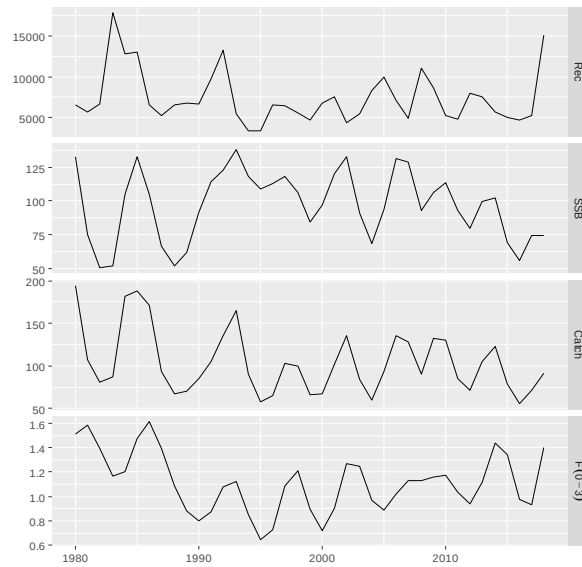


Figure 3.2.5.2. A4a results for European hake in GSA 5

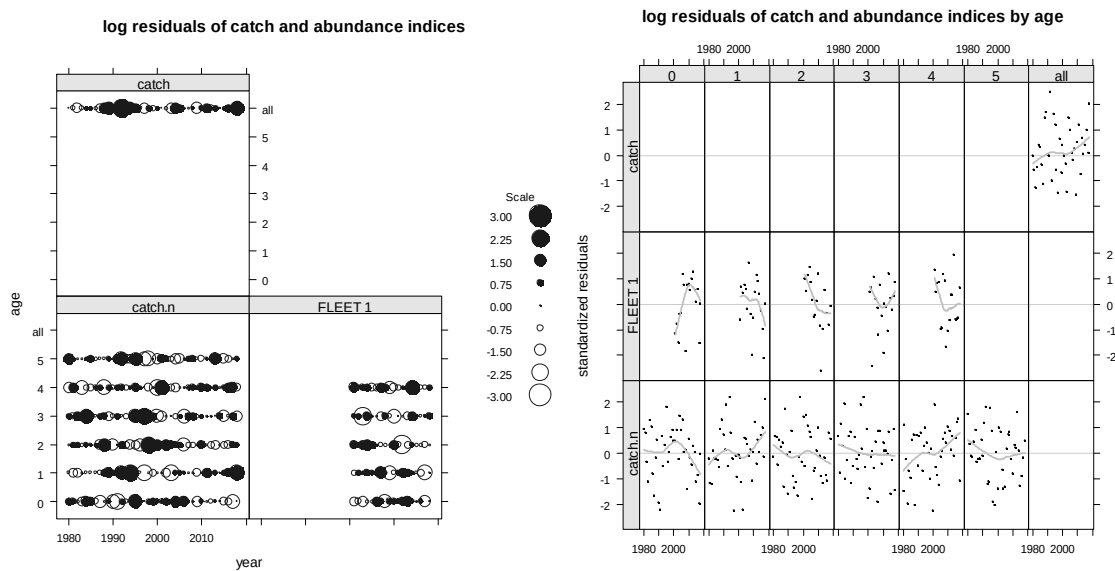


Figure 3.2.5.3. Residuals for the a4a model for European hake in GSA 5

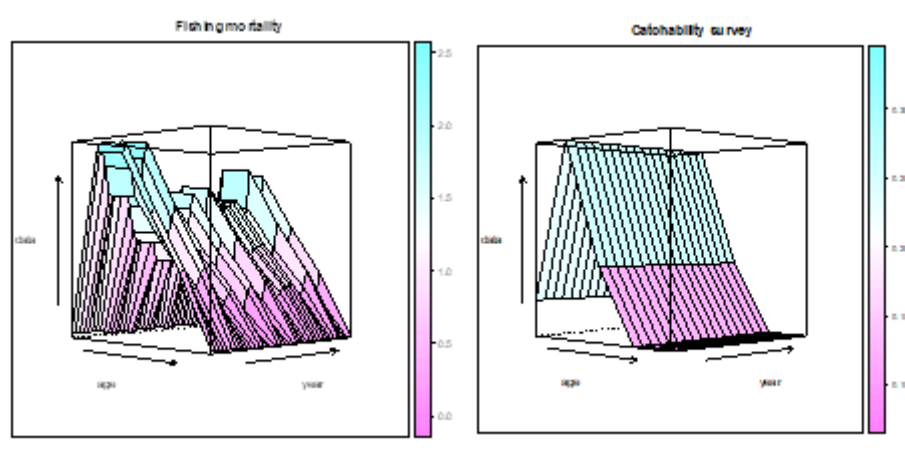


Figure 3.2.5.4. 3D contour plots of estimated fishing mortality and of estimated catchability at age and year for European hake in GSA 05

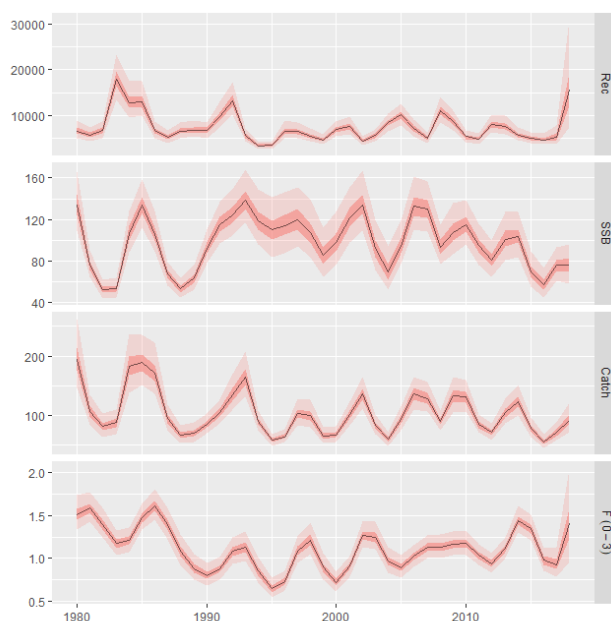


Figure 3.2.5.5. A4a simulated and fitted data for European hake in GSA 5

3.2.5.5. Final advice

On the basis of the discussion on assessment units for western Mediterranean (see section 3.2.1), the assessment of European hake in GSA 5, based on a4a, is provided as a complementary advice to the overall assessment carried out in GSAs 1, 5, 6, 7 (see Appendix 3).

3.2.6. Assessment unit: GSA 6

3.2.6.1. Fisheries information

European hake is a target demersal species of the Mediterranean fishing fleets. It is largely exploited in GSA 6, mainly by trawlers on the shelf and slope (95 percent landings), but also by small-scale fisheries using longlines (2 percent), and gillnets and trammel nets (3 percent) (average percentages estimated between 2016 and 2018).

According to official statistics, around 1 000 boats are involved in this fishery, with total annual landings oscillating around an average value of 2 600 tonnes for the period 2008–2018 (2 442 tonnes in 2018). The trawler fleet is the largest in number of boats and landings (424 trawlers and 2 359 tonnes in 2018).

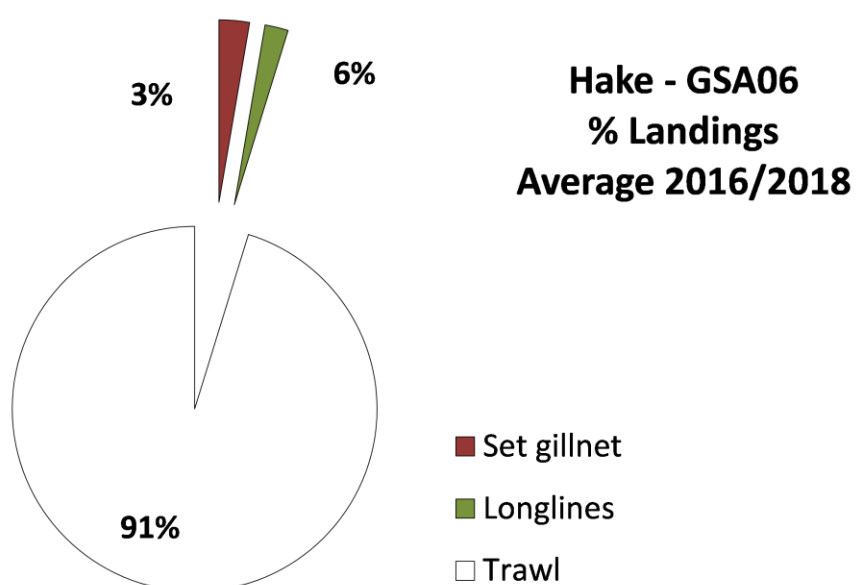
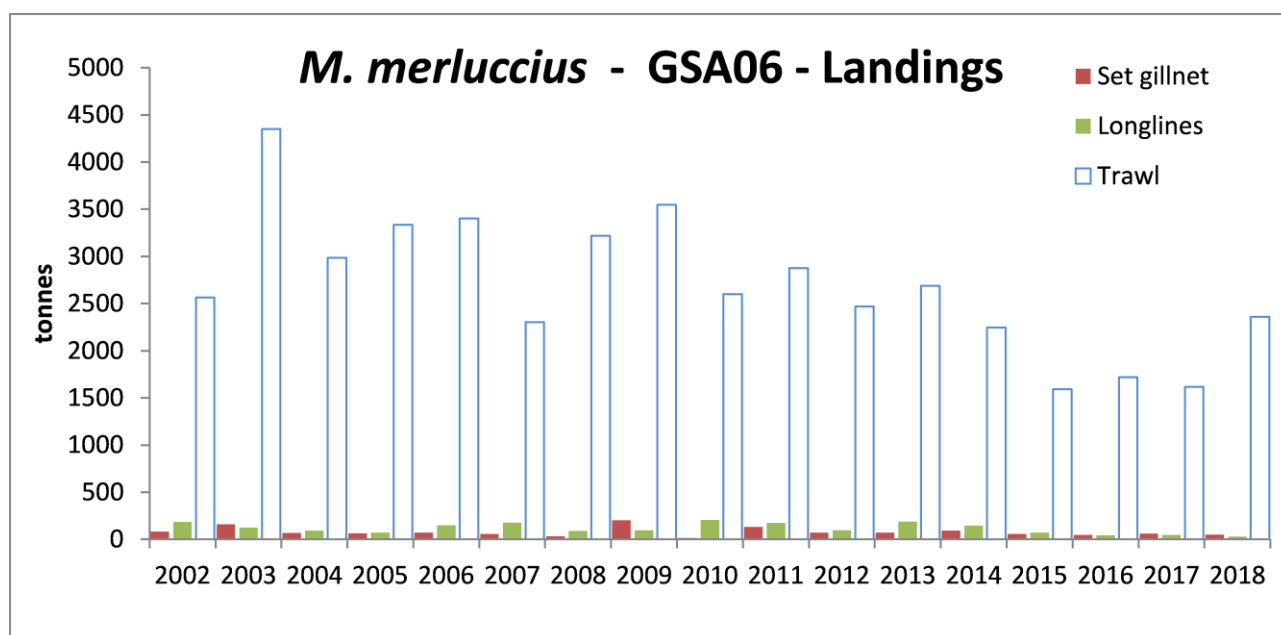
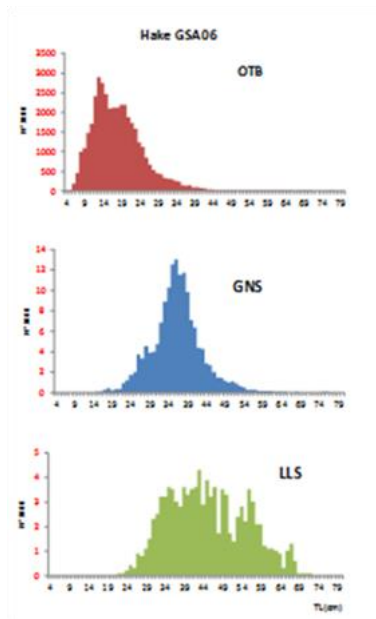


Figure 3.2.6.1. Total landings (tonnes) of European hake in GSA 6 (top) and percentage of contribution by fishing gear (bottom)



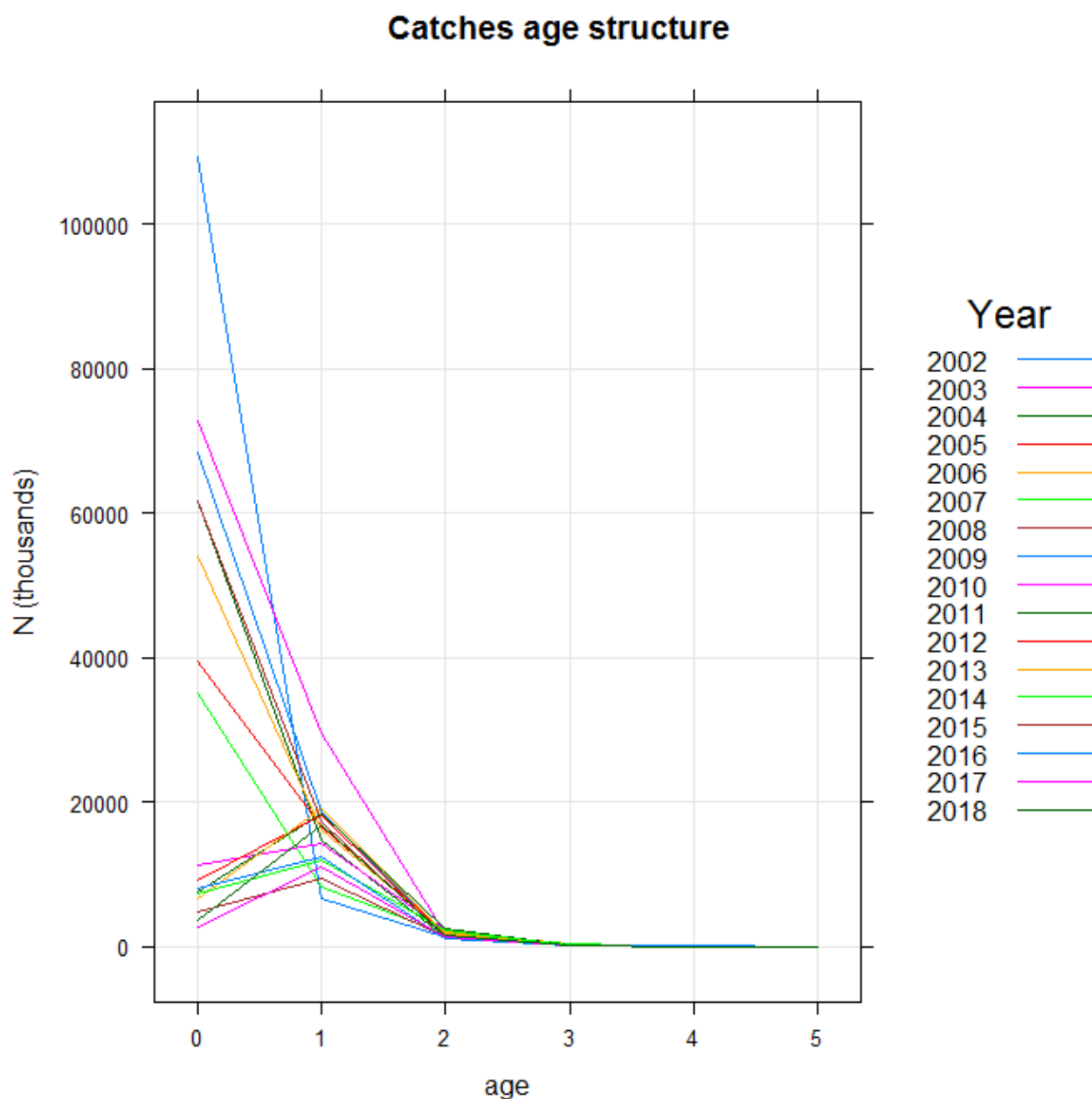


Figure 3.2.6.2. (Top) length frequency distribution of European hake catches by gear in the GSA 6 area (average 2016–2018) and (bottom) catches age structure of Traw, longlines and gillnet catches in GSA 6 (Northern Spain) for the period 2002–2018

3.2.6.2. Input data and parameters

A. Biological parameters

		Units	Sex			Years
			Female	Male	Combined	
Growth model	L_{∞}	Cm			110	
	K				0.178	
	t_0					
	Data source		Mellon-Duval <i>et al.</i> (2010)			
Length weight relationship	A				0.00677(*)	
	B				3.035097(*)	

(*) Spanish DCF

Natural mortality was obtained from the Excel spreadsheet provided during the meeting as an average of different M vectors.

	0	1	2	3	4	5+
M	1.8	0.79	0.41	0.3	0.24	0.18

Maturity by age was obtained from Spanish DCF data.

	0	1	2	3	4	5+
M	0	0.2965	0.9855	0.99	1	1

B. Size composition

Size composition was obtained from onboard and on port sampling, including discards.

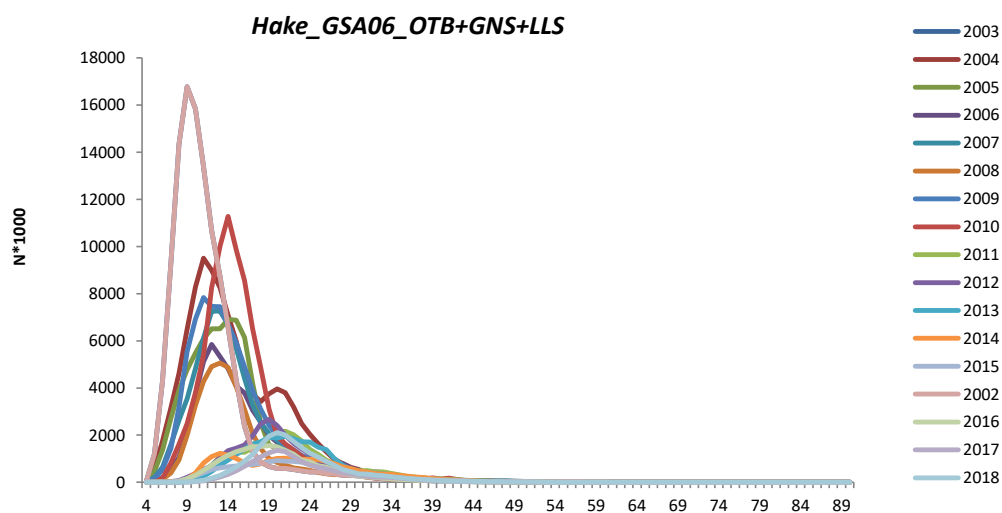


Figure 3.2.6.3. Total size composition by year

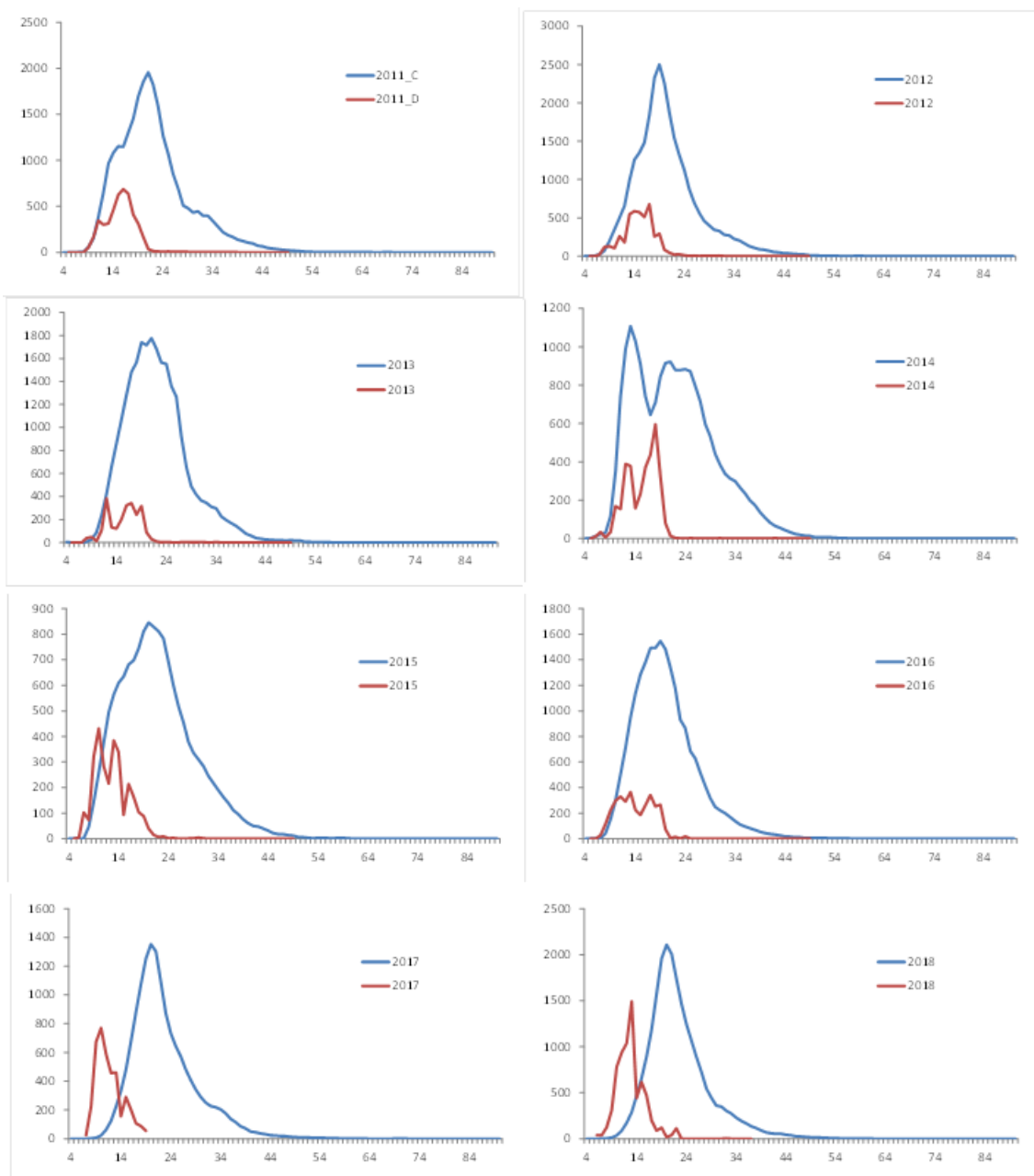


Figure 3.2.6.4. Discard structure for the 2011–2018 period

C. Survey data

Biomass and abundance indices of European hake in GSA 6 showed the highest values in 2006 and the lowest values in the series since then.

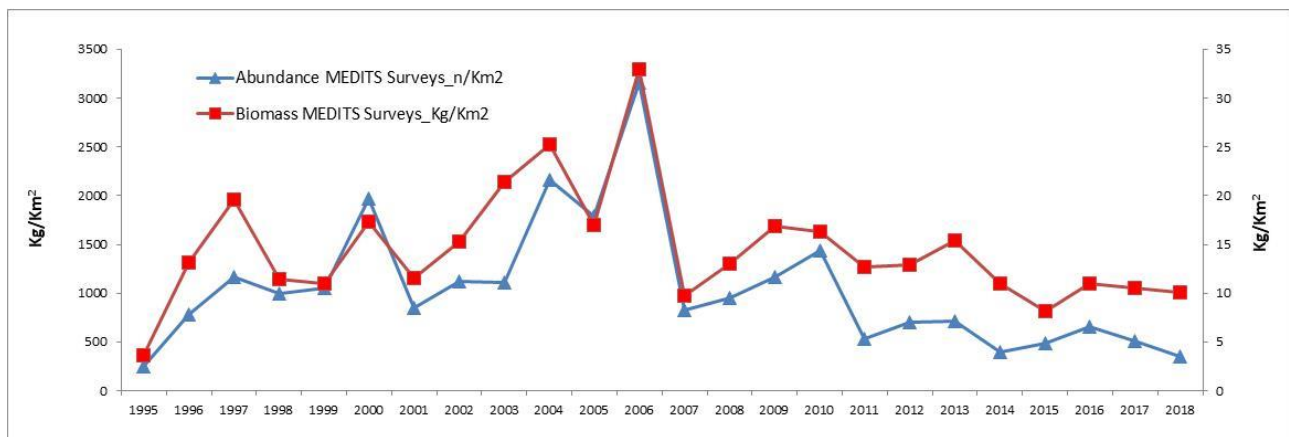


Figure 3.2.6.5. Time series of abundance and biomass from the MEDITS surveys in GSA 5

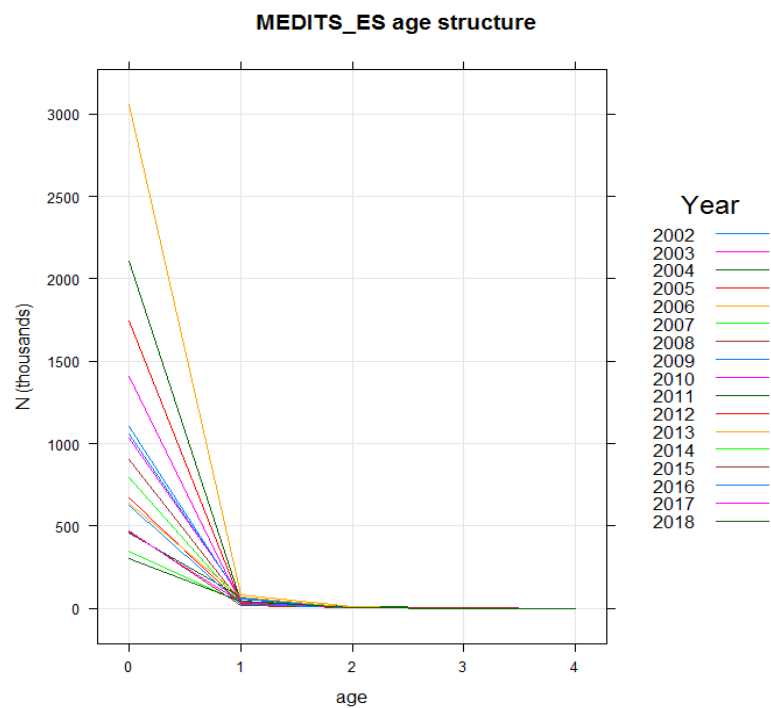


Figure 3.2.6.6. Age composition of the MEDITS surveys in GSA 5

3.2.6.3. Model attempts: XSA and a4a

An extended survivor analysis (XSA) tuned with MEDITS survey data was carried out over the period 2002–2018, considering age classes from 0 to 5+.

The statistical catch at age model a4a, (non-linear model implemented in R/FLR/ADMB, [flr-project.com]), was also used to model the stock (1995–2018 period).

A. Results

Several models in a4a were run with the following configurations (the final fit used was the third).

	F	q	Sr
1	$\sim \text{factor}(\text{age}) + \text{factor}(\text{year})$	$\text{list}(\sim \text{factor}(\text{age}) + \text{year})$	$\sim s(\text{year}, k=15)$
2	$\text{te}(\text{replace}(\text{age}, \text{age}>4,4), \text{replace}(\text{year}, \text{year}<2002,2002), k=c(4,10))$	$\text{list}(\sim \text{factor}(\text{age}) + \text{year})$	$\sim s(\text{year}, k=15)$
3	$s(\text{replace}(\text{age}, \text{age}>4,4), \text{by}=\text{breakpts}(\text{year},2009), k=4) + s(\text{year}, \text{by}=\text{breakpts}(\text{year},2004), k=8)$	$\text{list}(\sim \text{factor}(\text{age}) + \text{year})$	
4	$\sim s(\text{replace}(\text{age}, \text{age}>4,4), \text{by}=\text{breakpts}(\text{year},2009), k=5) + s(\text{year}, k=10)$	$\text{list}(\sim \text{factor}(\text{age}) + \text{year})$	
5	$\sim \text{factor}(\text{age}) + \text{factor}(\text{year}) + s(\text{year}, k=5, \text{by}=\text{as.numeric}(\text{age}==0))$	$\text{list}(\sim \text{factor}(\text{age}))$	$\sim s(\text{year}, k=15)$
6	$\sim \text{factor}(\text{age}) + s(\text{year}, k=6)$	$\text{list}(\sim s(\text{age}, k=4))$	$\sim s(\text{year}, k=15)$
7	$\sim s(\text{age}, k=4) + s(\text{year}, k=6) + s(\text{year}, k=5, \text{by}=\text{as.numeric}(\text{age}==0)) + s(\text{year}, k=6, \text{by}=\text{as.numeric}(\text{age}==4))$	$\text{list}(\sim I(1/(1+\exp(-\text{age}))))$	$\sim s(\text{year}, k=15)$

A4a results (left) show an important decreasing trend along the data series for recruitment. SSB shows a stable pattern, with a slight recovery in the last two years. XSA vs a4a adjust (right) showed good overlap using the two models. Residuals showed low values without a clear trend. The final results with simulated and fitted data for the 4a4 model are also included.

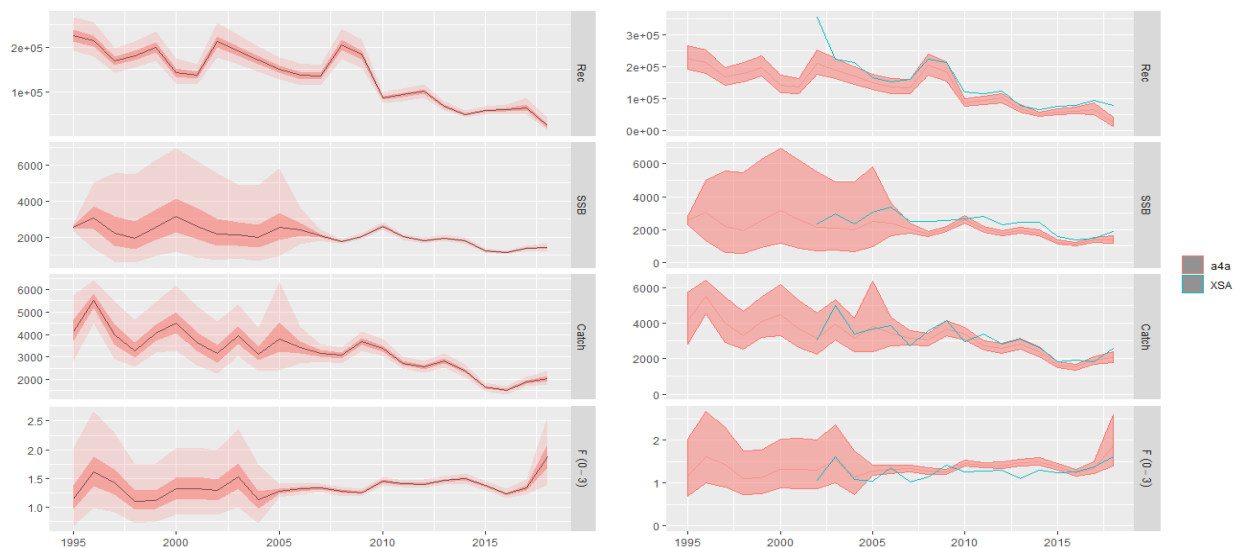


Figure 3.2.6.7. Comparison between the a4a and XSA models for GSA 6
log residuals of catch and abundance indices

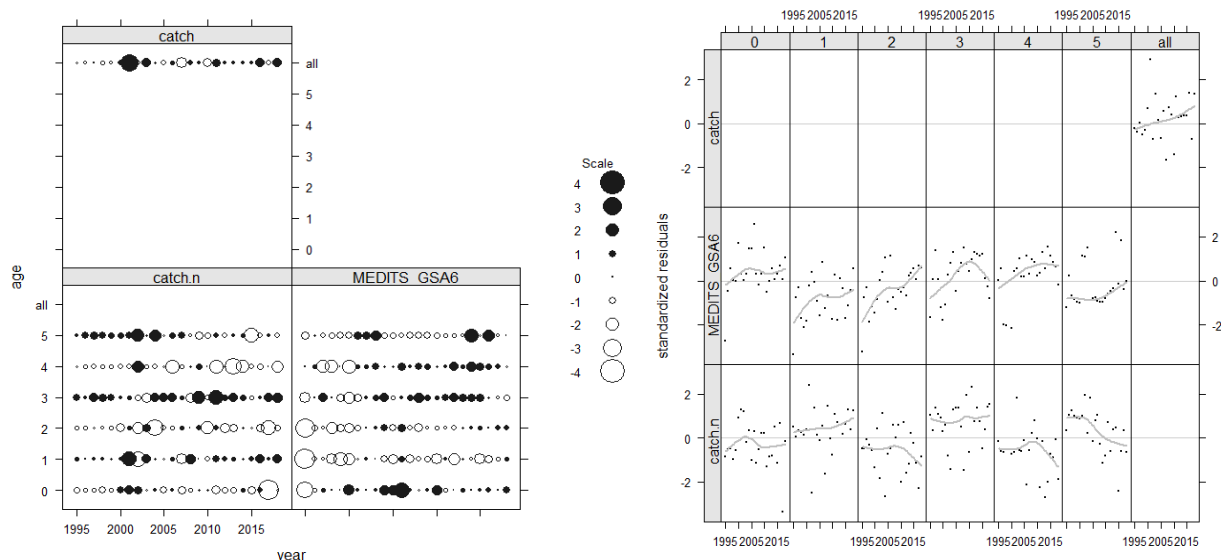


Figure 3.2.6.8. Residuals for XSA and a4a models

3.2.6.4. Final advice

On the basis of the discussion on assessment units for western Mediterranean (see section 3.2.1), no additional advice on the status of European hake is provided for this individual GSA 6 (see Appendix 3).

3.2.7. Assessment unit: GSA 7

3.2.7.1. Fisheries information

European hake is one of the most important demersal target species for the commercial fisheries in the Gulf of Lion (GSA 7). In this area, European hake is exploited by French trawlers, French gillnetters, Spanish trawlers and Spanish longliners. An average of 241 boats are involved in this fishery and, according to official statistics, the total annual catches for the period 1998–2018 have oscillated around an average value of 1 817 tonnes (911 tonnes in 2018). French trawlers are harvesting the major part of the catch (72 percent on average since 1998), targeting European hake ranging from 3 and 92 cm total length (TL), with an average size of 21 cm TL. Since 2002, the size of that fleet has decreased. This decrease has been further accentuated by the small pelagic crisis in 2009, when the French trawlers fishing small pelagic fish have re-directed their effort on the demersal species, resulting in an over-capacity situation. The second most important fleet is the French gillnetters (14 percent of the catch, range 13–86 cm TL and average size 39 cm TL), followed by the Spanish trawlers (9,5 percent of the catch, range 5–88 cm TL and average size 24 cm TL), and the Spanish longliners (4,5 percent of the catch, range 22–96 cm TL and average size 50 cm TL).

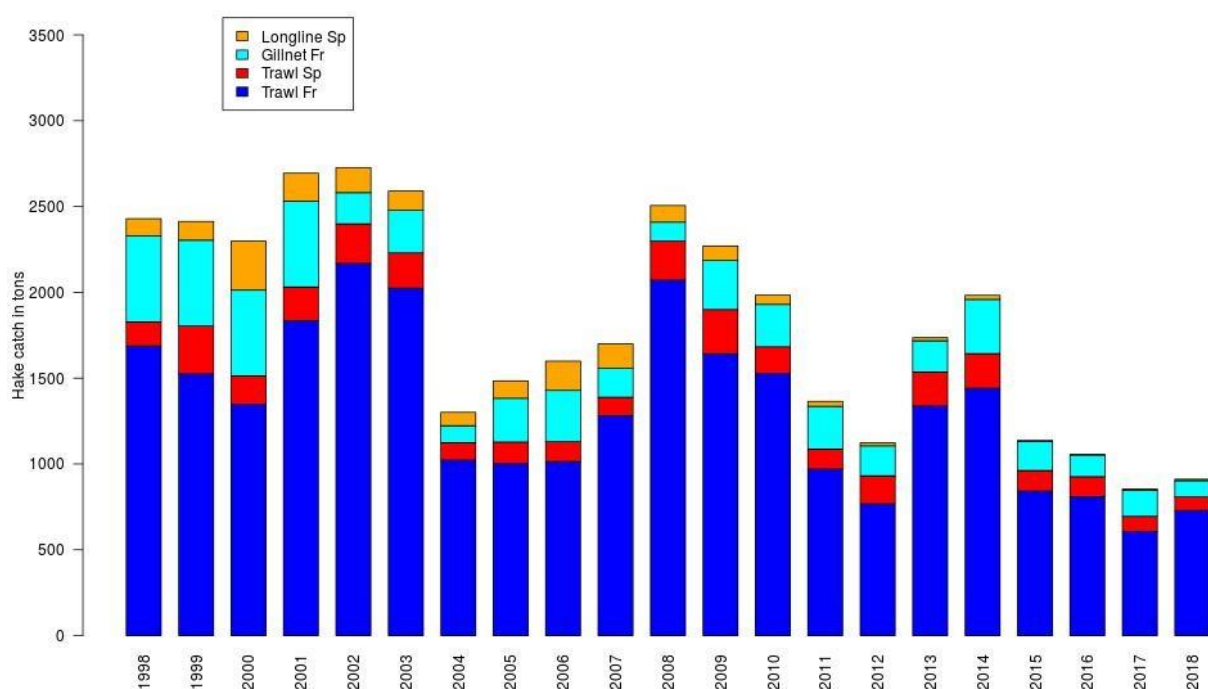


Figure 3.2.7.1. Time series of European hake catch per fleet

3.2.7.2. Input data and parameters

A. Catches

Annual landings (tonnes) by gear (DCF data)

Gears/Years	OTB-French	OTB-Spanish	GNS-French	GTR-French	LLS-Spanish
1998	1 688	140	500	NA	101
1999	1 525	279	500	NA	109
2000	1 347	166	500	NA	285
2001	1 835	196	500	NA	163
2002	2 168	231	182	NA	146
2003	2 024	206	248	NA	112
2004	1 023	101	99	NA	78
2005	1 002	125	255	NA	101
2006	1 014	116	299	NA	170
2007	1 282	107	168	NA	143
2008	1 898	192	111	NA	97

2009	1 633	258	286	NA	83
2010	1 527	156	247	NA	53
2011	970	113	245	5	29
2012	759	162	175	NA	18
2013	1 292	198	161	21	18
2014	1 392	200	284	32	24
2015	820	119	153	16	7
2016	783	116	126	NA	4
2018	598	89	148	5	6
2019	697	79	89	6	8

Annual discards (tonnes) by gear (DCF data)

Gears/Years	OTB-French	OTB-Spanish	GNS-French	GTR-French	LLS-Spanish
1998	NA	NA	NA	NA	NA
1999	NA	NA	NA	NA	NA
2000	NA	NA	NA	NA	NA
2001	NA	NA	NA	NA	NA
2002	NA	NA	NA	NA	NA
2003	NA	NA	NA	NA	NA
2004	NA	NA	NA	NA	NA
2005	NA	1	NA	NA	NA
2006	NA	NA	NA	NA	NA
2007	NA	NA	NA	NA	NA
2008	173	35	NA	NA	NA
2009	9	NA	NA	NA	1
2010	NA	NA	NA	NA	1
2011	NA	3	NA	NA	NA
2012	9	1	NA	NA	NA
2013	46	NA	NA	NA	NA
2014	49	2	NA	NA	NA
2015	22	1	NA	NA	NA
2016	26	1	NA	NA	NA
2018	8	0	0	0	0
2019	32	0	0	0	0

Annual catches (tonnes) by gear (DCF data)

Gears/Years	OTB-French	OTB-Spanish	GNS-French	GTR-French	LLS-Spanish
1998	1 688	140	500	0	101
1999	1 525	279	500	0	109
2000	1 347	166	500	0	285
2001	1 835	196	500	0	163
2002	2 168	231	182	0	146
2003	2 024	206	248	0	112
2004	1 023	101	99	0	78
2005	1 002	126	255	0	101
2006	1 014	116	299	0	170
2007	1 282	107	168	0	143
2008	2 071	227	111	0	97
2009	1 642	258	286	0	84
2010	1 527	156	247	0	54
2011	970	116	245	5	29
2012	768	163	175	0	18
2013	1 338	198	161	21	18
2014	1 441	202	284	32	24
2015	842	120	153	16	7
2016	809	117	126	0	4
2018	606	89	148	5	6
2019	729	79	89	6	8

B. Biological parameters

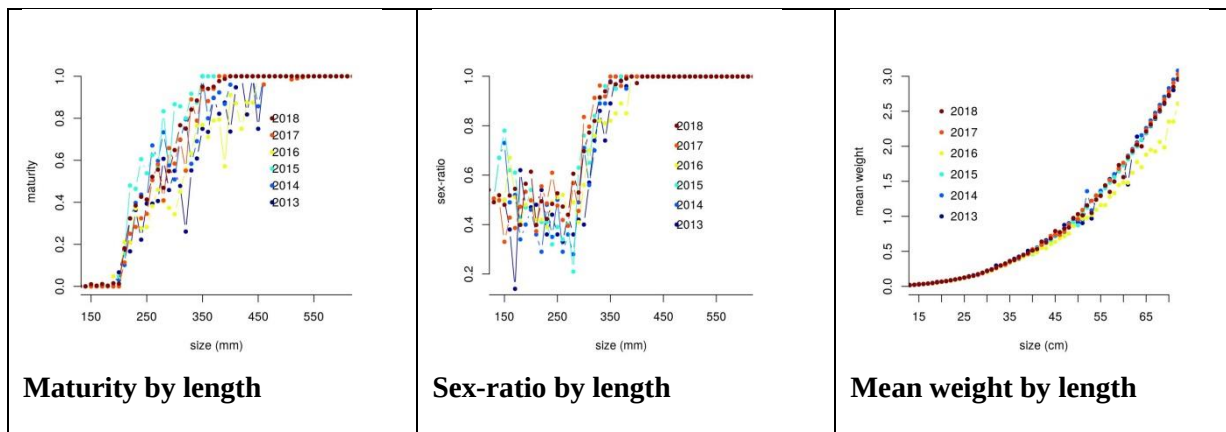
The growth of European hake in the Gulf of Lion was re-estimated from tagging experiments carried out by IFREMER (Mellon-Duval *et al.*, 2010). The new parameters have not been yet compared to a re-analysis of otoliths readings. Therefore, the data sent to the data call were in length and were converted into age using the length-to-age slicing functions available in the R package a4a. The growth parameters used are indicated in the table below.

		Sex				
		Units	female	male	Combined	Years
Growth model	L_{∞}	cm	100.7	72.8		
	K	years ⁻¹	0.236	0.233		
	t_0		-	-		
	Data source	Tagging experiments (Mellon-Duval <i>et al.</i> , 2010)				
Length weight relationship	A				0.0085	
	B				2.97	

Natural mortality was obtained from the new Excel spreadsheet provided during the benchmark.

	0	1	2	3	4	5+
MeanM used in 2019	1.83	0.78	0.46	0.34	0.27	0.20
Prodbiom used in 2018	1.24	0.58	0.45	0.40	0.37	0.35

The maturity was calculated using data collected in GSA 7 over the period 2004–2018 by IFREMER within the DCF (since 2002), using inbio for 2004–2012 and COST tools for 2013–2018.



C. Assessment input data (length frequency distribution, catch at age and index at age)

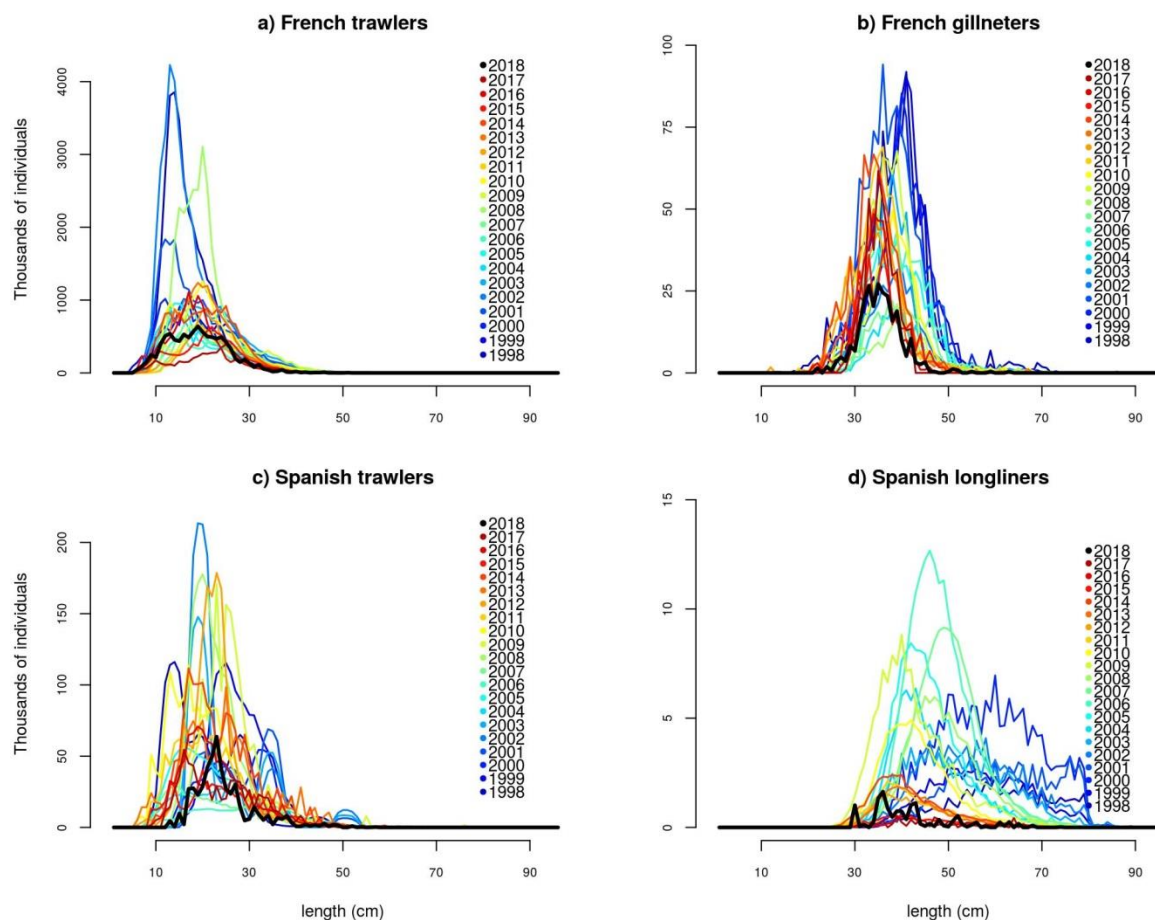


Figure 3.2.7.2. Length distribution of catches by year (colors) and types of gear (a-d)

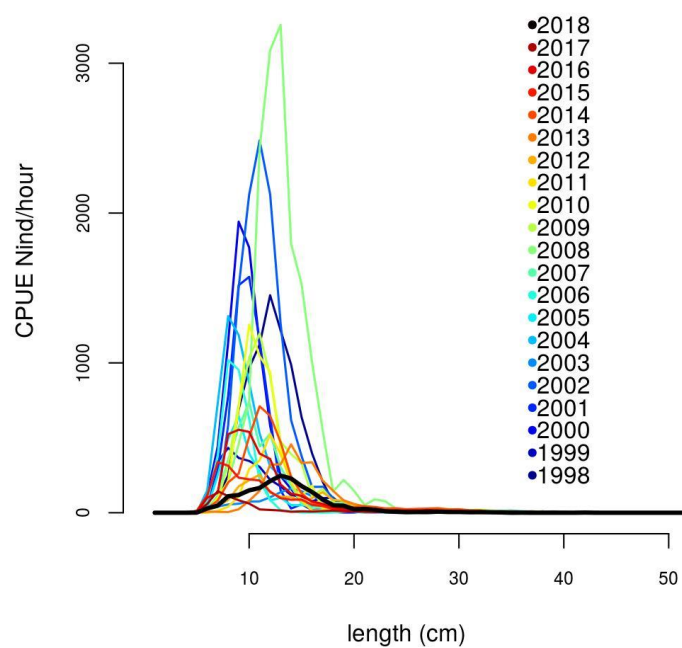


Figure 3.2.7.3. Length distribution of MEDITS index by years

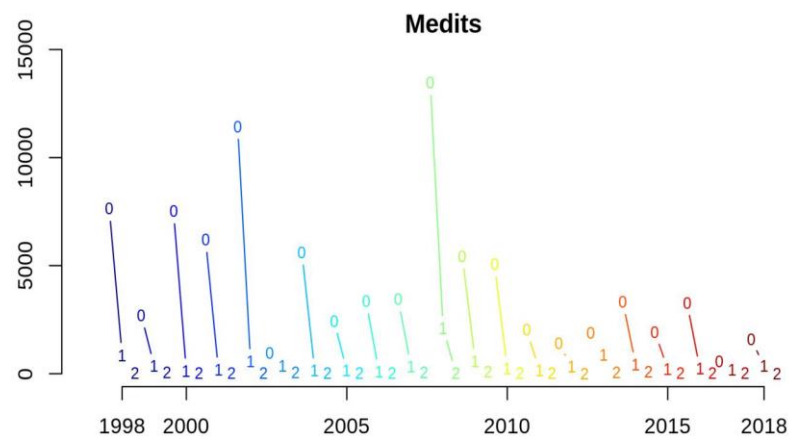
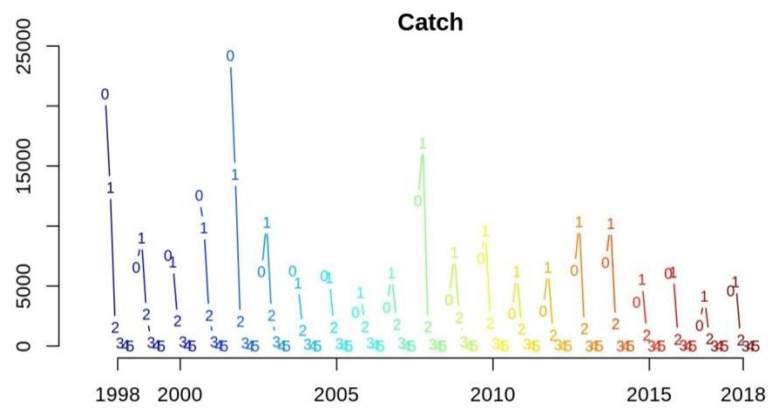


Figure 3.2.7.4. Time series of catch and MEDITS index at age and year

Catch at age in numbers in thousands (discards included)

Years/Ages	0	1	2	3	4	5
1998	21 010	13 203	1 554	228	39	12
1999	6 570	8 996	2 644	281	34	8
2000	7 575	6 992	2 079	330	60	24
2001	12 526	9 850	2 561	344	39	21
2002	24 183	14 310	2 066	231	25	13
2003	6 190	10 323	2 561	347	23	16
2004	6 225	5 268	1 284	162	12	3
2005	5 826	5 691	1 565	177	15	3
2006	2 816	4 452	1 616	240	28	6
2007	3 211	6 097	1 821	231	21	7
2008	12 079	16 923	1 595	148	13	5

2009	3 841	7 804	2 371	375	15	4
2010	7 289	9 621	1 924	210	12	1
2011	2 679	6 188	1 403	163	5	1
2012	2 912	6 558	915	101	4	1
2013	6 287	10 374	1 439	14	3	0
2014	6 959	10 223	1 839	22	1	0
2015	3 636	5 539	914	15	1	0
2016	6 071	6 153	571	32	1	0
2017	1 701	4 137	602	7	1	0
2018	4 609	5 347	517	8	1	0

MEDITs index at age (1998–2018)

Years/Ages	0	1	2
1998	7 503	840	19
1999	2 627	347	52
2000	7 573	128	40
2001	6 264	186	44
2002	11 196	551	41
2003	963	371	74
2004	5 613	135	25
2005	2 417	153	22
2006	3 396	97	30
2007	3 406	331	56
2008	13 836	2 161	43
2009	5 490	590	103
2010	5 126	248	40
2011	1 990	165	34
2012	1 414	338	14

2013	1 868	881	52
2014	3 359	431	83
2015	1 934	202	24
2016	3 099	228	24
2017	556	167	31
2018	1 584	344	13

Weight at age (kg) by year

Years/Ages	0	1	2	3	4	5
1998	0.020	0.090	0.350	0.690	1.770	2.540
1999	0.030	0.130	0.330	0.620	1.530	2.080
2000	0.020	0.130	0.380	0.730	1.840	2.590
2001	0.020	0.130	0.330	0.580	1.740	2.600
2002	0.020	0.090	0.310	0.660	1.660	2.180
2003	0.030	0.130	0.300	0.600	1.610	3.070
2004	0.020	0.120	0.320	0.590	1.160	1.680
2005	0.020	0.120	0.340	0.560	0.980	1.310
2006	0.030	0.140	0.420	0.650	1.050	1.310
2007	0.040	0.120	0.350	0.700	1.200	1.270
2008	0.040	0.080	0.300	0.690	1.370	1.820
2009	0.030	0.150	0.320	0.530	1.040	1.440
2010	0.030	0.110	0.290	0.520	1.240	1.230
2011	0.040	0.130	0.270	0.480	1.230	1.160
2012	0.040	0.100	0.280	0.560	1.120	1.200
2013	0.040	0.110	0.270	1.080	2.130	2.780
2014	0.030	0.130	0.260	0.880	2.480	3.080
2015	0.030	0.140	0.280	1.500	2.470	3.340
2016	0.030	0.110	0.280	0.690	2.330	3.060

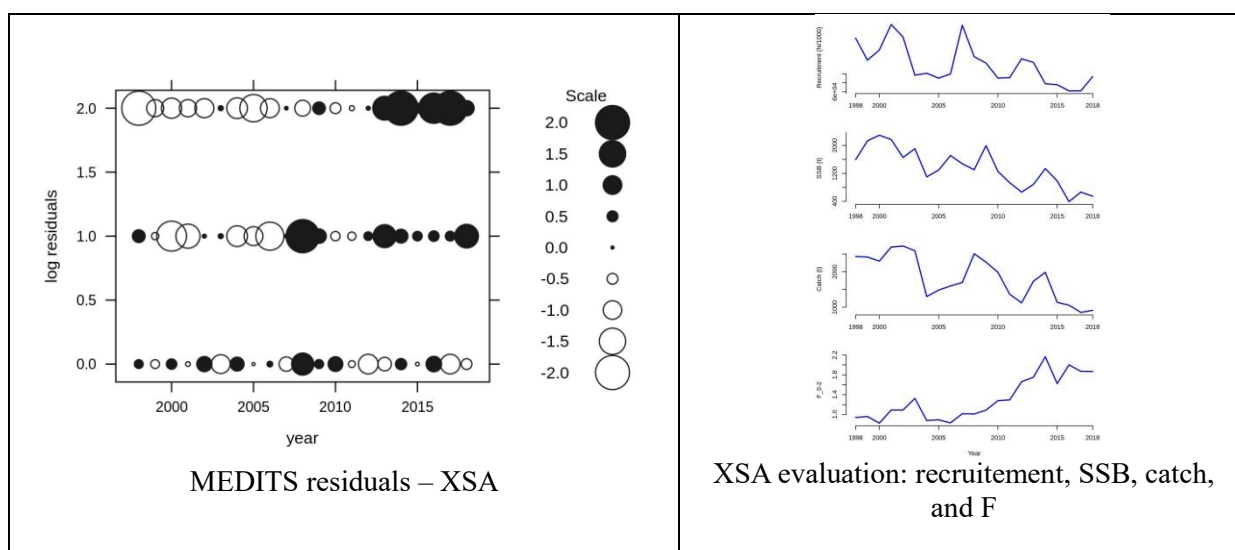
2017	0.030	0.150	0.280	0.890	2.300	3.450
2018	0.030	0.110	0.310	1.020	2.300	1.140

3.2.7.3. Method 1: XSA

A. Model assumptions

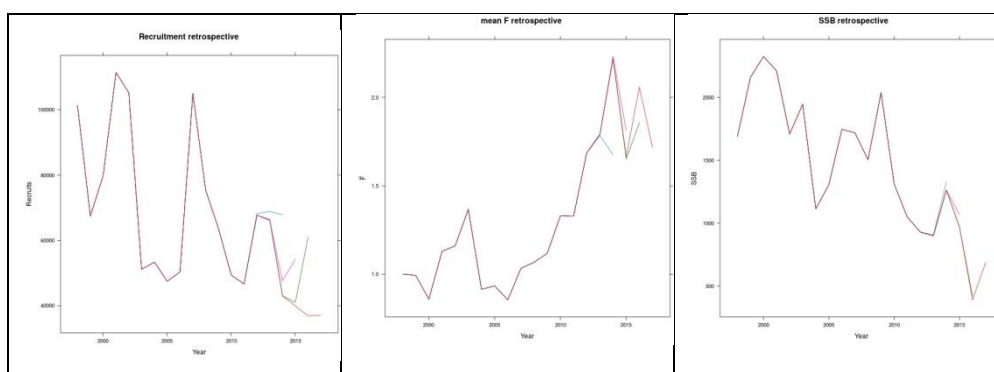
The stock assessment was performed over the period 1998–2018 using an XSA model over age classes ranging from 0 to 5+ and with MEDITS index, as tuning fleet (ages 0-2).

B. XSA results

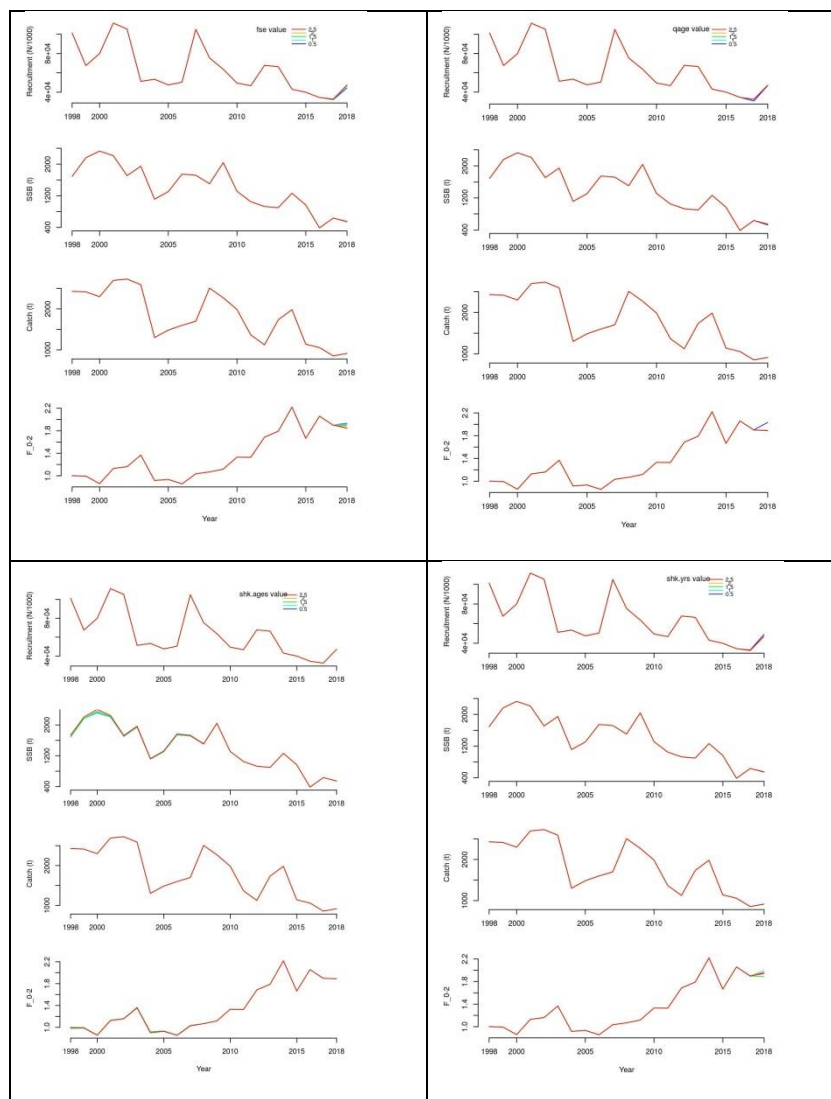


Model residuals for the assessment of GSA 7 have some patterns for the older ages with negative residuals in the older dates and positive residuals in the newer dates. These patterns persist for several alternative model configurations.

C. Retrospective analysis. comparison between model runs, sensitivity analysis



Retrospective analysis



Sensitivity analysis

3.2.7.4. Method 2: A4A

A. Model assumptions

The a4a model developed by the Joint Research Center was also used to model the stock (a4a is a statistical catch at age model whose flexibility allows to fit a wide range of models to the data).

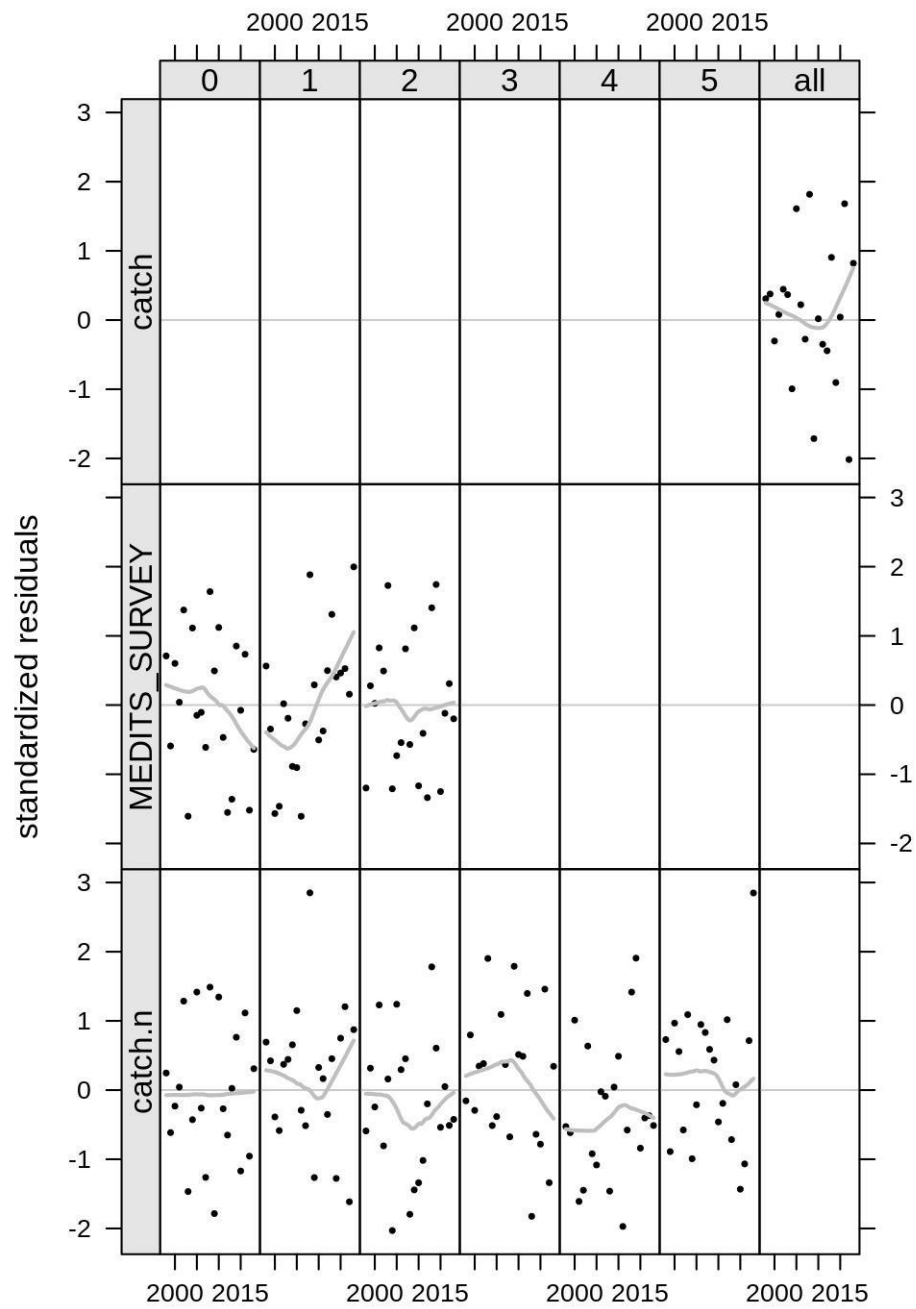
B. Input data and parameters

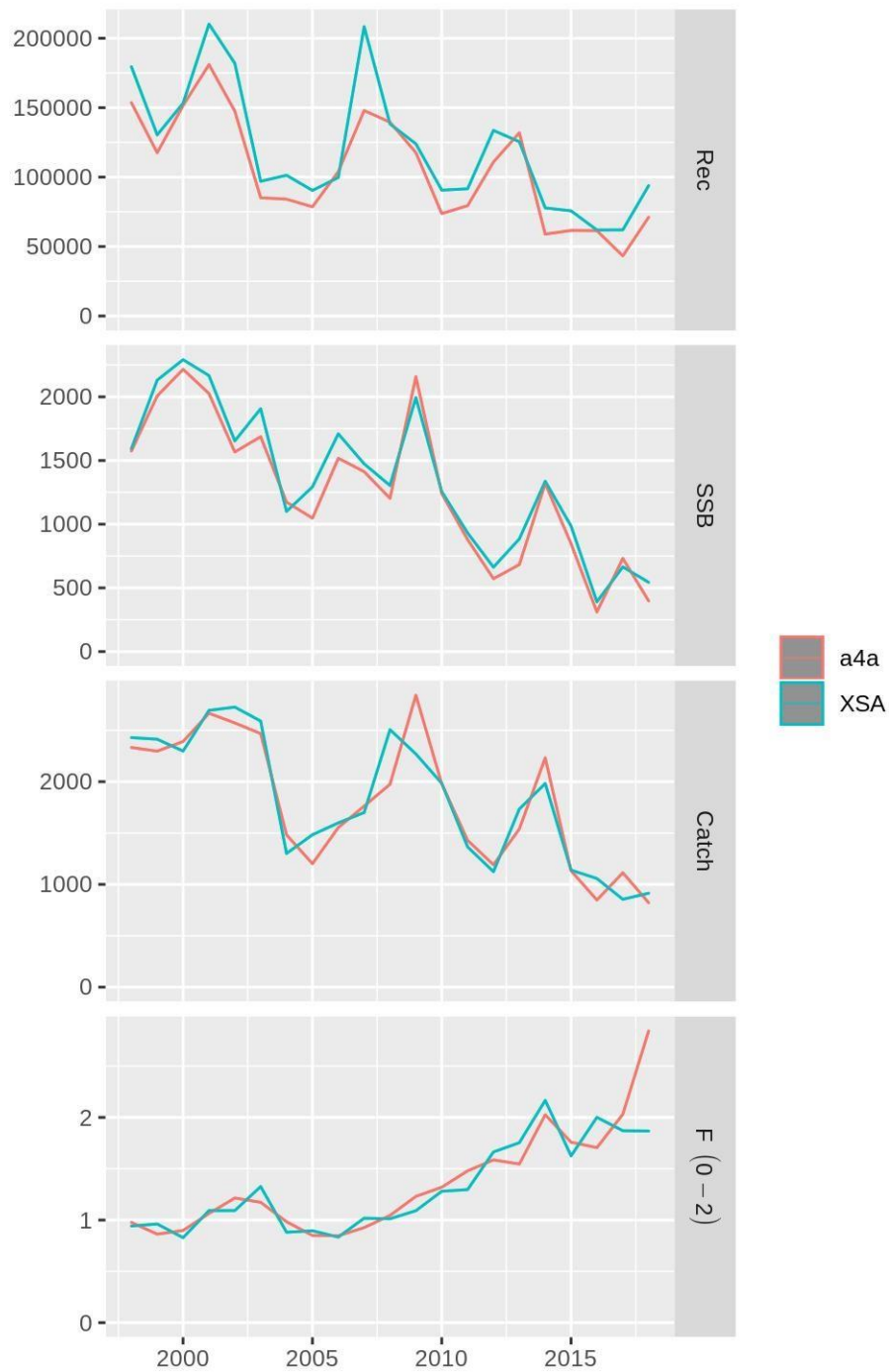
The same input data and parameters were used for the a4a and XSA methods. The a4a model is specified as follows:

```
qmod <- list(~s(age, k = 3) + s(year, k=3, by=as.numeric(age==2)))
fmod <- ~ s(year, k=10, by=breakpts(age, 0.5)) + s(age, k=4, by=breakpts(year, c(2009,2013))) + te(year, age,
k = c(3, 3))
fit <- sca(stock = hke, indices = index, fmodel = fmod, qmodel = qmod)
```

C. Results

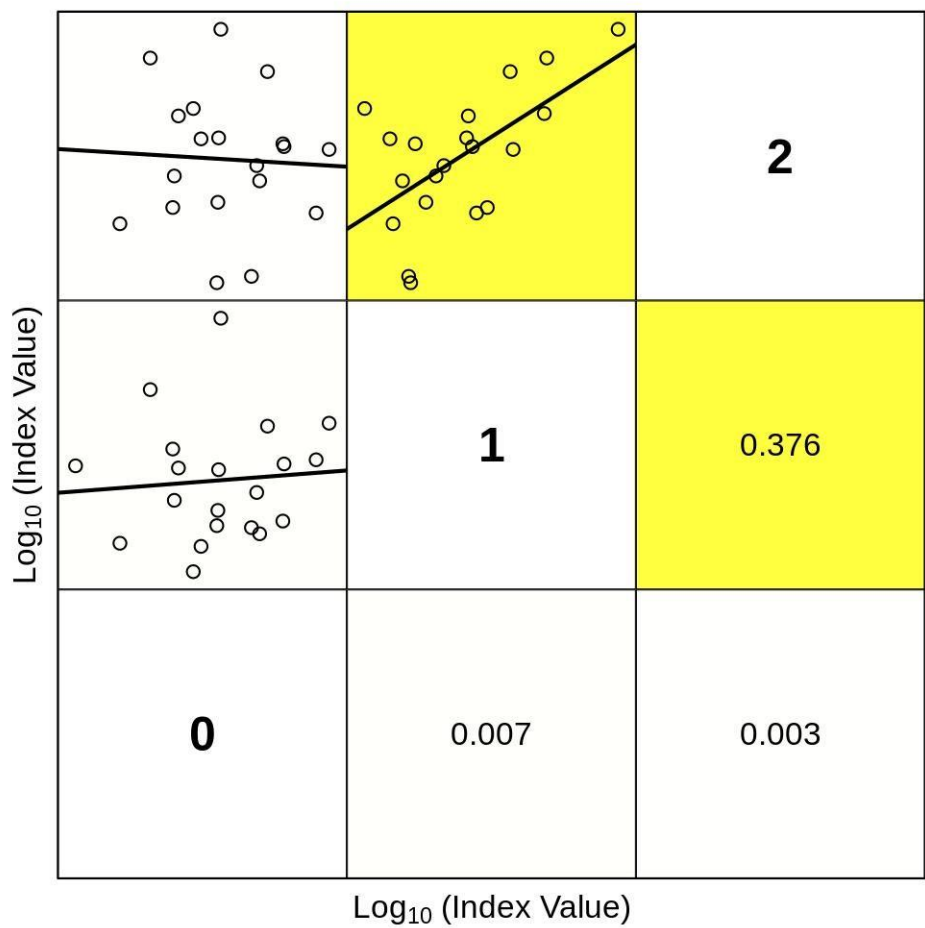
log residuals of catch and abundance indices by age





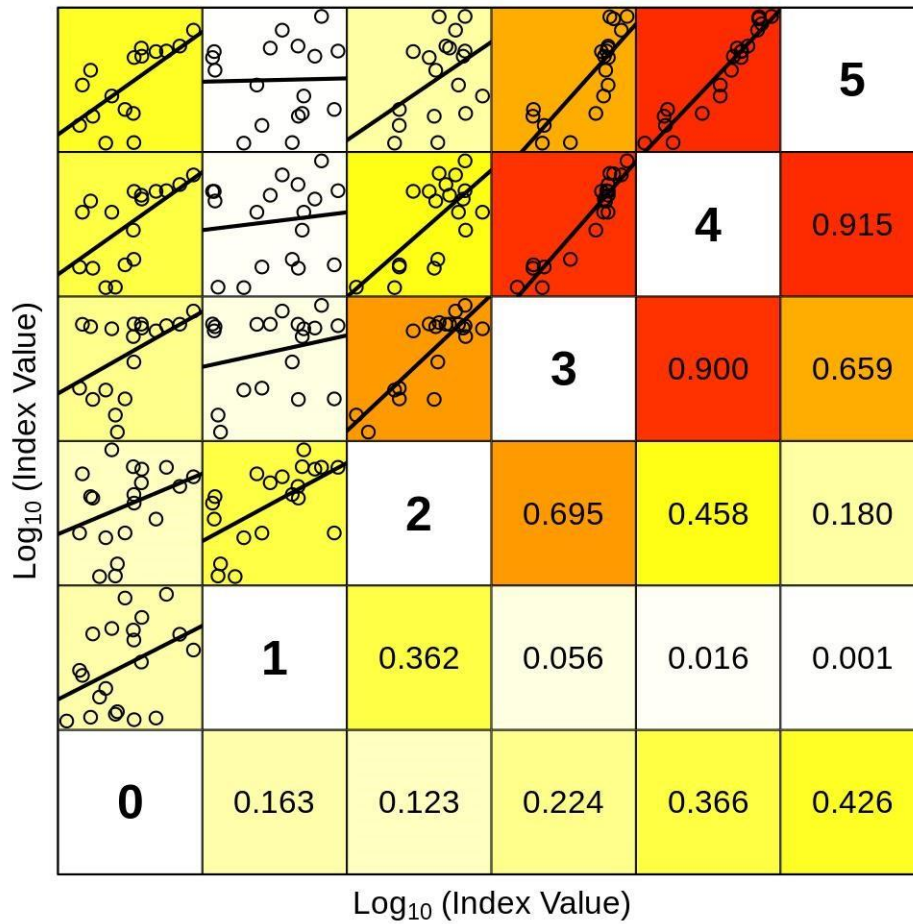
A4a and XSA assessment outputs

Cohorts consistence in the cpue

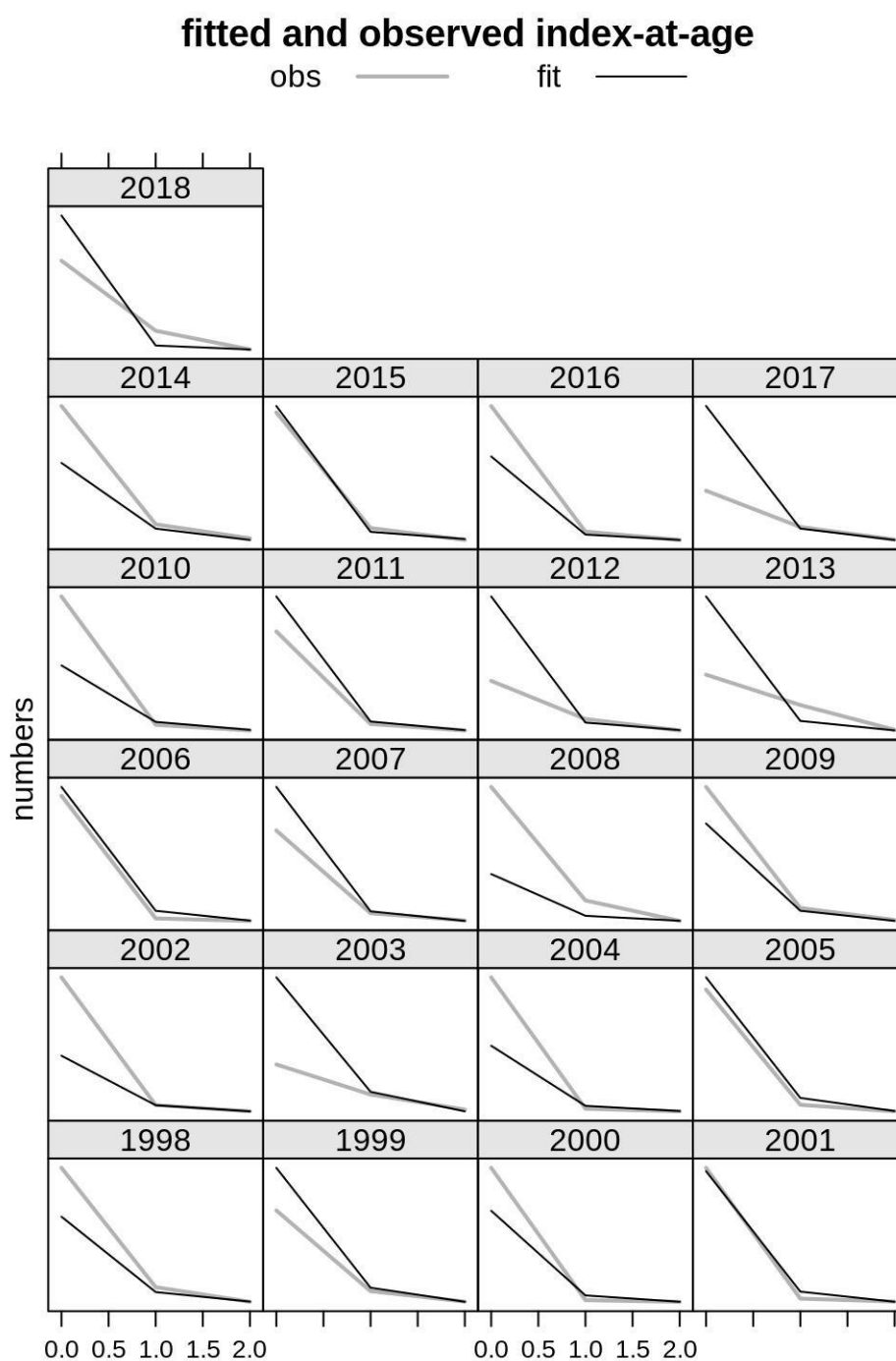


Lower right panels show the Coefficient of Determination (r^2)

Cohorts consistence in the catch



Lower right panels show the Coefficient of Determination (r^2)



Correlations of catch-at-age for GSA 7 indicate strong cohort tracking in the fishery and moderate cohort tracking in the survey.

Model residuals for the assessment of GSA 7 have a major residual pattern in which all residuals for ages 1-2 and 2012–2018 are positive. These patterns persist for several alternative model configurations and could only be resolved by allowing the survey catchability to change.

D. Retrospective analysis, comparison between model runs, sensitivity analysis

No retrospective analysis was performed.

3.2.7.5. Final advice

Model residuals for the assessment of GSA 7 have some residual pattern in which residuals for ages 1 and 2012–2018 are positive. These patterns persist for several alternative model configurations and could only be resolved by allowing survey catchability to change. Furthermore, the assessment of European hake in GSA 7 indicates an exploitation status ($F_{\text{current}}/F_{0.1}=18$) that may be unrealistic.

On the basis of the discussions, no additional advice on the status of European hake is provided for this individual GSA (see section 3.2.1 and Appendix 3).

3.2.8. Assessment unit: GSAs 8, 9, 10 and 11

In the absence of robust scientific evidence on stock boundaries, initially the present assessment of European hake considered the stock shared by GSAs 9, 10 and 11. In the view of the discussion during the benchmark meeting and the comments of the reviewers, it was decided to include GSA 8 (Corsica Island) in the stock unit for the assessment.

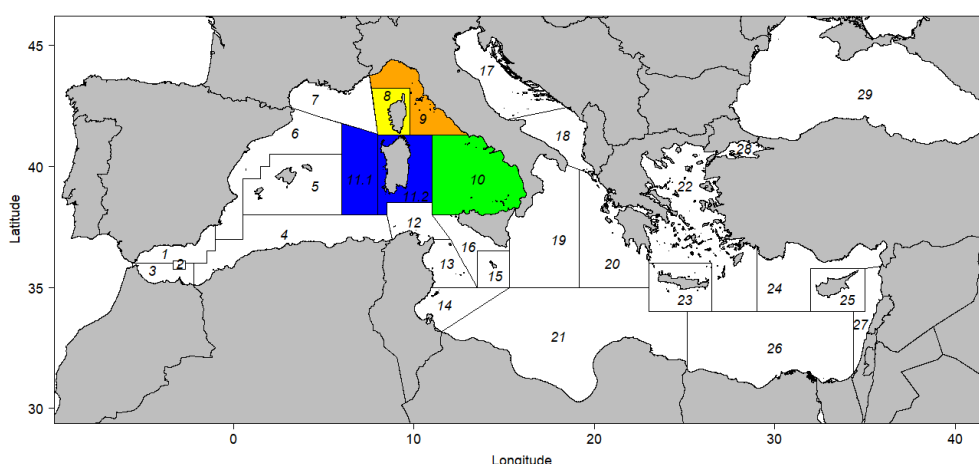


Figure 3.2.8.1. Map of the stock unit of European hake in GSAs 8, 9, 10 and 11

European hake is distributed in the whole area between 10 and 800 m depth (Biagi *et al.*, 2002; Colloca *et al.*, 2003). Recruits peak in abundance between 150 and 250 m depth over the continental shelf-break and appear to move slightly deeper when they reach 10 cm total length. Crinoid (*Leptometra phalangium*) beds over the shelf-break are the main settlement habitat for European hake in the area (Colloca *et al.*, 2004, 2009). Migration from nurseries takes place when juveniles attained a critical size between 13 and 15.5 cm TL (Bartolino *et al.*, 2008a, 2008b). Maturing hakes (15–35 cm TL) persist on the continental shelf with a preference for water of 70–100 m depth, while larger hakes can be found in a larger depth range from the shelf to the upper slope. Juveniles show a patchy distribution with some main density hot spots (i.e. nurseries areas) showing a high spatio-temporal persistence (Abella *et al.*, 2005; Colloca *et al.*, 2009) as also highlighted by the MEDISEH project in areas with frontal systems and other oceanographic structures that can enhance larval transport and retention (Abella *et al.*, 2008).

Although European hake are demersal fish feeding typically upon fast-moving pelagic preys while ambushed in the water column (Alheit and Pitcher, 1995), there is evidence that European hake feed in mid-water or at the surface during night-time, undertaking daily vertical migrations (Orsi-Relini *et al.*, 1989; Carpentieri *et al.*, 2008) which are more intense for juveniles. In GSA 9, many different studies are available on European hake diet. Results from stomach data collected in the 1996–2001 period can be found in Sartor *et al.* (2003) and Carpentieri *et al.* (2005). European hake diet shifts from euphausiids and mysids consumed by smaller hake (<16 cm TL) to fishes consumed by larger hake.

Before the transition to the complete ichthyophagous phase (TL > 36 cm), European hake show more generalized feeding habits where decapods, benthic (*Gobiidae*, *Callionymus* spp.) and nektonic fish (*Sardina pilchardus*, *Engraulis encrasicolus*) dominated the diet, whereas cephalopods had a lower incidence.

Estimation of cannibalism rate has been provided for the southern part of the GSA (Latium, EU Because project). Cannibalism increased with size and can be considered significant for hakes between 30 and 40 cm TL (up to 20 percent by weight in diet) and seems to relate closely to European hake recruitment density and level of spatial overlapping.

Consumption rate has been estimated for juveniles and piscivorous hakes. Daily consumption of juveniles, calculated in proportion of body weight (percent BW), varied between 5 (July) and 5.9 percent BW (Carpentieri *et al.*, 2008). The estimated relative daily consumption for European hake between 14 and 40 cm TL, using a bioenergetic approach (EU Because project), was between 2.9 and 2.3 percent BW.

In GSA 10, European hake ranks among the species with highest abundance indices in the trawl surveys (e.g. Spedicato and Lembo, 2011). It is a long lived fish mainly exploited by trawlers, especially on the continental shelves of the gulfs (e.g. Gaeta, Salerno, Palermo) but also by artisanal fishers using fixed gears (gillnets and bottom longlines).

Trawl-survey data have highlighted highest biomass indices on the continental shelf of the GSA 10 (100-200 m; Spedicato and Lembo, 2011), where juveniles (less than 12 cm total length) are mainly concentrated. During autumn trawl surveys, one of the main recruitment pulses of this species is observed. Two main recruitment events (in spring and autumn; Spedicato and Lembo, 2011) are reported in GSA 10 as for other Mediterranean areas. European hake is considered fully recruited to the bottom at 10 cm TL (from SAMED, 2002). The length structures from trawl surveys are generally dominated by juveniles, while large size individuals are rare. This pattern might be also due to the different vulnerability of older fish beside the effect of high exploitation rates. The few large European hake caught during trawl surveys are generally females and inhabit deeper waters. The overall sex ratio (~0.41-0.47) estimated from trawl survey data is slightly skewed towards males. The size at first maturity for females was recently estimated by Carbonara *et al.* (2019) at 33 cm, with a maturity range of 2.55 cm, and is in line with previous studies in the area (Recasens *et al.*, 2008).

In GSA 11, European hake is distributed in the whole area between 10 and 800 m depth. Recruits peak in abundance over the continental shelf-break (between 150 and 250 m depth). The stock is mainly exploited by the local fishing fleet, although seasonally and occasionally some other Italian fleets use to fish in some areas of GSA 11. Spawning is taking place almost all year round, with a peak during winter and spring.

Juveniles showed a patchy distribution with some main density hot spots (nurseries) showing a high spatio-temporal persistence (Murenu *et al.*, 2010) in western areas.

In GSA 8, European hake is distributed along the narrow shelf and slope at depths up to 1000 m, but is mainly concentrated in the depth range 0-400 m. There is no evidence that a single, homogeneous European hake stock that behaves as a single well-mixed and self-perpetuating population is inhabiting within GSA 8 boundaries. The GSA boundaries are, as for other areas, arbitrary and do not consider neither the existence of local biological features nor differences in the spatial allocation of fishing pressure within it. It is likely some connectivity exists as larval drifts, movements of individuals and sharing of spawning areas, in particular with GSA 9, 10 and 11.

3.2.8.1. Method 1: a4a

A statistical catch-at-age assessment was carried out for this stock, using the assessment for all initiative (a4a) method (Jardim *et al.*, 2015). The a4a method utilizes catch-at-age data to derive estimates of historical population size and fishing mortality. Model parameters estimated using catch-at-age analysis are done so by working forward in time and analyses do not require the assumption that removals from the fishery are known without error.

A. Model assumptions

The assessment was carried out using the period 2005–2018 for catch data and tuning file. Both catch numbers at length and index number at length were sliced using the a4a age slicing routine in FLR, using for each GSA the selected growth parameters by sex. The analyses were carried out for the ages 0 to 7+. Concerning the Fbar, the age range used was 1-3 age groups.

B. Input data and parameters

European hake is one of the main target species in terms of landings, incomes and vessel involved in the area. In GSAs 9 and 10, it is mainly exploited by trawlers on the shelf and slope, but also by small-scale fisheries using set nets (gillnets and trammel nets) and bottom longlines. In GSA 11, although European hake is not the target of a specific fishery, it is one of the most important species in terms of biomass landed. It is caught exclusively by a mixed bottom trawl fishery that operates at depth between 50 and 800 m. No gillnet or longline fleets target this species, but it can be found as bycatch of gillnet fleets targeting other species.

In Corsica (GSA 8), six trawlers are active and their average length is 15 m. These ships operate with OTB and are targeting demersal species (Norway lobster, striped red mullet, deep-water rose shrimp, etc.) including some very few catches of European hake (average 8.2 tonnes per year on the period 2015–2017). Even though small-scale fisheries are quite important along the coasts, fishers target other resources such as lobster and spiny lobster, finfish living on hard bottoms (e.g. sparids, scorpenids, etc.). There are no available data for the size structure of the landings of European hake, since it is not a target species of trawlers and it is mainly absent from other types of gear catches (very few catches from gillnetters). Moreover, it is important to notice that trawlers can only work on the eastern part of Corsica since the western part is characterized by a very narrow continental shelf and steep slopes.

Landings data were reported to the benchmark meeting through the official EU DCF data provided by Italy. In GSAs 9, 10 and 11, most of the landings come from otter trawls. The contribution of set nets to the total landings is around the 35 percent in GSAs 9 and 10, longlines in GSA 10 contribute for around the 17 percent to the total landings. In GSA 11, landings data come exclusively from the bottom trawl fishery. In GSA 8, catch data, proceeding from the limited number of trawlers cover only the period 2009–2018. Landings are very low in all the years where data are available and the discards are not included in the catch because no information is available. Reconstructed data were estimated from 2005 to 2008, considering an average of the available information.

Landings and discards by GSA, total landings and discards, and total catches used in the assessment are shown in Table 3.2.8.1.

In addition, discards were not available in GSAs 9, 10 and 11 for some years, therefore they were estimated using an average proportion between landings and discards computed on the available years. The estimated values of discards are highlighted in red in Table 3.2.8.1.

Table 3.2.8.1. Landings and discards data for European hake in GSAs 8, 9, 10 and 11 (values highlighted in red were missing and re-estimated from adjacent years)

	GSA 9		GSA 11		GSA 10		GSA 8	Total		
Year	Landings	Discards	Landings	Discards	Landings	Discards	Landings	Landings	Discards	Total catches
2005	1 859.98	348.30	397.39	158.59	1 484.74	66.70	15.00	3 757.11	573.59	4 330.70
2006	2 176.49	105.20	341.06	595.48	1 544.07	26.57	15.00	4 076.63	727.26	4 803.88
2007	1 733.03	338.74	169.58	106.57	1 268.66	69.84	15.00	3 186.28	515.14	3 701.42
2008	1 321.13	302.32	138.77	87.20	1 122.85	54.57	15.00	2 597.74	444.09	3 041.83
2009	1 308.47	697.27	260.54	106.87	1 090.51	99.78	15.10	2 674.61	903.92	3 578.53
2010	1 467.11	116.41	175.88	164.79	1 329.45	68.06	11.97	2 984.41	349.27	3 333.67
2011	1 351.74	527.79	277.42	268.67	1 278.52	54.93	13.24	2 920.92	851.39	3 772.31
2012	1 011.52	174.23	176.05	16.72	1 107.24	117.90	13.01	2 307.83	308.85	2 616.68
2013	1 341.63	242.43	195.79	32.27	1 052.19	35.63	3.52	2 593.13	310.33	2 903.46
2014	1 264.95	285.84	44.96	24.51	1 271.11	17.00	12.61	2 593.63	327.36	2 920.99
2015	1 047.70	231.04	220.04	102.85	1 043.44	29.71	12.19	2 323.36	363.60	2 686.96
2016	782.25	305.13	339.15	102.29	1 051.95	28.38	39.85	2 213.19	435.79	2 648.98
2017	572.37	75.68	356.52	212.34	870.43	3.18	14.60	1 813.92	291.21	2 105.12
2018	605.35	114.35	391.98	166.70	819.86	0.18	21.09	1 838.28	281.22	2 119.50

Historical landings from 1972 up to the introduction of EU data collection in 2002 were gathered from Italian official fisheries statistics. These data show a decreasing trend starting from mid 1970s, reaching a minimum at the beginning of 2000s. Then, suddenly, they showed a sharp increase when the EU data collection started.

This pattern is considered unreliable, as it cannot be explained with any fishing capacity or activity change, and it will deserve further investigation and analysis in the possible view of incorporating it into stock assessment.

For this reason, it was agreed to start the assessment from 2005, given that all GSAs were then covered by the available DCF data.

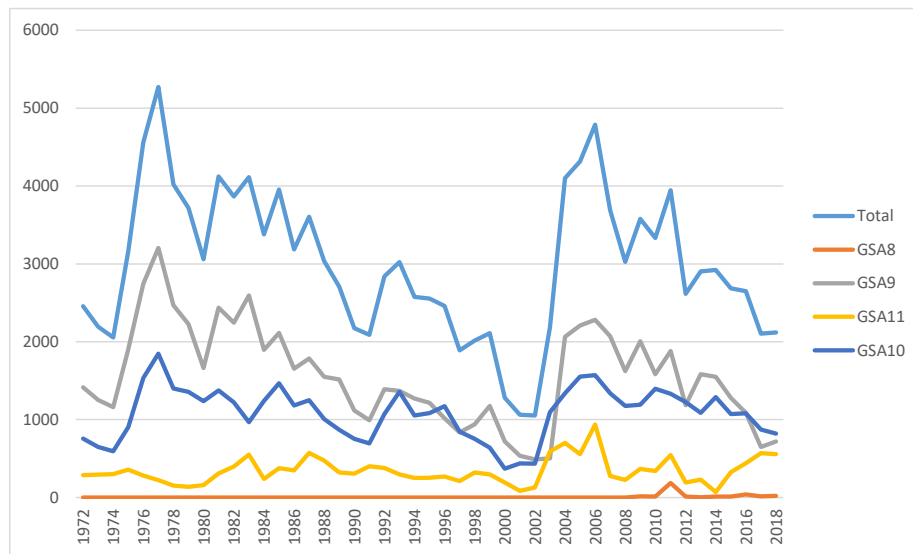


Figure 3.2.8.2. Historical landings of European hake in GSAs 8, 9, 10 and 11

Landings and discards data by year and fishing gear/metier are presented in Figures 3.2.8.3 to 3.2.8.8, while length-frequency distributions of landings and discards by GSA, year and fishing gear are shown in Figures 3.2.8.9 to 3.2.8.14.

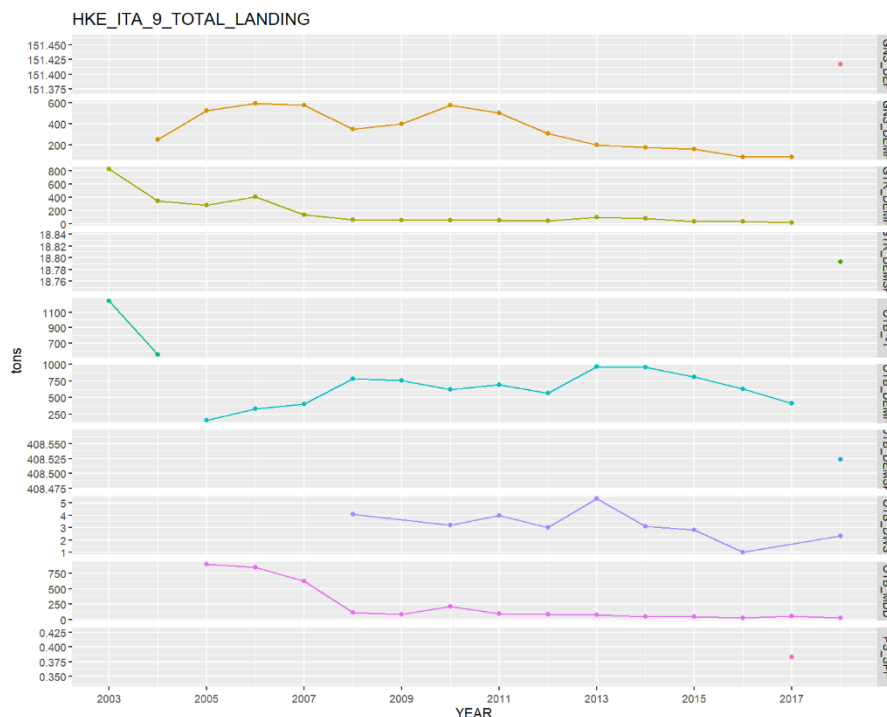


Figure 3.2.8.3. Landings by year and metier for European hake in GSA 9

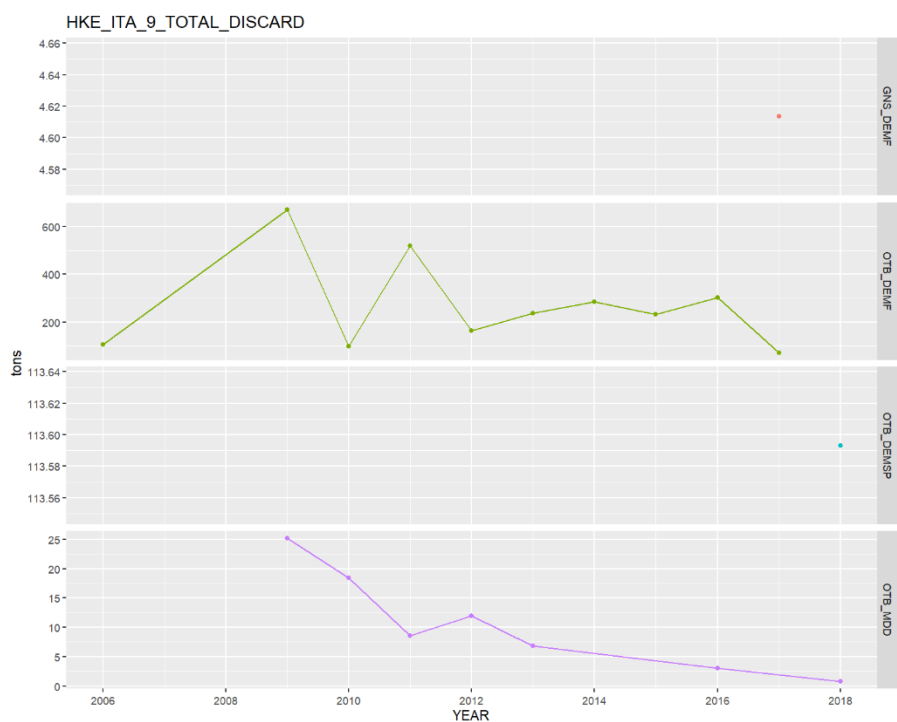


Figure 3.2.8.4. Discards by year and metier for European hake in GSA 9

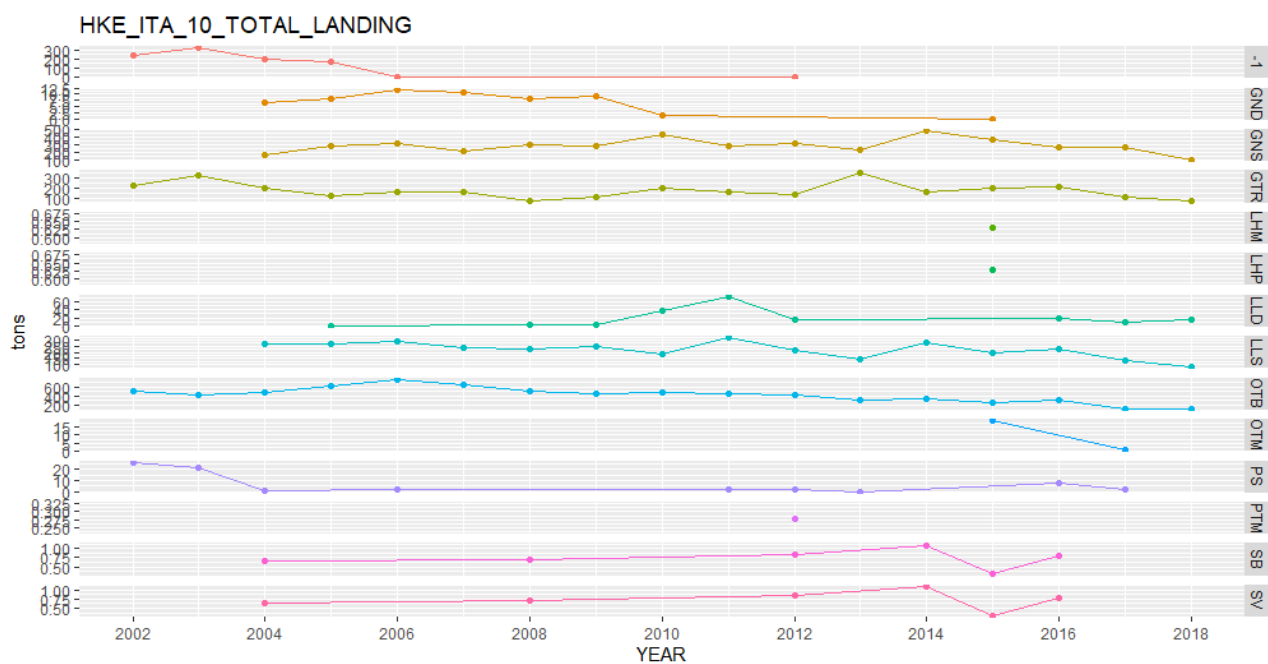


Figure 3.2.8.5. Landings by year and gear for European hake in GSA 10

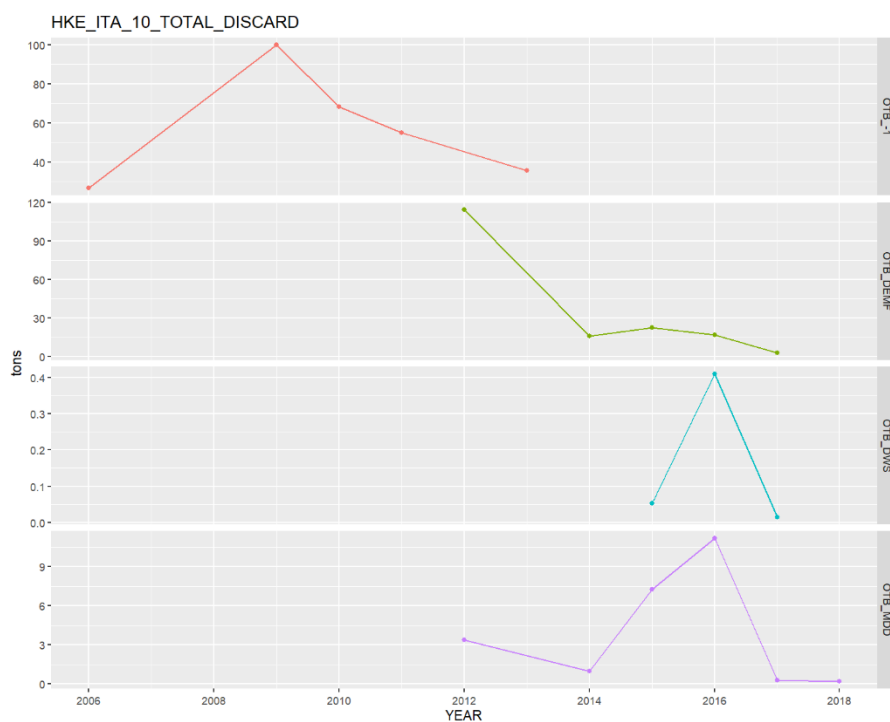


Figure 3.2.8.6. Discards by year and metier for European hake in GSA 10

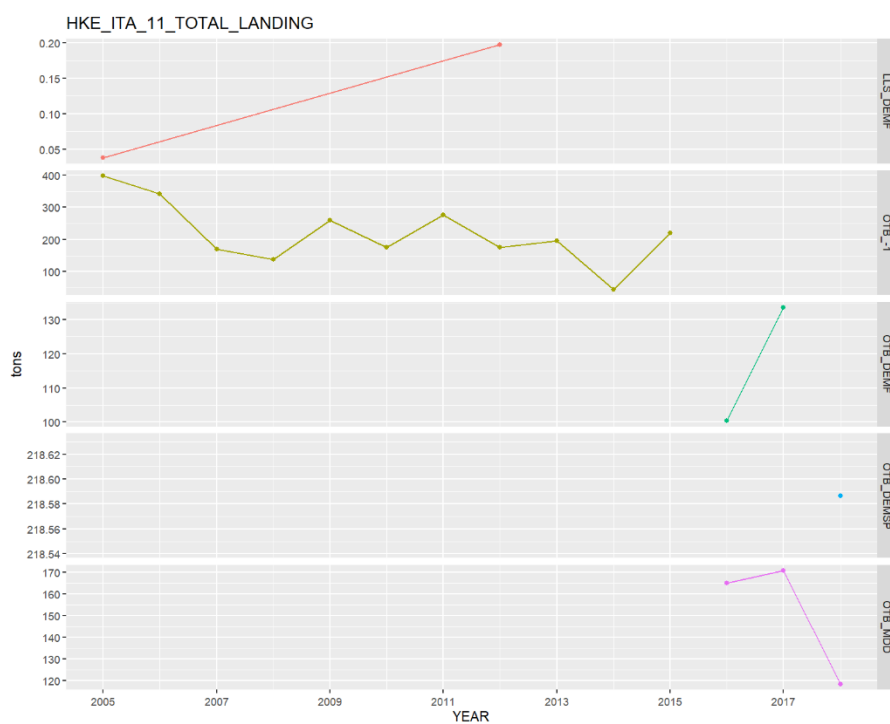


Figure 3.2.8.7. Landings by year and metier for European hake in GSA 11

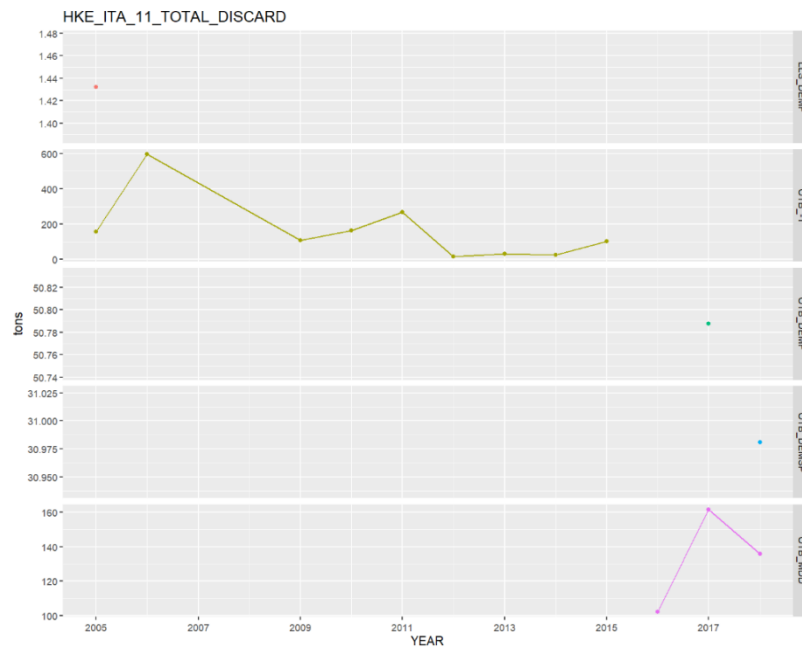


Figure 3.2.8.8. Discards by year and metier for European hake in GSA 11

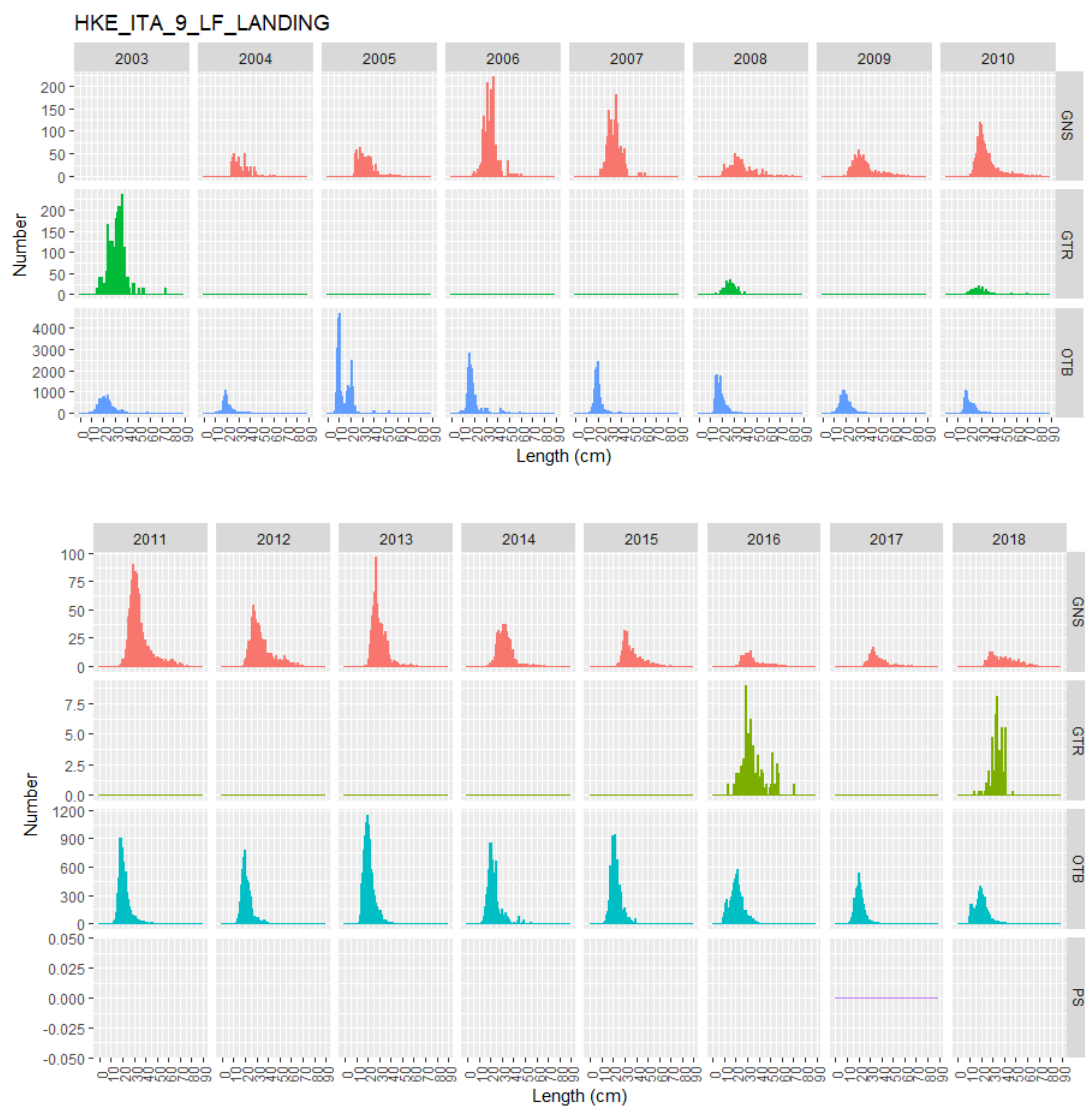


Figure 3.2.8.9. Landing LFDs by year and gear for European hake in GSA 9



Figure 3.2.8.10. Landing LFDs by year and gear for European hake in in GSA 10

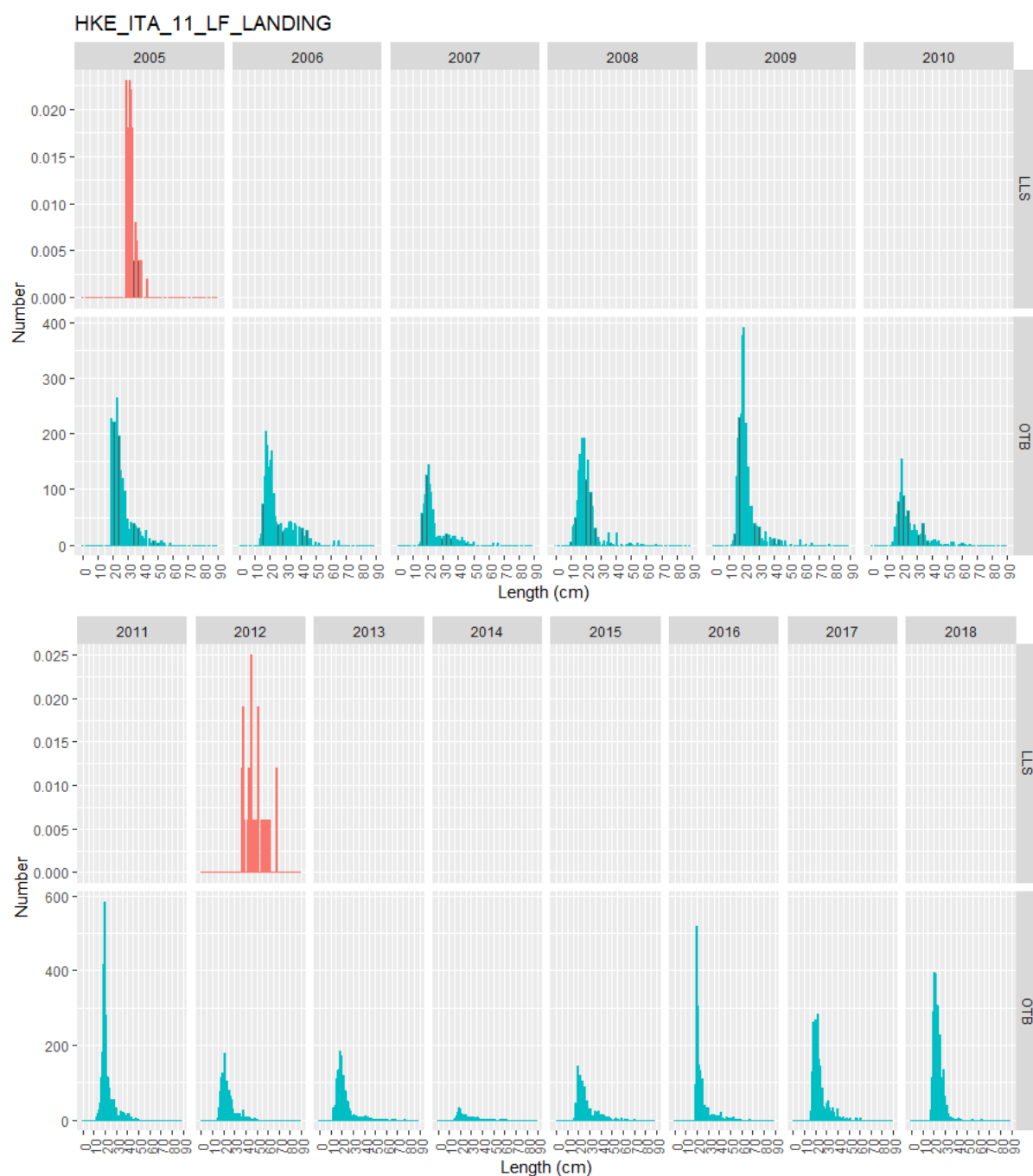


Figure 3.2.8.11. Landing LFDs by year and gear for European hake in GSA 11

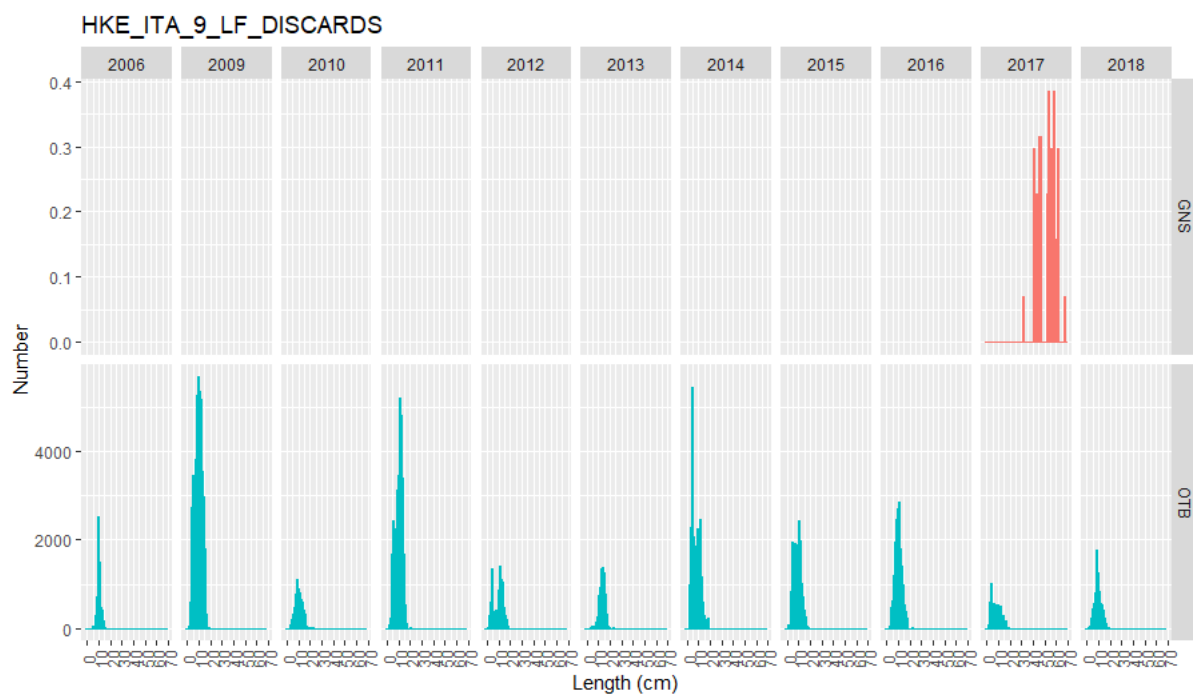


Figure 3.2.8.12. Discard LFDs by year and gear for European hake in GSA 9

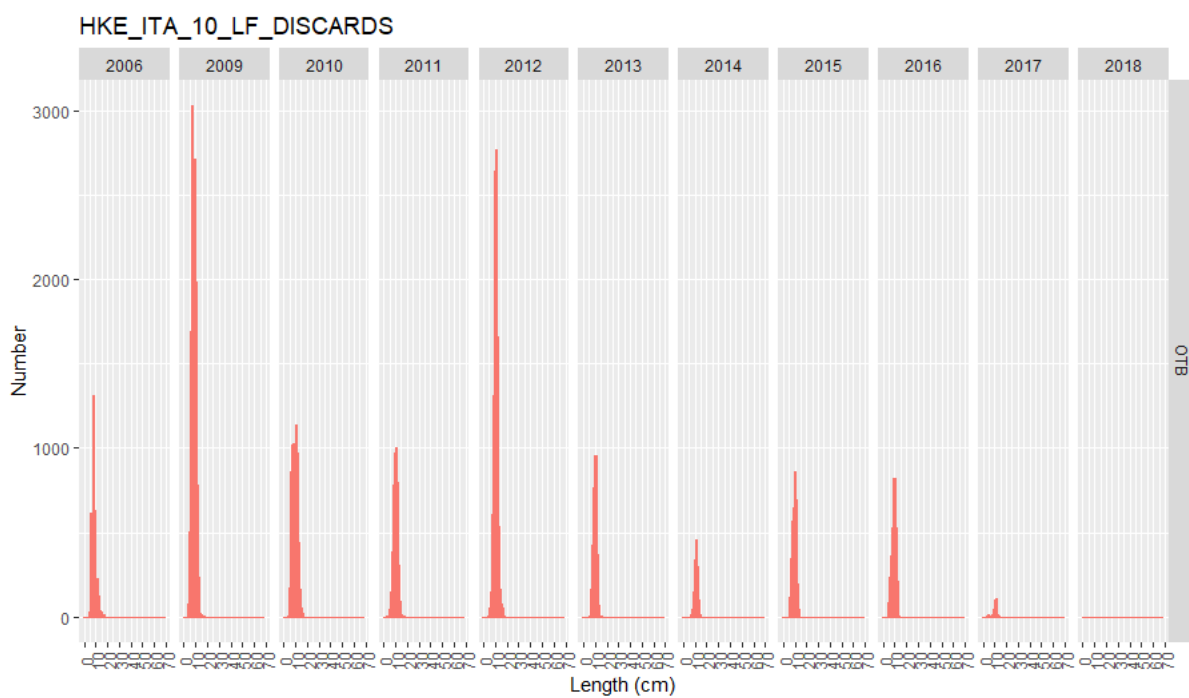


Figure 3.2.8.13. Discard LFDs by year and gear for European hake in GSA 10

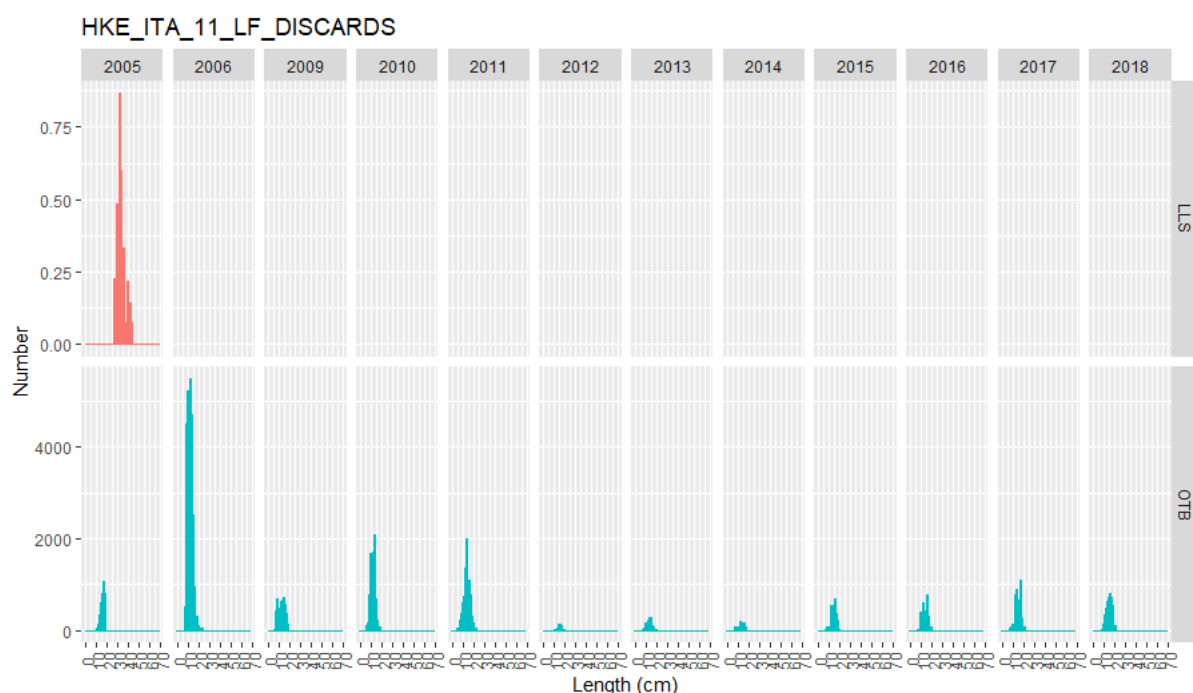


Figure 3.2.8.14. Discard LFDs by year and gear for European hake in GSA 11

As concerns biological parameters, several sets of VBGF parameters are available in the investigated area from both scientific studies and the collection of biological data under EU DCR/DCF.

In a recent assessment performed by STECF (STECF, 2019), two different sets of growth parameters were used for GSA 10 and GSAs 9 and 11 (Table 3.2.2.2). During the preparatory work in the view of the benchmark meeting, different approaches were used to estimate new growth parameters combining the information available in GSAs 9, 10 and 11.

Starting from the LFDs from MEDITS surveys (1994–2018), two sets of VBGF parameters were estimated by sex using the routine Elefan available in the software package FiSAT II.

Taking advantage of the age-length data collected under EU DCR/DCF, two sets of VBGF parameters were computed by sex using the package FSA available in R (Ogle, 2016). In order to obtain an estimate of t_0 close to 0, data of age and length of juveniles coming from studies on otolith daily rings (Belcari *et al.*, 2006; Ligas *et al.*, 2015) were added to the data sets.

Table 3.2.8.2. VBGF parameters available in the investigated area

GSAs	Sex	L_{∞}	k	t_0	Source	Notes
9, 11	M	54.78	0.22	-0.3	Otolith reading	STECF EWG 19-10
	F	87.18	0.15	-0.27	Otolith reading	STECF EWG 19-10
10	M	73.00	0.13	-0.82	Otolith reading	STECF EWG 19-10
	F	111.00	0.1	-0.59	Otolith reading	STECF EWG 19-10
9, 10, 11	M	73.00	0.23	-0.05	MEDITS LFDs fitting	Benchmark data preparation
	F	100.00	0.18	-0.05	MEDITS LFDs fitting	Benchmark data preparation
9, 10, 11	M	60.00	0.265	-0.06	Otolith reading	Benchmark data preparation
	F	95.00	0.16	-0.06	Otolith reading	Benchmark data preparation

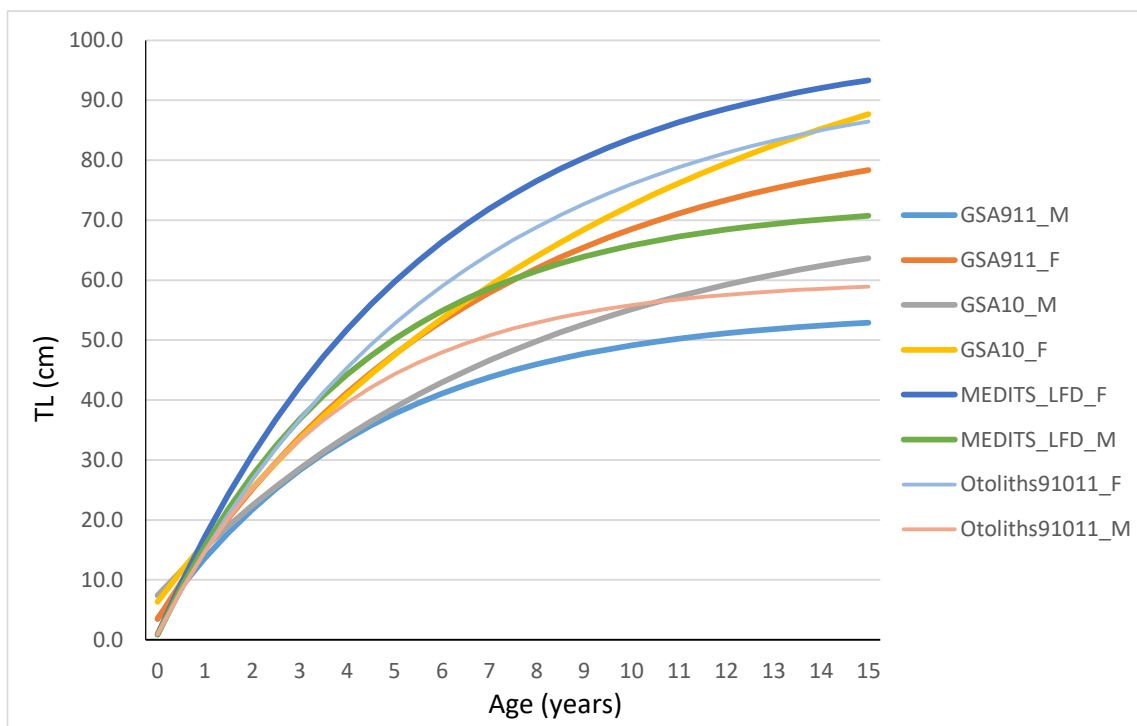


Figure 3.2.8.15. Available VBGF curves

Following the discussion with the local experts during the preparatory work and with the experts and reviewers at the benchmark meeting, it was decided to use the sets of VBGF parameters by sex calculated using otoliths data (including juveniles) to perform the deterministic age slicing to convert LFDs from landings, discards and survey into age distributions, as well as to estimate mean-weights-at-age, natural mortality and proportion of matures-at-age.

Length-weight relationship parameters were estimated by sex as the average of those available in GSAs 9, 10 and 11 under EU DCR/DCF (Table 3.2.2.3). No biological data are available for European hake in GSA 8.

Table 3.2.8.3. Length-weight relationship parameters used in the assessment

GSAs	Sex	a	b
9, 10, 11	M	0.004645	3.133
	F	0.005009	3.107705

Using the selected VBGF parameters, a combined vector of proportion of matures-at-age was estimated starting from the vectors of maturity-at-length available under the EU DCR/DCF. The maturity vector used for the benchmark assessment is shown in Table 3.2.2.4.

Table 3.2.8.4. Proportion of matures by age used in the assessment

Age	0	1	2	3	4	5	6	7+
Mat-at-age	0.00	0.25	0.80	1.00	1.00	1.00	1.00	1.00

The selected VBGF and LW relationship parameters were used to estimate a range of natural mortality (M) vectors using different models and empirical formulas, as agreed during the benchmark meeting. The vectors for males and females are shown in Tables 3.2.2.5 and 3.2.2.6. The combined M vector used in the benchmark assessment is shown in Table 3.2.8.5.

The updated version of the PRODBIOM method (Abella *et al.*, 1998) provided by Martiradonna (2012) was used.

Table 3.2.8.5. Natural mortality vectors (from age 0 to age 20) estimated with different models, and average M vector for females

Gislason et al., 2010	Abella et al., 1998	Chen & Watanabe, 1989	Brodziak et al., 2011	Brodziak et al., 2012	Gulland, 1987	Lorenz 1996	Mean
3.72	1.42	1.87	0.56	0.45	2.85	1.52	1.77
1.40	0.58	0.72	0.31	0.24	1.10	0.88	0.75
0.71	0.33	0.48	0.20	0.16	0.57	0.60	0.44
0.48	0.28	0.37	0.16	0.13	0.39	0.48	0.33
0.36	0.26	0.31	0.13	0.11	0.29	0.41	0.27
0.29	0.21	0.27	0.12	0.09	0.24	0.37	0.23
0.25	0.19	0.18	0.10	0.08	0.20	0.34	0.19
0.22	0.18	0.18	0.10	0.08	0.19	0.32	0.18
0.20	0.17	0.18	0.09	0.07	0.17	0.30	0.17
0.18	0.16	0.18	0.09	0.07	0.15	0.28	0.16
0.18	0.16	0.17	0.08	0.07	0.15	0.28	0.15
0.17	0.16	0.17	0.08	0.07	0.14	0.27	0.15
0.16	0.16	0.17	0.08	0.06	0.14	0.26	0.15
0.16	0.16	0.17	0.08	0.06	0.13	0.26	0.15
0.15	0.16	0.17	0.08	0.06	0.13	0.25	0.14
0.14	0.16	0.17	0.08	0.06	0.12	0.25	0.14
0.14	0.16	0.17	0.07	0.06	0.12	0.24	0.14
0.13	0.16	0.17	0.07	0.06	0.11	0.24	0.13
0.13	0.16	0.17	0.07	0.06	0.11	0.23	0.13
0.13	0.16	0.17	0.07	0.06	0.11	0.23	0.13
0.12	0.16	0.17	0.07	0.05	0.10	0.23	0.13

Table 3.2.8.6. Natural mortality vectors (from age 0 to Aae 15) estimated with different models, and average M vector for males

Gislason et al., 2010	Abella et al., 1998	Chen & Watanabe, 1989	Brodziak et al., 2011	Brodziak et al., 2011	Gulland, 1987	Lorenz 1996	Mean
3.18	1.47	1.92	0.73	0.64	4.08	1.52	1.93
1.27	0.58	0.78	0.41	0.36	1.69	0.91	0.86
0.70	0.34	0.54	0.29	0.25	0.95	0.66	0.53
0.50	0.24	0.43	0.23	0.20	0.68	0.54	0.41
0.39	0.22	0.38	0.20	0.18	0.54	0.48	0.34
0.35	0.20	0.34	0.19	0.16	0.49	0.45	0.31
0.31	0.19	0.29	0.17	0.15	0.43	0.42	0.28
0.29	0.18	0.29	0.17	0.15	0.40	0.40	0.27
0.27	0.18	0.29	0.16	0.14	0.38	0.39	0.26
0.27	0.18	0.28	0.16	0.14	0.38	0.39	0.26
0.26	0.18	0.28	0.15	0.14	0.36	0.38	0.25
0.26	0.18	0.28	0.15	0.14	0.36	0.38	0.25
0.24	0.18	0.27	0.15	0.13	0.34	0.36	0.24
0.23	0.18	0.27	0.14	0.13	0.32	0.35	0.23
0.22	0.18	0.27	0.14	0.12	0.31	0.34	0.23
0.21	0.18	0.27	0.13	0.12	0.29	0.33	0.22

Table 3.2.8.7. Natural mortality vector combined by sex used in the benchmark assessment

Age	0	1	2	3	4	5	6	7+
M	1.85	0.80	0.48	0.37	0.30	0.27	0.24	0.22

The MEDITS survey has been carried in GSAs 8, 9, 10 and 11 since 1994. Since 1994, MEDITS trawl surveys have been regularly carried out each year (centred in the early summer). A random stratified sampling by depth (five strata with depth limits at 50, 100, 200, 500 and 800 m) is applied. Haul allocation was proportional to the stratum area. All the abundance data (number and total weight of fish per surface unit) are standardized to the km² using the swept area method.

Length distributions represented an aggregation (sum) of all standardized length frequencies (subsamples raised to standardized haul abundance per hour) over the stations of each stratum. Aggregated length frequencies were then raised to stratum abundance and finally aggregated (sum) over the strata to the four GSAs.

French contribution to the internationally coordinated MEDITS survey in Corsica (GSA 8) is represented by about one week of operations occurring in the second quarter every year since 1994 (excluding 2002 due to

vessel technical problems). A GOV bottom trawl with short wings is used. On average, 23 hauls are carried out. MEDITS provides a representative picture of the 4 562 km² of Eastern Corsica shelf.

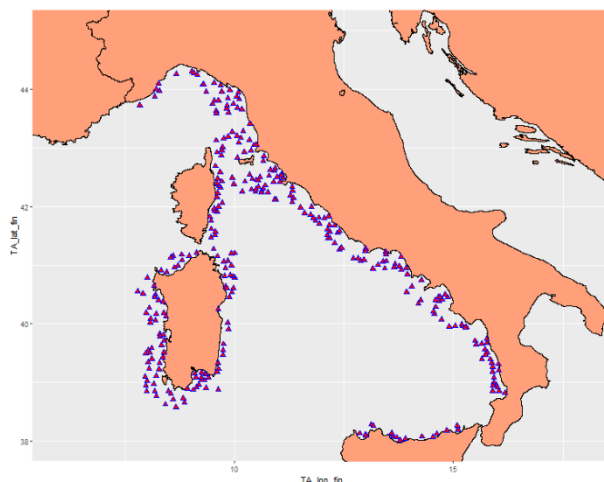


Figure 3.2.8.16. Distribution of sampling stations in MEDITS 2018 for European hake in GSAs 8, 9, 10 and 11

The following maps show the biomass indices (kg/km²) by haul of some years of the MEDITS surveys. It is evident that the highest biomass indices of European hake are found around the coasts of Sardinia (GSA 11). In terms of density (N/km²), the highest values are found along the coasts of GSA 9 and in the southwestern part of GSA 11. Those areas are characterized by high densities of juveniles, representing the most important nursery areas.

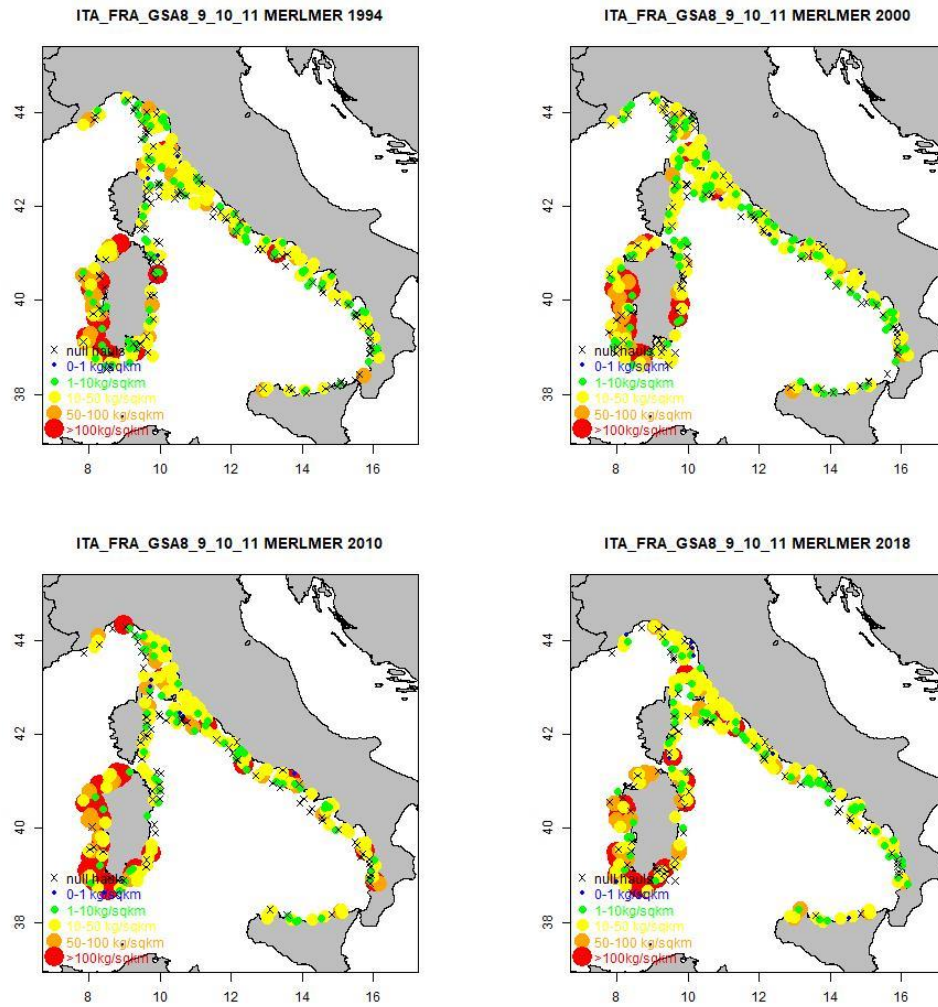


Figure 3.2.8.17. MEDITS biomass indices (kg/km²) by haul in 1994, 2000, 2010, and 2018 for European hake in GSAs 8, 9, 10 and 11

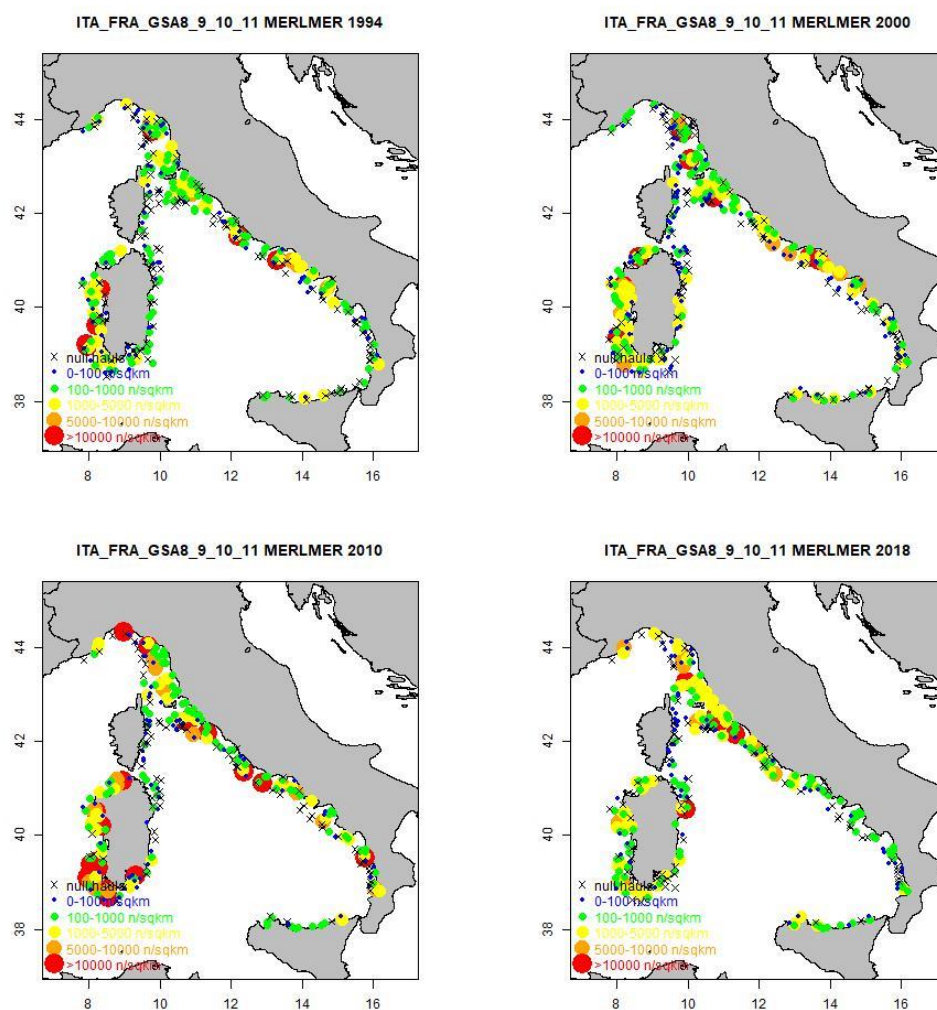


Figure 3.2.8.18. MEDITS density indices (N/km²) by haul in 1994, 2000, 2010, and 2018 for European hake in GSAs 8, 9, 10 and 11

The trends of the MEDITS indices (biomass and density) computed on the four GSAs combined are shown in Figures 3.2.8.29-3.2.8.21.

The time series are characterized by wide fluctuations, though a general decreasing trend can be observed. The biomass and density indices obtained from 2014 onwards are among the lowest observed in the whole time series of the MEDITS data in GSAs 8, 9, 10 and 11.

The stratified abundance indices by length (total and by sex) computed on the four GSAs combined during the MEDITS surveys from 1994 to 2018 are shown in Figures 3.2.8.22 – 3.2.8.24. These plots show that the densities observed from 2011 onwards are among the lowest observed in the whole time series of the MEDITS survey in the GSAs 8, 9, 10 and 11.

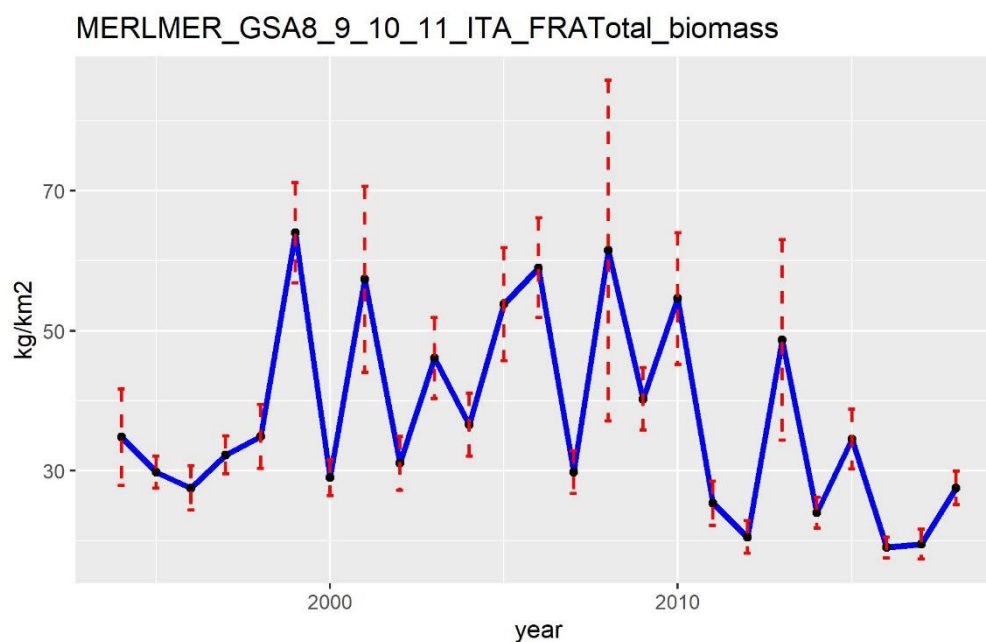


Figure 3.2.8.19. Historical trend of the MEDITS biomass index (kg/km²) for European hake estimated on GSAs 8, 9, 10 and 11 combined

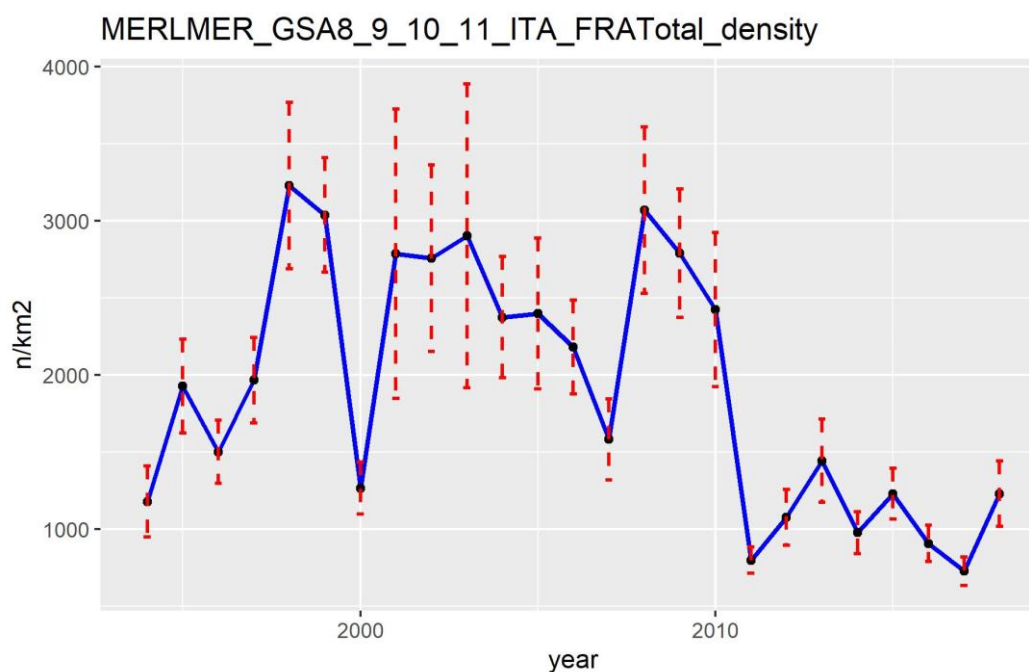


Figure 3.2.8.20. Historical trend of the MEDITS density index (N/km²) for European hake estimated on GSAs 8, 9, 10 and 11 combined

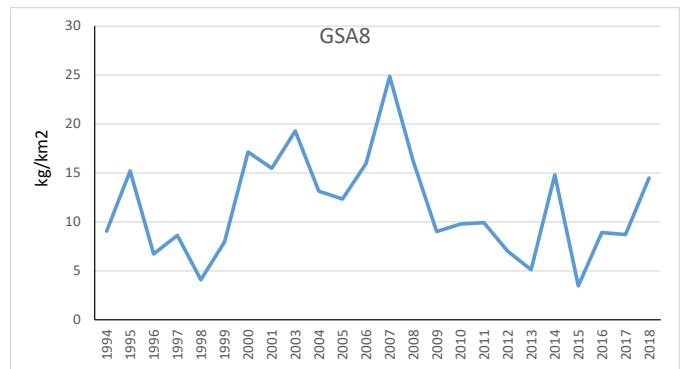
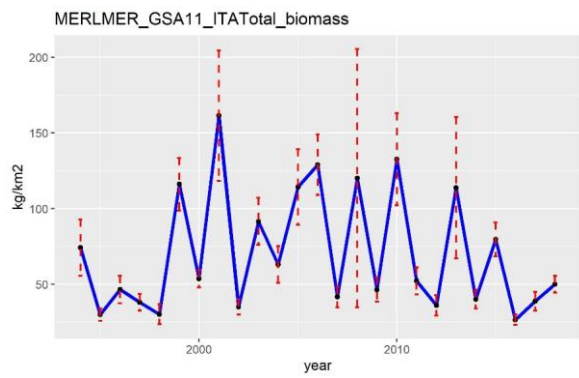
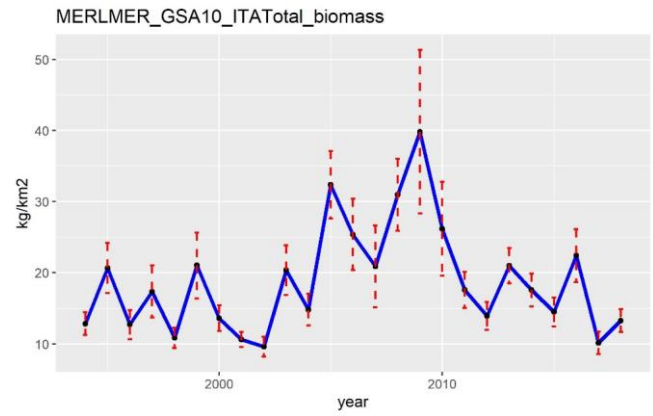
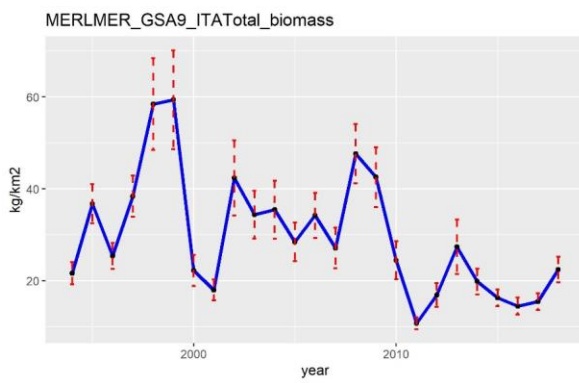


Figure 3.2.8.21. Historical trend of the MEDITS biomass index (kg/km^2) for European hake in GSAs 8, 9, 10 and 11

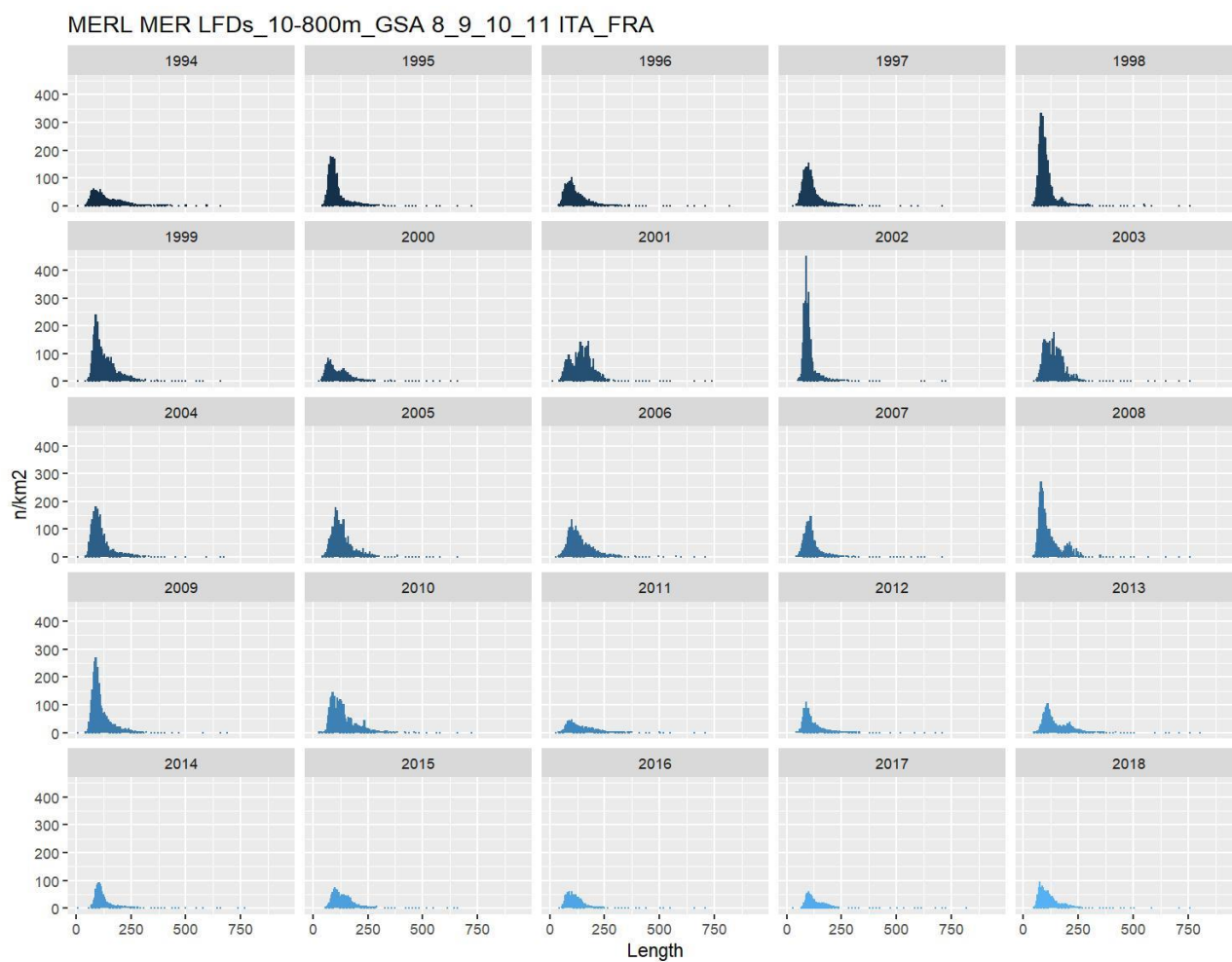


Figure 3.2.8.22. Total length-frequency distributions (N/km^2) of the MEDITS survey for European hake in GSAs 8, 9, 10 and 11 combined

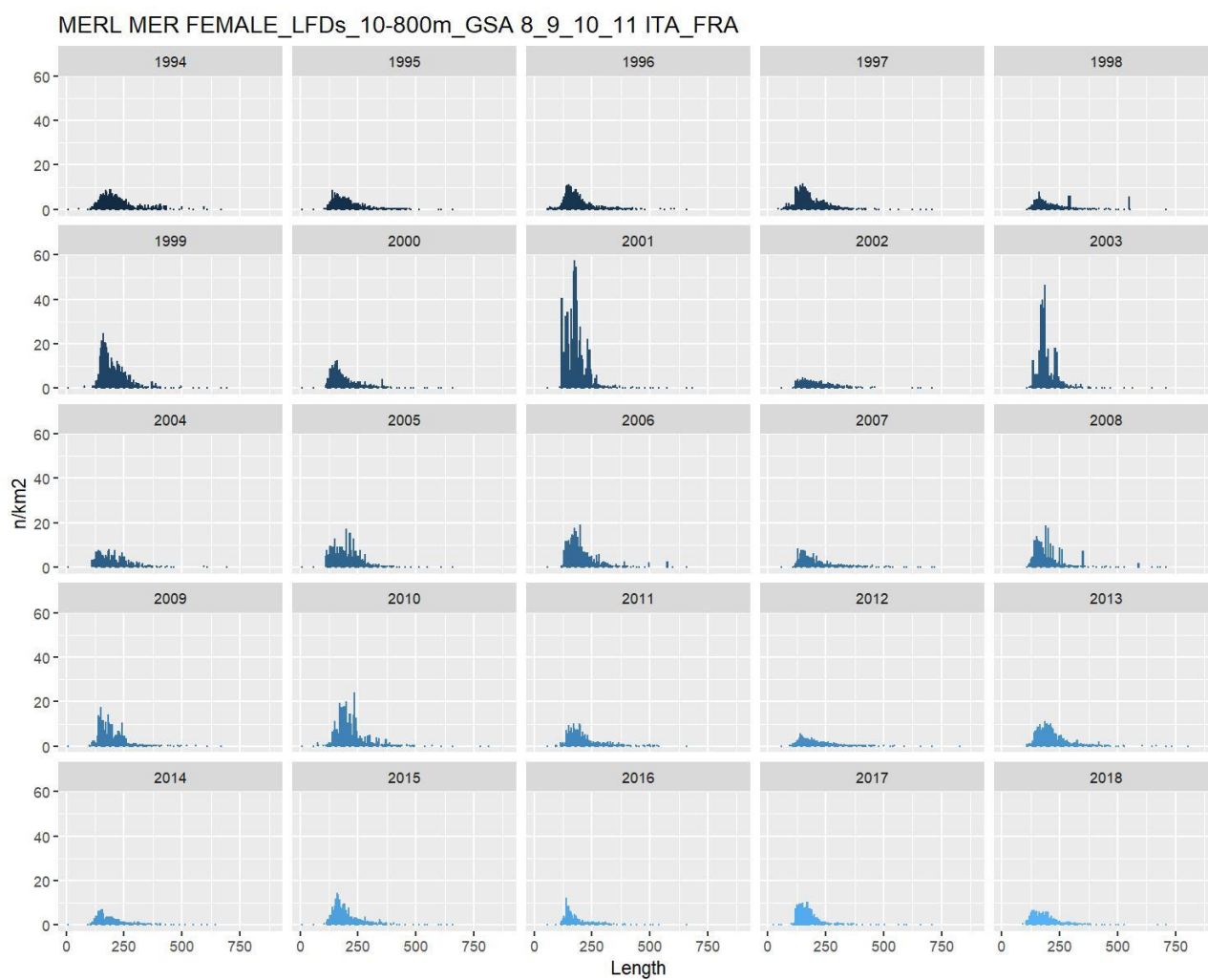


Figure 3.2.8.23. Female European hake length-frequency distributions (N/km²) of the MEDITS survey in GSAs 8, 9, 10 and 11 combined

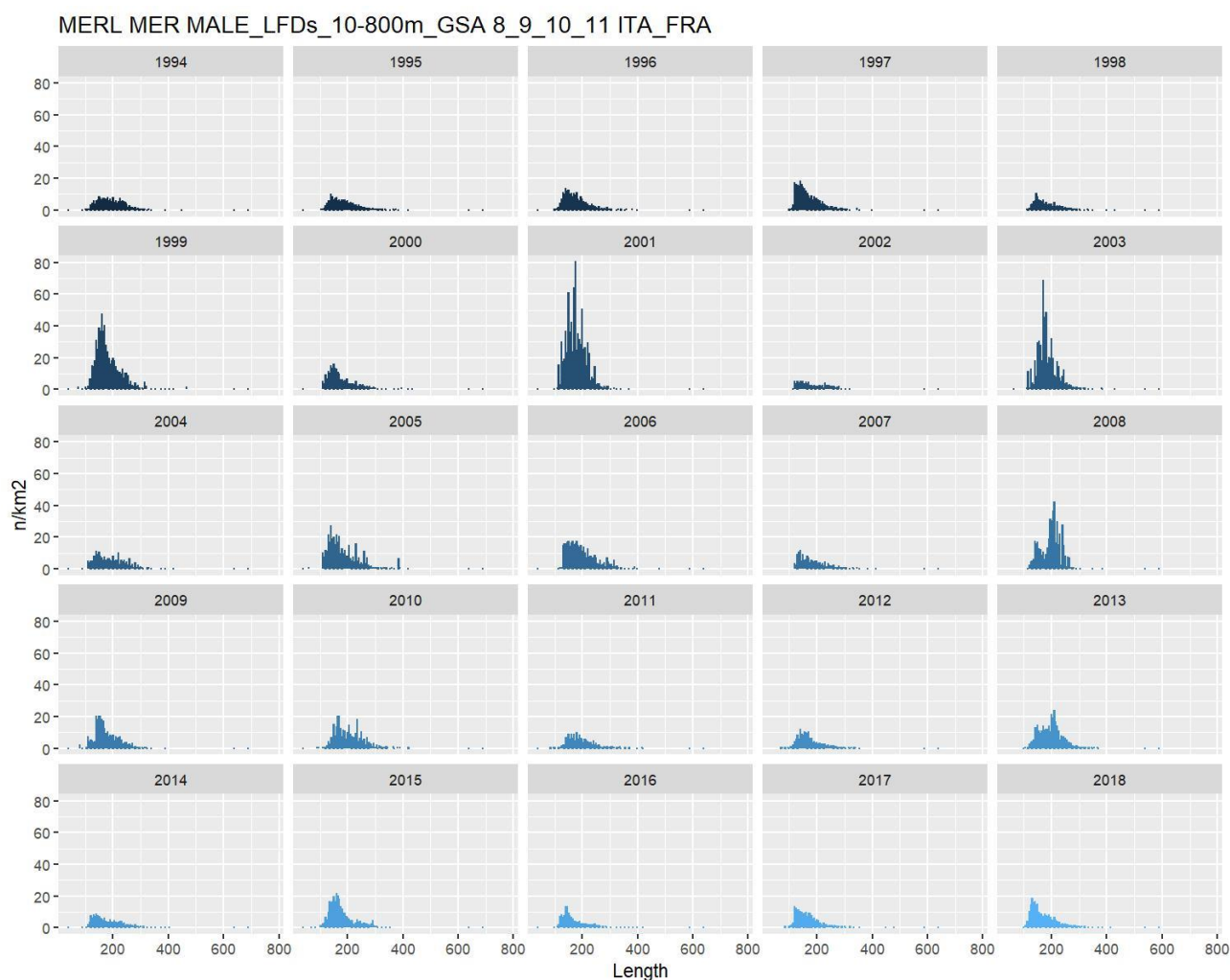


Figure 3.2.8.24. Male European hake length-frequency distributions (N/km^2) of the MEDITS survey in GSAs 8, 9, 10 and 11 combined

After performing the deterministic age slicing on the LFDs of catches (landings + discards) and MEDITS survey, the following age structures were obtained. The internal consistency of catches (also by fleet) and survey numbers-at-age are also shown.

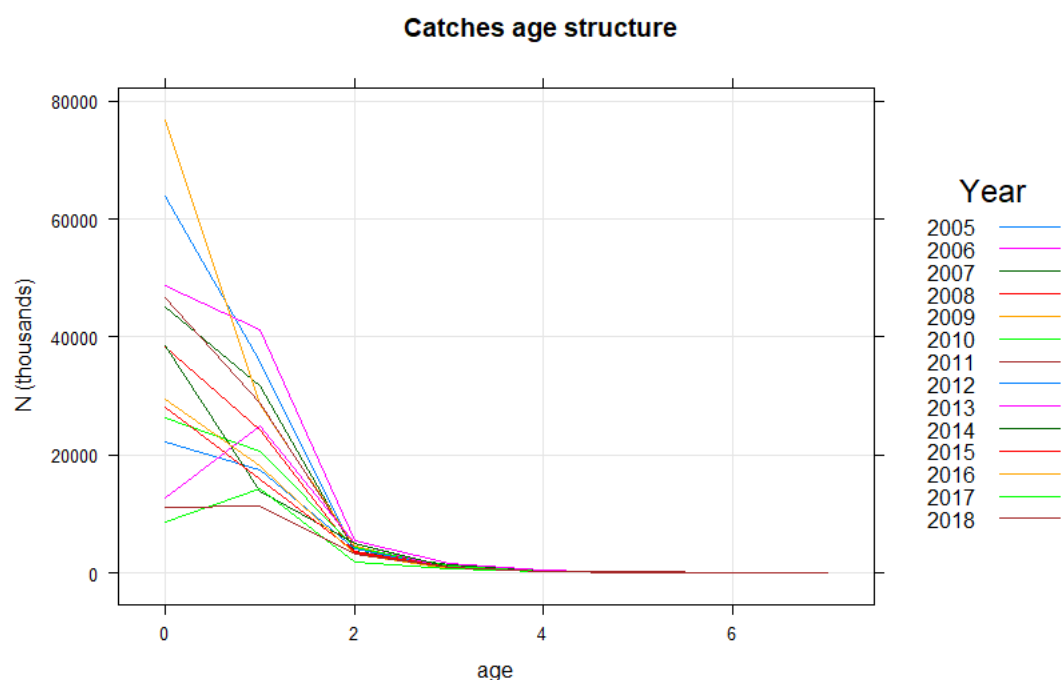


Figure 3.2.8.25. European hake catch-at-age structure by year obtained using the deterministic age slicing in GSAs 8, 9, 10 and 11

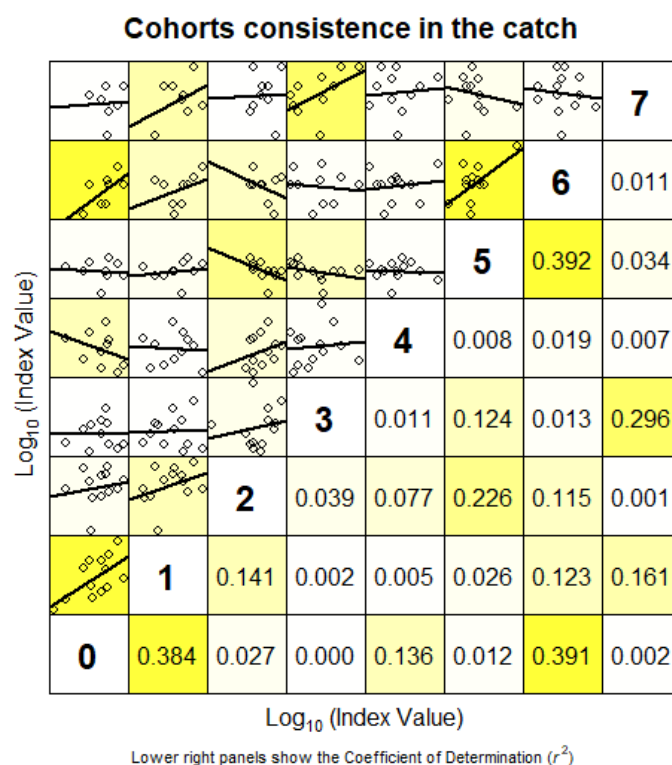


Figure 3.2.8.26. Internal consistency of the catch-at-age for European hake in GSAs 8, 9, 10 and 11

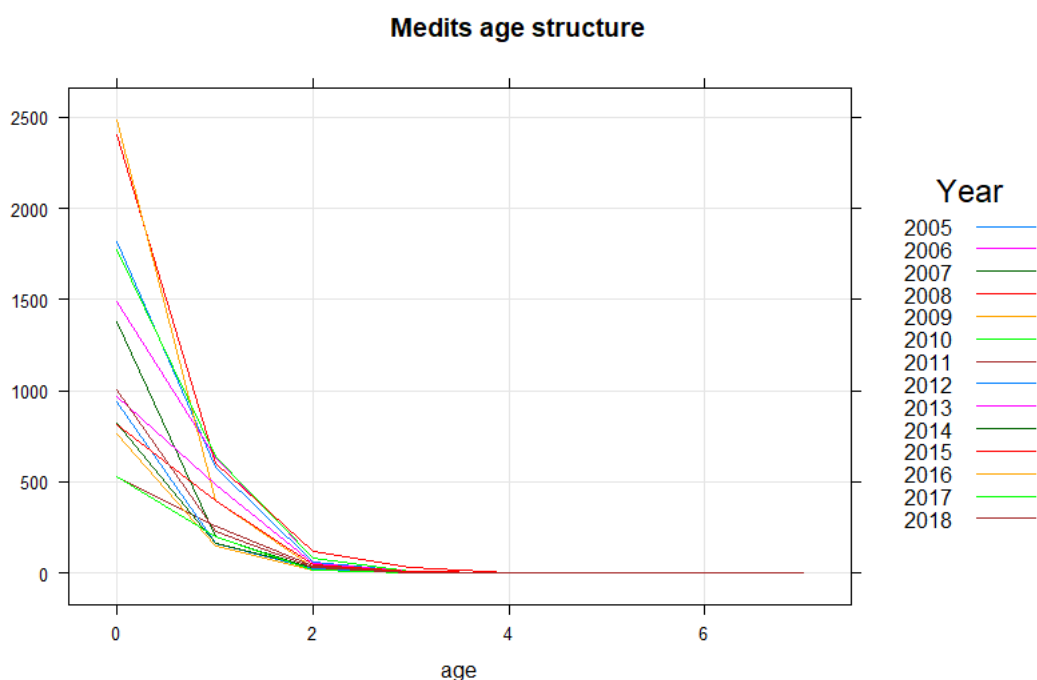
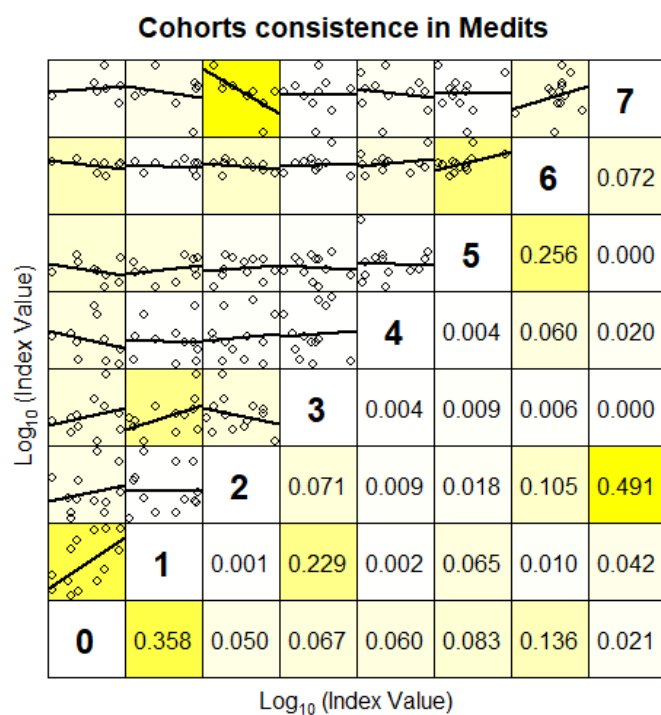


Figure 3.2.8.27. Numbers-at-age structure by year of the MEDITS index for European hake in GSAs 8, 9, 10 and 11 obtained using the deterministic age slicing



Lower right panels show the Coefficient of Determination (r^2)

Figure 3.2.8.28. Internal consistency of the numbers-at-age matrix of the MEDITS survey for European hake in GSAs 8, 9, 10 and 11

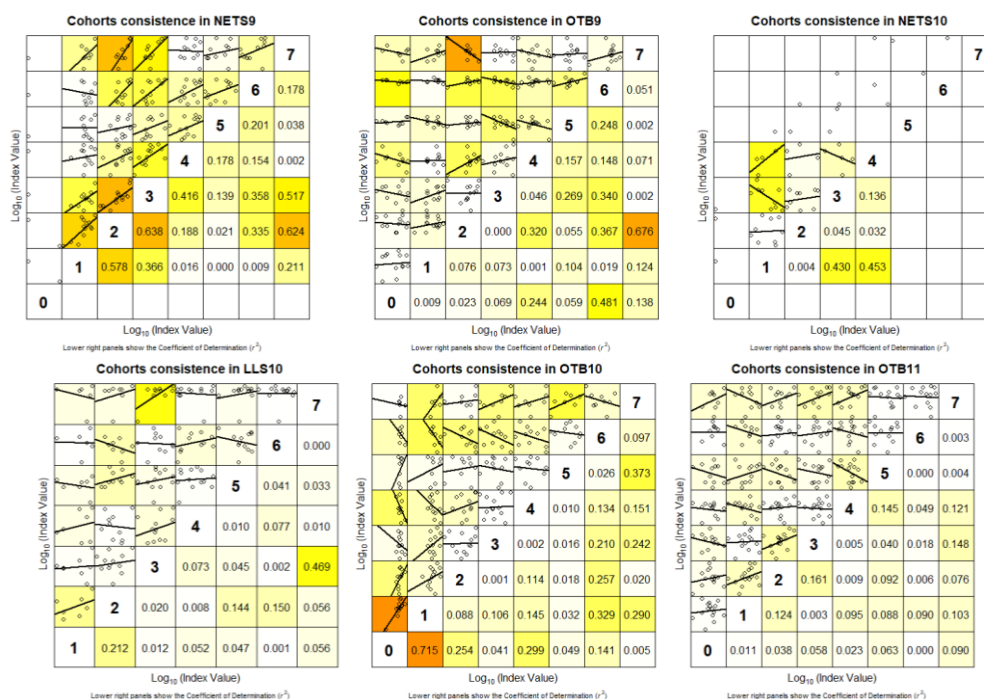


Figure 3.2.8.29. Internal consistency of the catch-at-age by fleet for European hake in GSAs 8, 9, 10 and 11

The following tables are showing the input data used to run the assessment of European hake in GSAs 8, 9, 10 and 11 with a4a.

Total catches (tonnes)

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
4 330.7	4 803.9	3 701.4	3 041.8	3 578.5	3 333.7	3 772.3	2 616.7	2 903.5	2 921	2 687	2 649	2 105.1	2 119.5

Catch numbers-at-age (thousands)

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	63 859	48 782	45 146	38 308	76 875	26 297	46 661	22 281	12 744	38 659	28 208	29 796	8 997	11 098
1	35 900	41 352	31 800	24 278	28 679	20 570	28 821	17 410	24 925	13 843	15 940	18 283	1 4391	11 407
2	3 562	5 454	3 614	3 406	4 522	4 444	4 109	4 011	5 019	4 965	3 590	3 242	1 884	3 120
3	999	1 694	1 318	673	716	1 173	1 007	718	643	967	890	747	821	929
4	221	456	190	238	158	262	342	221	178	297	246	199	268	171
5	322	133	95	117	116	134	152	113	69	105	138	104	113	127
6	71	98	50	70	46	53	64	46	31	31	46	46	50	25
7+	44	39	29	60	61	78	81	31	26	49	35	49	38	14

Catch mean weight-at-age (kg)

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.009	0.011	0.010	0.010	0.009	0.010	0.010	0.010	0.013	0.007	0.009	0.010	0.008	0.010
1	0.052	0.039	0.048	0.046	0.044	0.050	0.044	0.051	0.049	0.056	0.050	0.050	0.053	0.053
2	0.178	0.202	0.198	0.181	0.185	0.187	0.193	0.179	0.178	0.191	0.195	0.193	0.186	0.200
3	0.453	0.437	0.437	0.438	0.410	0.449	0.424	0.431	0.414	0.388	0.427	0.403	0.456	0.437
4	0.768	0.781	0.765	0.842	0.821	0.764	0.850	0.815	0.828	0.794	0.801	0.834	0.794	0.771
5	1.269	1.228	1.278	1.270	1.325	1.273	1.280	1.243	1.305	1.245	1.336	1.264	1.250	1.345
6	1.742	1.738	1.702	1.717	1.753	1.735	1.743	1.755	1.742	1.619	1.687	1.721	1.736	1.735
7+	2.329	2.419	2.582	2.626	2.634	2.801	2.569	2.560	2.664	2.913	2.662	2.927	2.604	2.414

Stock mean weight-at-age (kg)

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.009	0.011	0.010	0.010	0.009	0.010	0.010	0.010	0.013	0.007	0.009	0.010	0.008	0.010
1	0.052	0.039	0.048	0.046	0.044	0.050	0.044	0.051	0.049	0.056	0.050	0.050	0.053	0.053
2	0.178	0.202	0.198	0.181	0.185	0.187	0.193	0.179	0.178	0.191	0.195	0.193	0.186	0.200
3	0.453	0.437	0.437	0.438	0.410	0.449	0.424	0.431	0.414	0.388	0.427	0.403	0.456	0.437
4	0.768	0.781	0.765	0.842	0.821	0.764	0.850	0.815	0.828	0.794	0.801	0.834	0.794	0.771
5	1.269	1.228	1.278	1.270	1.325	1.273	1.280	1.243	1.305	1.245	1.336	1.264	1.250	1.345
6	1.742	1.738	1.702	1.717	1.753	1.735	1.743	1.755	1.742	1.619	1.687	1.721	1.736	1.735
7+	2.329	2.419	2.582	2.626	2.634	2.801	2.569	2.560	2.664	2.913	2.662	2.927	2.604	2.414

Natural mortality and proportion of matures-at-age

Age	0	1	2	3	4	5	6	7+
M	1.85	0.80	0.48	0.37	0.30	0.27	0.24	0.22
mat-at-age	0.00	0.25	0.80	1.00	1.00	1.00	1.00	1.00

MEDITs numbers-at-age (N/km2)

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	1821.3	1491.1	1381.4	2404.2	2485.5	1772.4	525.9	935.9	968.0	823.1	812.1	766.2	527.8	1004.1
	0	0	0	0	0	0	6	0	1	4	9	5	2	0
							256.4	163.3	480.7	161.2	397.8	144.7	200.9	
1	580.76	627.48	197.88	599.69	394.58	635.28	5	9	7	3	3	4	6	227.25
2	60.92	84.53	24.77	116.61	26.50	84.80	34.19	18.96	51.97	27.83	47.31	18.70	15.52	28.44
3	11.41	6.64	5.90	27.47	1.40	9.24	4.92	2.38	6.46	3.38	4.62	2.77	2.10	3.86
4	0.54	2.80	2.55	0.92	0.59	1.80	2.27	0.55	0.77	0.98	1.05	0.93	0.61	1.14
5	0.34	2.61	0.61	0.44	0.46	0.22	0.27	0.28	0.16	0.47	0.13	0.25	0.56	0.40
6	0.00	0.09	0.41	1.47	0.11	0.07	0.04	0.05	0.15	0.12	0.16	0.15	0.19	0.24
7+	0.19	0.11	0.15	0.36	0.12	0.20	0.06	0.23	0.20	0.26	0.14	0.25	0.45	0.18

C. Results

A model selection procedure was performed taking into account statistical measures (AIC, BIC) and model diagnostics (residuals, retrospective) and fitting.

Model selection:

Model 1:

```
qmodel <- list(~ factor(age))
```

```
fmodel <- ~ factor(age)+factor(year)
```

Model 2:

```
qmodel <- list(~ factor(age))
```

```
fmodel <- ~ factor(age)+s(year, k=8)
```

Model 3:

```
qmodel <- list(~ factor(age))
```

```
fmodel <- ~ factor(replace(age, age>4,4))+s(year, k=8)
```

Model 4:

```
qmodel <- list(~ factor(replace(age, age>4,4)))
```

```
fmodel <- ~ factor(replace(age, age>4,4))+s(year, k=8)
```

Table 3.2.8.8. Model selection based on AIC and BIC for European hake in GSAs 8, 9, 10 and 11. (best model highlighted in bold)

	Degrees of freedom	AIC	BIC
Model 1	50	369.7	540.3
Model 2	44	365.3	515.4
Model 3	41	363.7	503.6
Model 4	38	366.6	496.2

In the view of the AIC and BIC statistics, as well as diagnostics (residuals, fitting, retrospective), Model 4 was selected as the final model.

The final model specifications are the following (the default settings were used for srmodel, n1model and vmodel):

Submodels:

fmodel: $\sim \text{factor}(\text{replace}(\text{age}, \text{age} > 4, 4)) + s(\text{year}, k = 8)$

srmodel: $\sim \text{factor}(\text{year})$

n1model: $\sim s(\text{age}, k = 3)$

qmodel:

MEDITS_SA08091011: $\sim \text{factor}(\text{replace}(\text{age}, \text{age} > 4, 4))$

vmodel:

catch: $\sim s(\text{age}, k = 3)$

MEDITS_SA08091011: ~ 1

The summary of the final model statistics are reported below. The final model estimates 38 parameters out of 224 observations. It is therefore well below the threshold of 25 percent that is considered for possible risk of overparameterization.

Table 3.2.8.9. Summary of the statistics of the final model for European hake in GSAs 8, 9, 10 and 11

n. parameters	38.00
nlogl	145.29
maxgrad	0.00
n. observations	224.00
gcv	0.10
convergence	0.00
accrate	NA
nlogl_comp1	13.73
nlogl_comp2	131.55

D. Retrospective analysis, comparison between model runs and sensitivity analysis

Besides the model selection procedure, a further check was performed regarding the number of knots (k) of the smoother on year in the fmodel. A test based on AIC, BIC and GCV was performed on k ranging between 5 and 11. This analysis confirmed that the k value performing the best is 8, as specified in the final model

selected (Figure 3.2.2.12). Nonetheless, all the model specifications highlight a consistent behavior in terms of main outcomes (Figure 3.2.2.13).

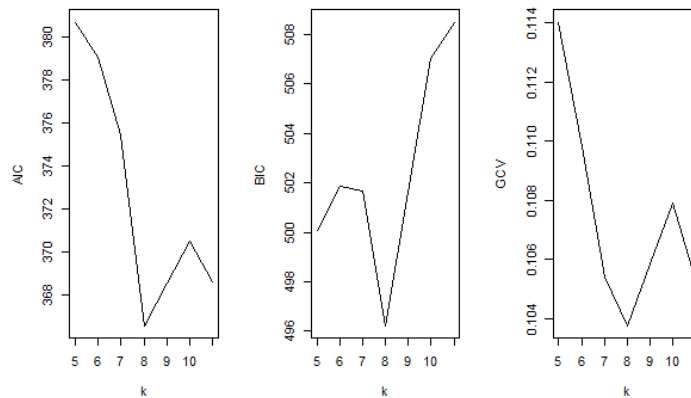


Figure 3.2.8.30. AIC, BIC and GCV values estimated on a range of k values of the smoother on year of the f model for European hake in GSAs 8, 9, 10 and 11.

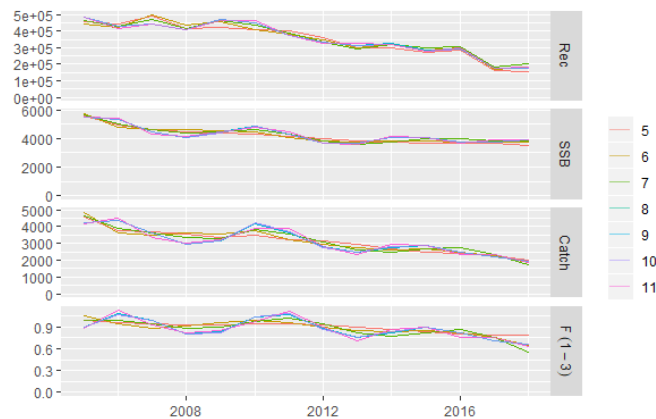


Figure 3.2.8.31. Outputs of model runs with different k values on the smoother on year in the f model for European hake in GSAs 8, 9, 10 and 11

The residuals of the final model are shown in the following figures.

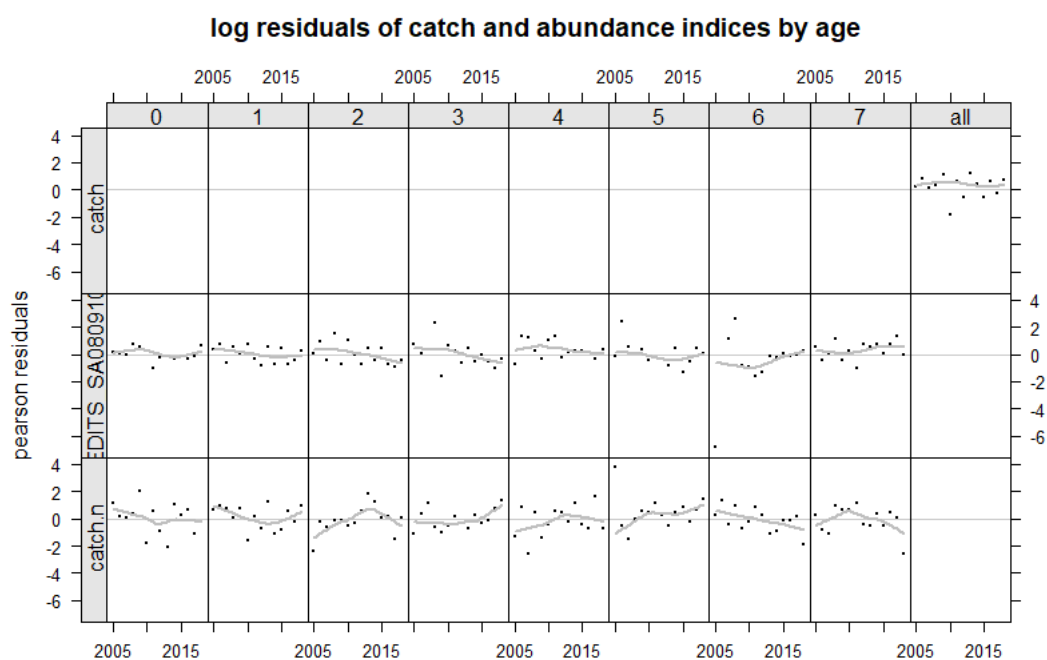


Figure 3.2.8.32. European hake in GSAs 8, 9, 10, 11 with Pearson's residuals of the final model

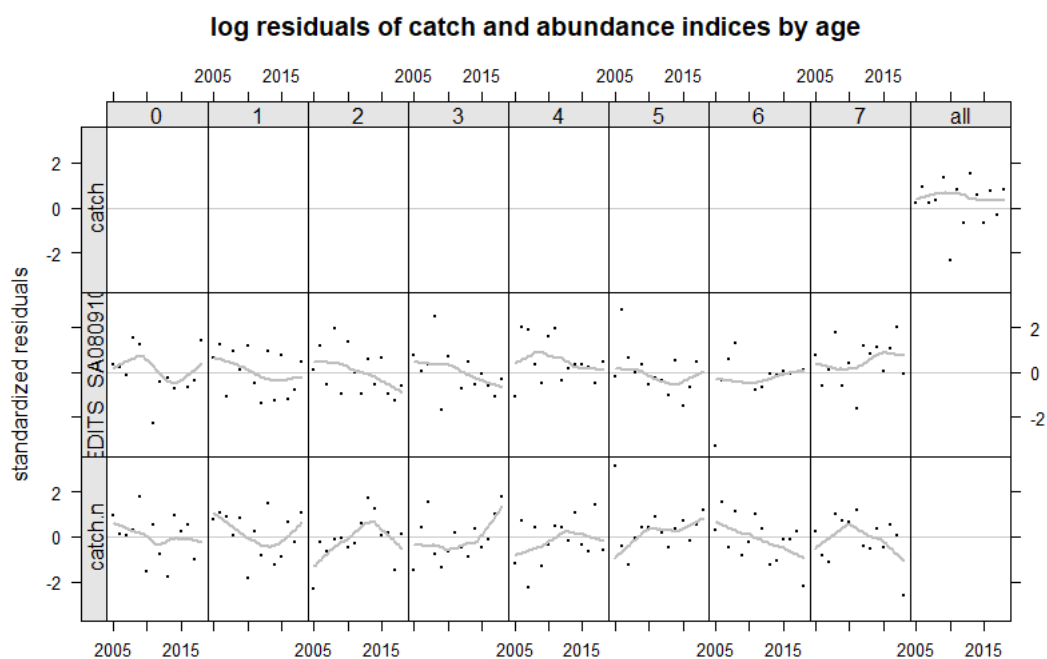


Figure 3.2.8.33. Standardized log residuals of the final model for European hake in GSAs 8, 9, 10 and 11

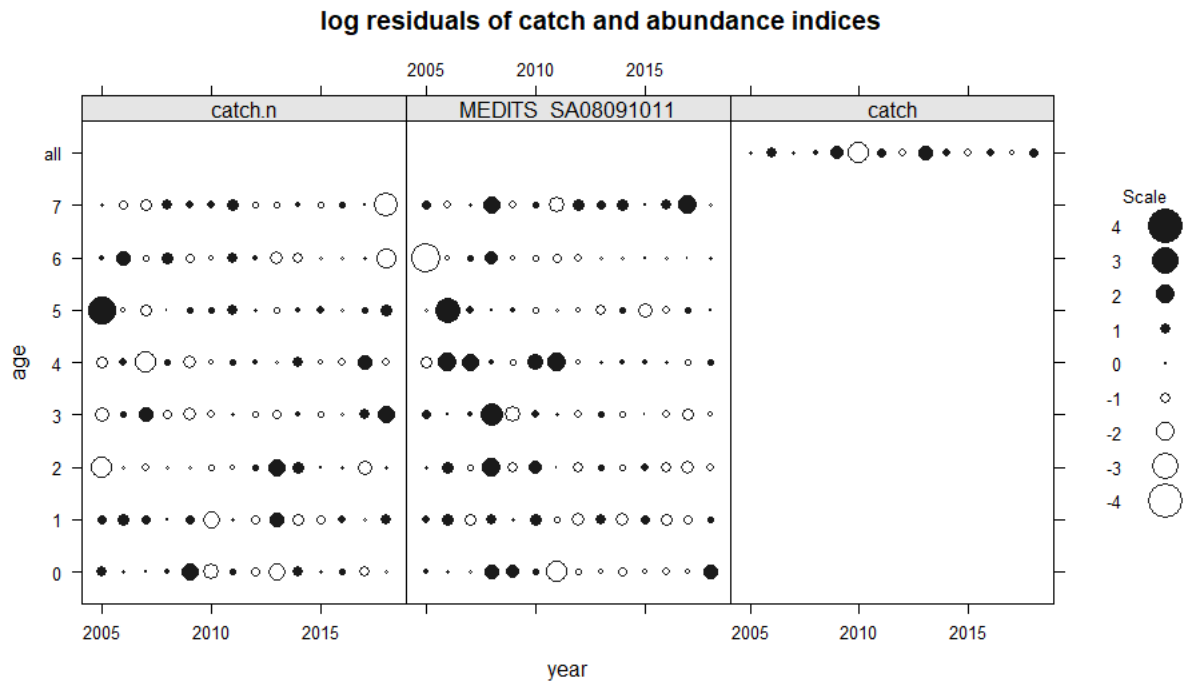


Figure 3.2.8.34. Bubble plot of the standardized log residuals of the final model for European hake in GSAs 8, 9, 10 and 11

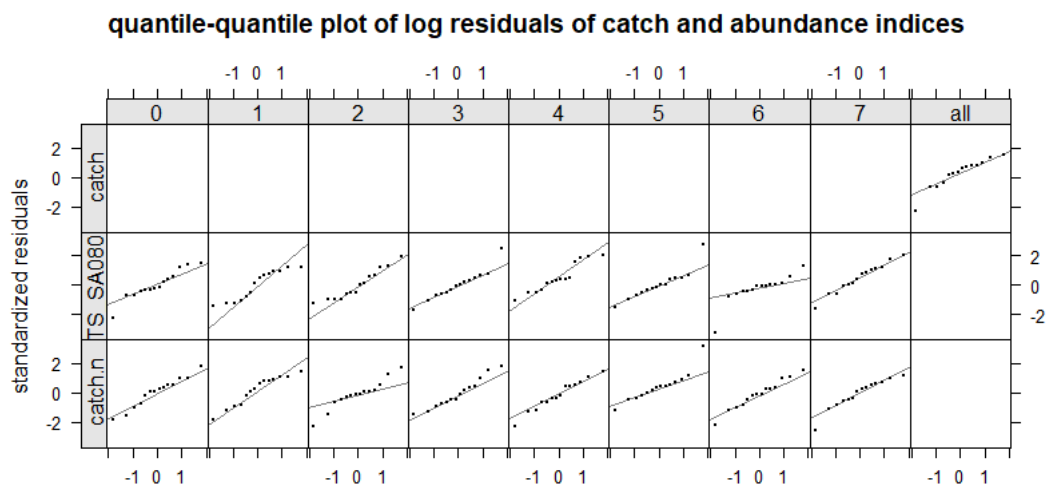


Figure 3.2.8.35. QQ plot of the standardized log residuals of the final model for European hake in GSAs 8, 9, 10 and 11

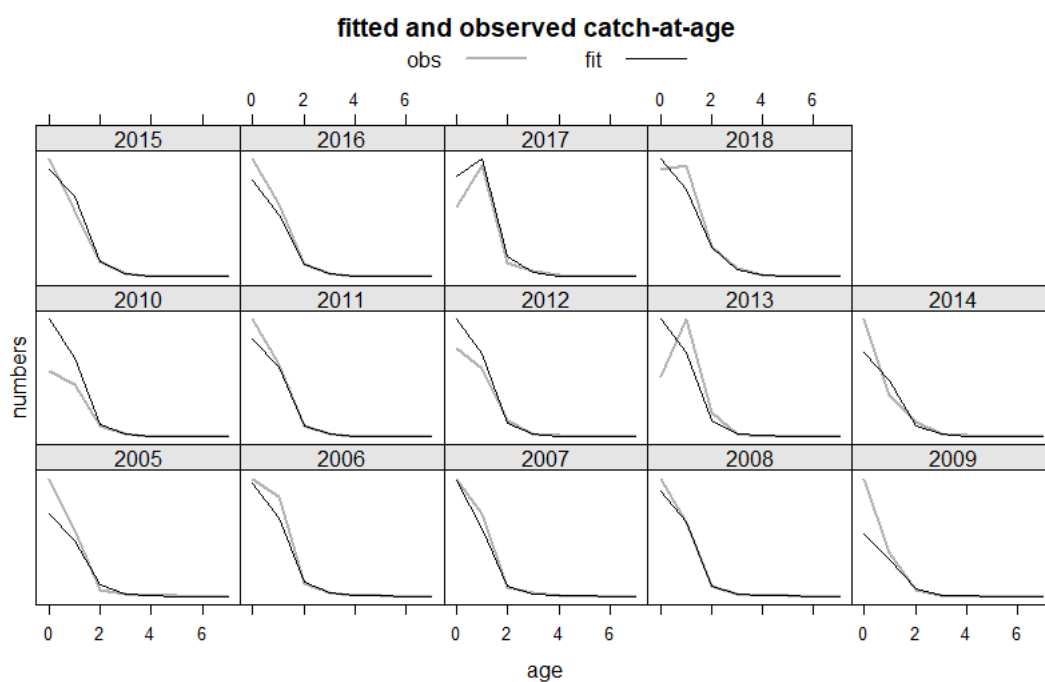


Figure 3.2.8.36. Fitting of the final model with the observed catch-at-age for European hake in GSAs 8, 9, 10 and 11

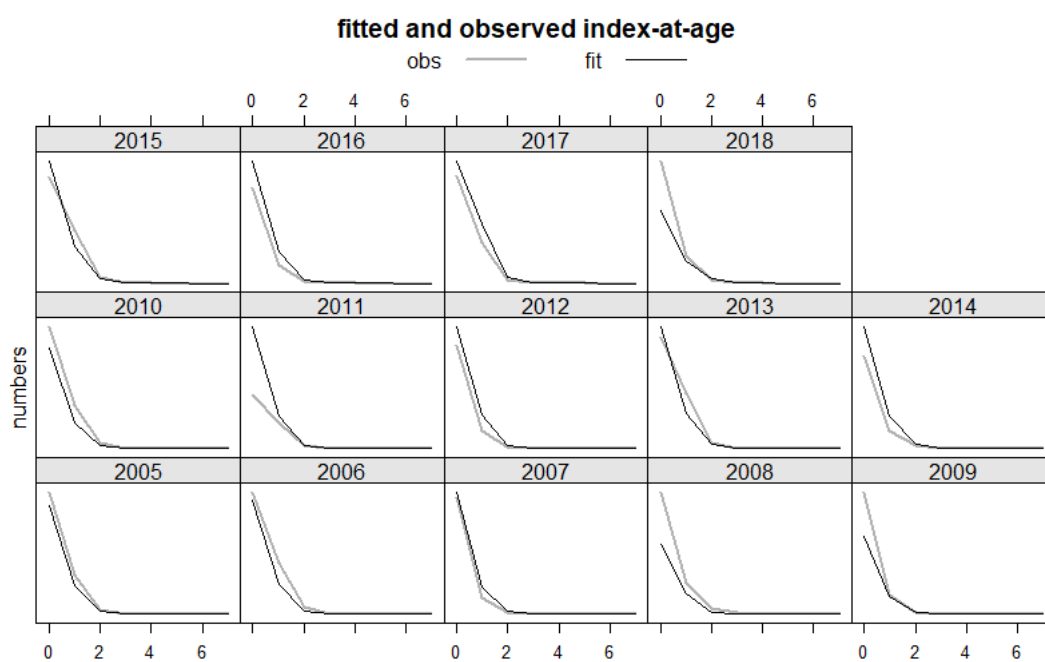


Figure 3.2.8.37. Fitting of the final model with the observed index (MEDITS891011) numbers-at-age for European hake in GSAs 8, 9, 10 and 11

The Mohn's rho was also estimated for recruitment, SSB and F_{bar} . The estimated values are -0.13, -0.05 and 0.09, respectively.

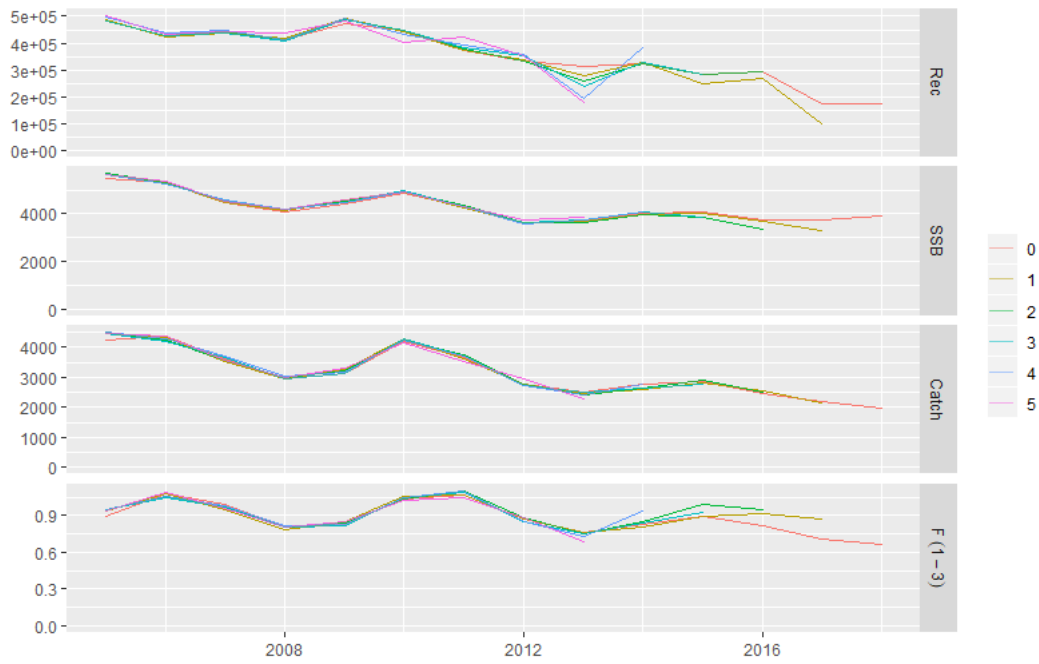


Figure 3.2.8.38. Retrospective analysis for European hake in GSAs 8, 9, 10 and 11

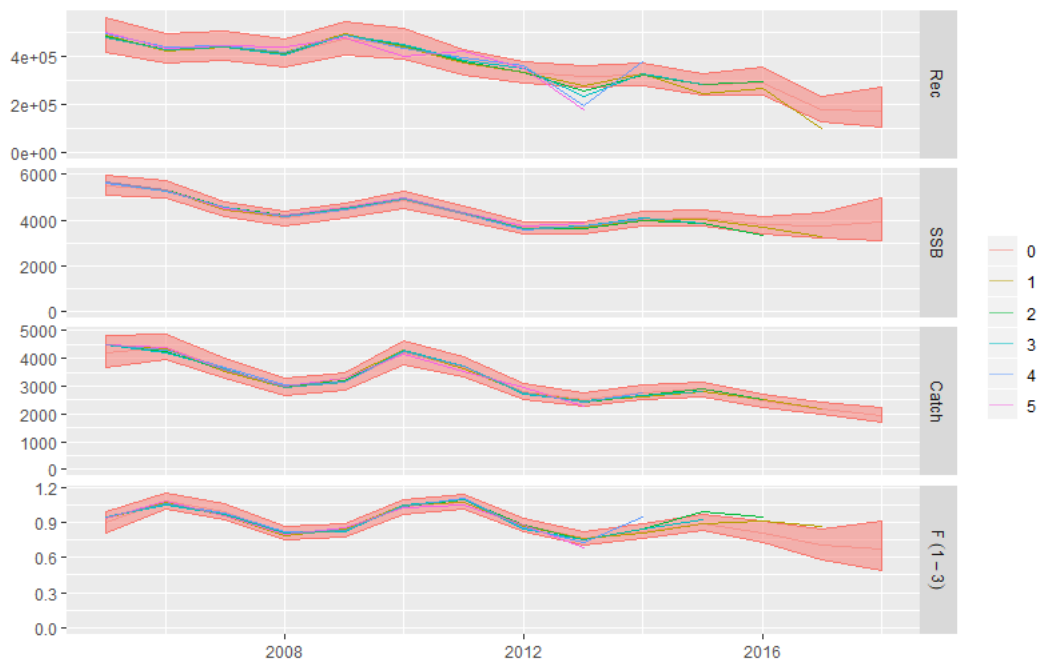


Figure 3.2.8.39. Retrospective analysis plotted against the final model run with confidence intervals for European hake in GSAs 8, 9, 10 and 11

The cryptic biomass estimated as the percentage of SSB in the plus group (age 7+) against the total SSB was computed and did not show any relevant issue, as it ranged between 4 and 9 percent of the total SSB.

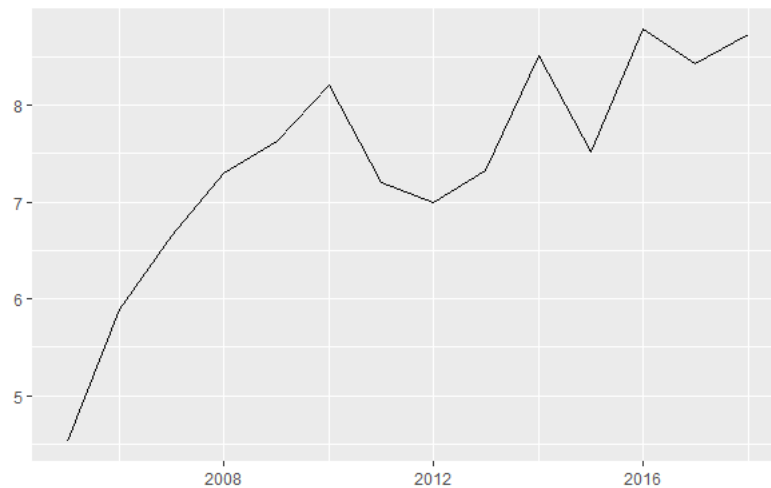


Figure 3.2.8.40. Cryptic biomass estimated as the percentage of SSB in the plus group compared to the total SSB for European hake in GSAs 8, 9, 10 and 11 (values are in percentage)

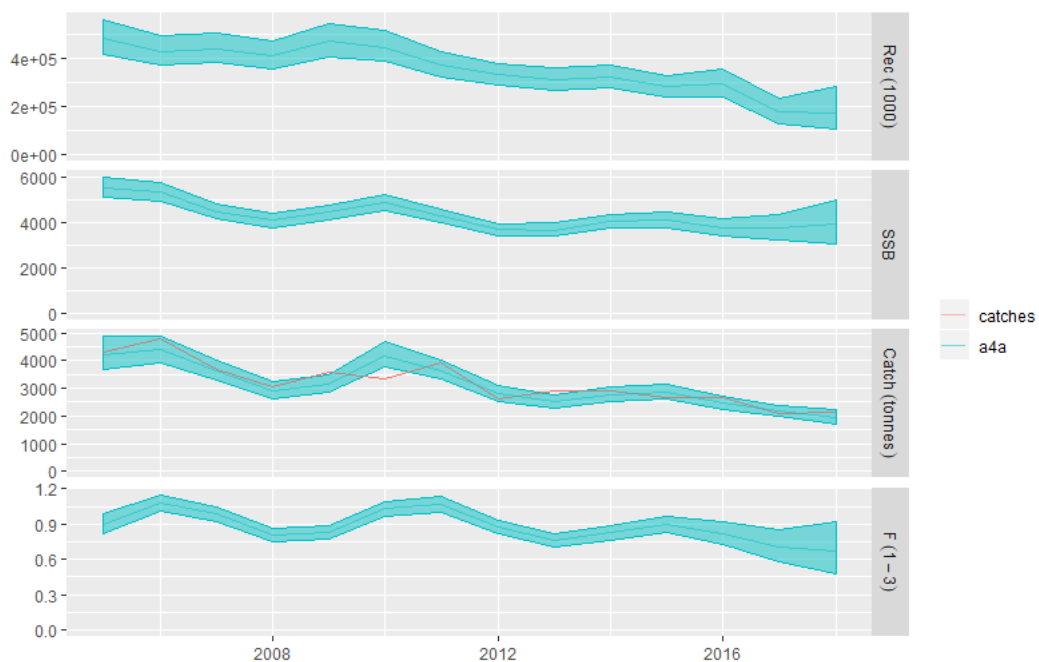


Figure 3.2.8.41. Final model run outputs with confidence intervals plotted against observed catches (red line) for European hake in GSAs 8, 9, 10 and 11

Based on the a4a results, the European hake SSB shows a decreasing trend from the beginning of the time series, from a maximum of 5 475 tonnes in 2005 to minimum of 3 629 tonnes in 2012. The assessment shows a decreasing trend in the number of recruits in the time series. The recruitment (age 0) reached a minimum of 17 2487 thousands individuals in 2018. F_{bar} (1-3) shows a fluctuating pattern with a slightly decreasing trend in the time series, with a value of 0.67 reached in 2018. The retrospective performance is moderate, but shows that the F is high, well above F_{MSY} over the whole time series. The Mohn's rho was also computed on the retrospective analysis of recruitment, SSB and F_{bar} . The estimated values are -0.13, -0.05 and 0.09, respectively.

Table 3.2.8.10. Final model run outputs: stock numbers-at-age ('000) for European hake in GSAs 8, 9, 10 and 11

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	484531	431227	444467	409405	466201	438775	369863	331508	314210	323692	281613	293058	175312	172487
1	64380	61228	52172	54990	52872	59808	53724	44954	42251	41090	41652	35641	37817	23216
2	12444	10359	8031	7601	9800	9133	8298	7200	7530	7986	7200	6751	6329	7583
3	2793	3075	2132	1816	2058	2580	1977	1741	1845	2149	2130	1791	1822	1904
4	821	904	856	642	634	702	749	559	581	673	741	693	624	694
5	330	355	351	351	293	284	281	294	247	273	304	321	315	302
6	174	147	142	148	165	135	117	114	134	120	127	136	151	158
7+	107	130	115	113	128	141	118	99	101	118	115	113	121	141

Table 3.2.8.11. Final model run outputs: F-at-age for European hake in GSAs 8, 9, 10 and 11

Age	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.22	0.26	0.24	0.20	0.20	0.25	0.26	0.21	0.18	0.20	0.22	0.20	0.17	0.16
1	1.03	1.23	1.13	0.92	0.96	1.18	1.21	0.99	0.87	0.94	1.02	0.93	0.81	0.76
2	0.92	1.10	1.01	0.83	0.85	1.05	1.08	0.88	0.77	0.84	0.91	0.83	0.72	0.68
3	0.76	0.91	0.83	0.68	0.71	0.87	0.89	0.73	0.64	0.69	0.75	0.69	0.60	0.56
4	0.54	0.65	0.59	0.49	0.50	0.62	0.64	0.52	0.45	0.49	0.54	0.49	0.42	0.40
5	0.54	0.65	0.59	0.49	0.50	0.62	0.64	0.52	0.45	0.49	0.54	0.49	0.42	0.40
6	0.54	0.65	0.59	0.49	0.50	0.62	0.64	0.52	0.45	0.49	0.54	0.49	0.42	0.40
7+	0.54	0.65	0.59	0.49	0.50	0.62	0.64	0.52	0.45	0.49	0.54	0.49	0.42	0.40

Table 3.2.8.12. Final model run outputs: catch (tonnes), SSB (tonnes), recruitment ('000), F_{bar} and total biomass (tonnes) for European hake in GSAs 8, 9, 10 and 11

	Catch (t)	SSB (t)	Rec ('000)	$F_{\text{bar}(1-3)}$	Total biomass (t)
2005	4 242.1	5 475.4	484 531	0.90	12 795.2
2006	4 370.1	5 325.9	431 227	1.08	12 455.4
2007	3 639.9	4 472.7	444 467	0.99	11 191.1
2008	2 956.9	4 065	409 405	0.81	10 386.5
2009	3 149.9	4 408.7	466 201	0.84	10 554.0
2010	4 115.8	4 800.1	438 775	1.03	11 795.2
2011	3 570.7	4 217.4	369 863	1.06	10 100.1
2012	2 756.7	3 629.2	331 508	0.87	8 916.8
2013	2 504.1	3 658.4	314 210	0.76	9 411.5
2014	2 767.9	4 037.9	323 692	0.83	8 297.5
2015	2 877.2	4 077.5	281 613	0.89	8 449.5
2016	2 463.6	3 754.4	293 058	0.81	8 224.4
2017	2 175.5	3 742.5	175 312	0.71	6 961.4
2018	1 961.6	3 908.5	172 487	0.67	6 825.3

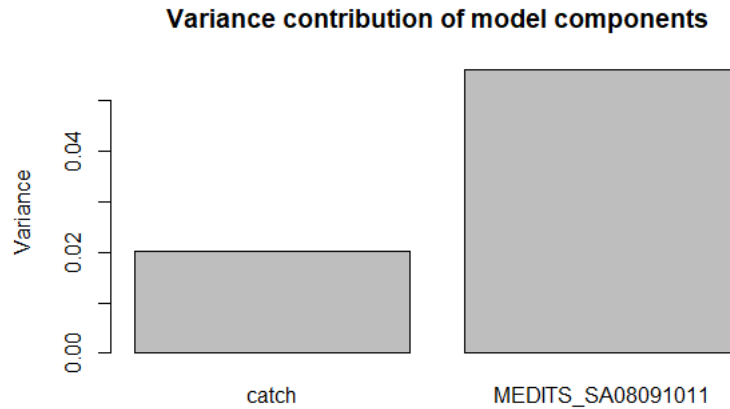


Figure 3.2.8.42. Variance contribution of model components (catch-at-age and MEDITS survey numbers-at-age) for European hake in GSAs 8, 9, 10 and 11

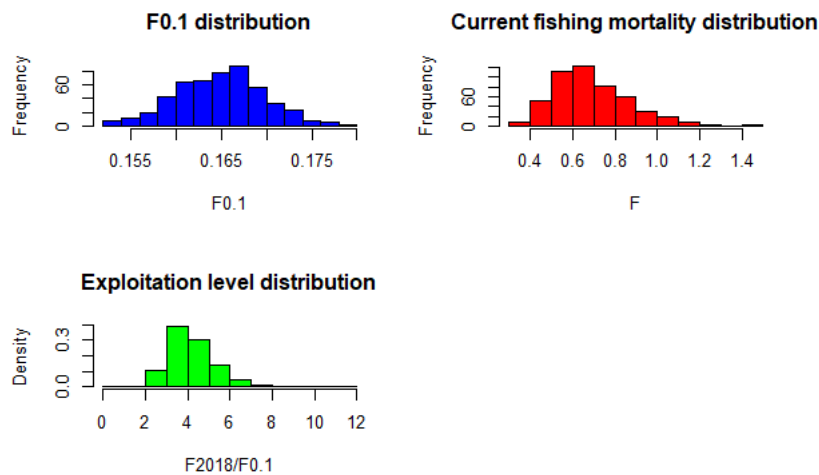


Figure 3.2.8.43. Histograms of the outputs of the simulation runs in terms of F0.1, Fcurrent ($F_{\text{bar } 1-3}$) and ratio between F current and F0.1 (green bars) for European hake in GSAs 8, 9, 10 and 11

Figures 3.2.8.44-3.2.8.46 are showing the catches and fishing mortality by age, year and fleet. Landings from GSA 8 represent less than 1 percent of total landings in the four GSAs. Since European hake in GSA 8 is not a target species and the landings over the period of the assessment are negligible compared to catches in the other three GSAs, partial fishing mortality of the gear fishing European hake in GSA 8 are very low in comparison to fishing mortalities of the other combined GSAs of this assessment, and cannot be estimated.

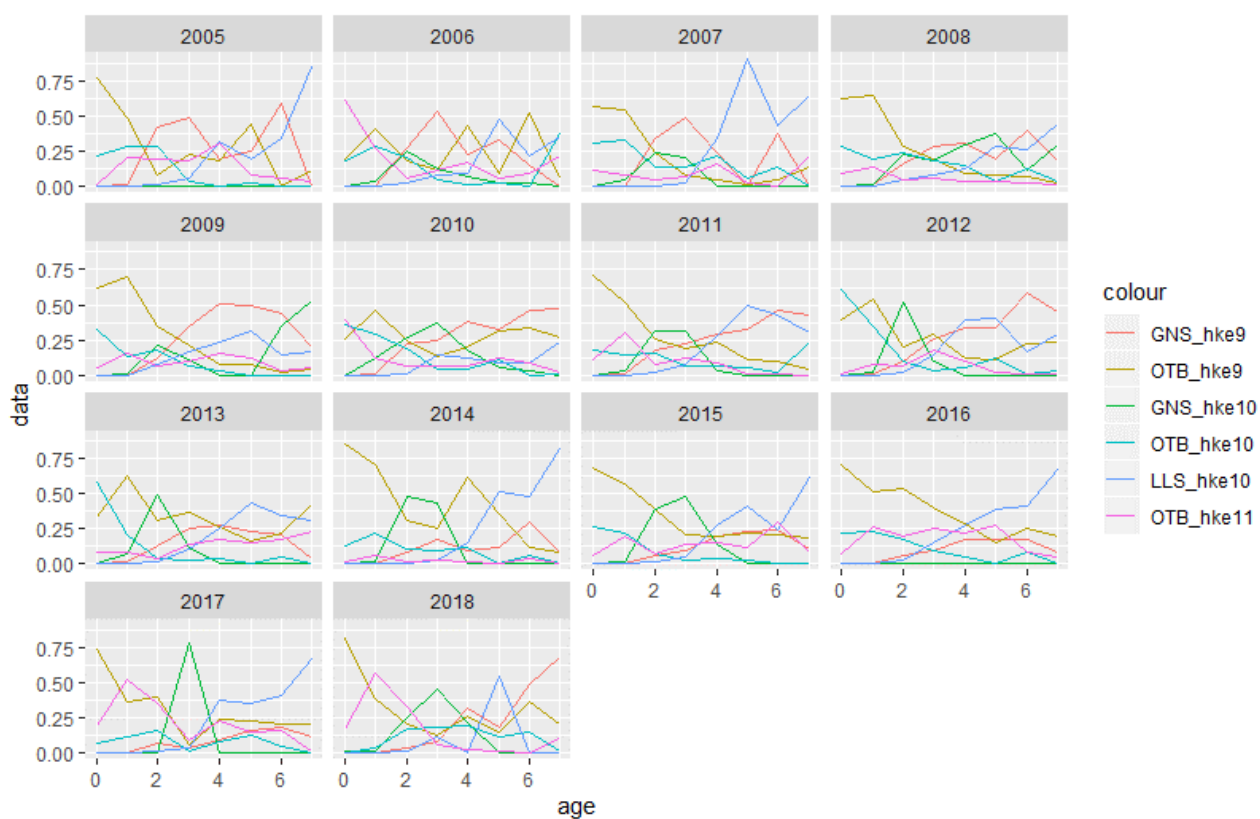


Figure 3.2.8.44. Plots of the partial catch-at-age by fleet and year for European hake in GSAs 8, 9, 10 and 11 (values expressed as proportions of the total catches-at-age)

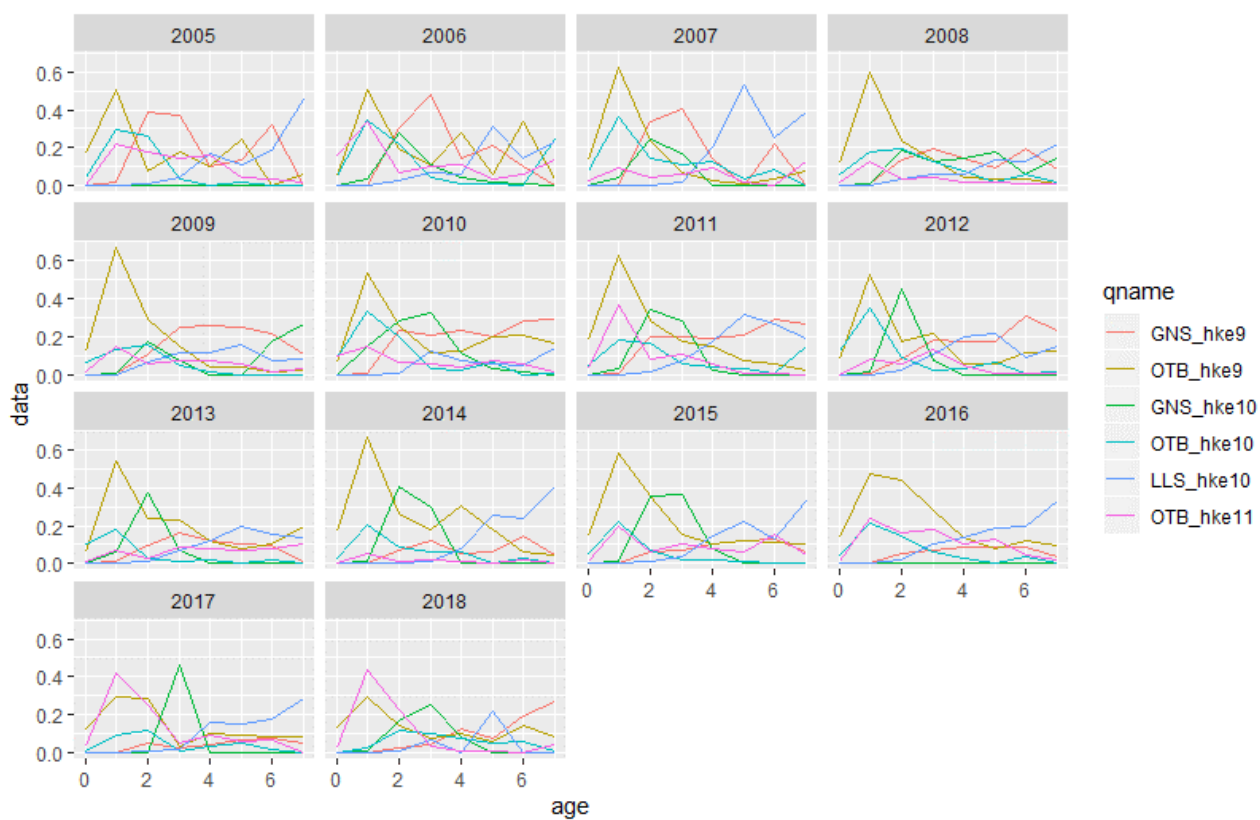


Figure 3.2.8.46. Plots of the partial F-at-age by fleet and year for European hake in GSAs 8, 9, 10 and 11

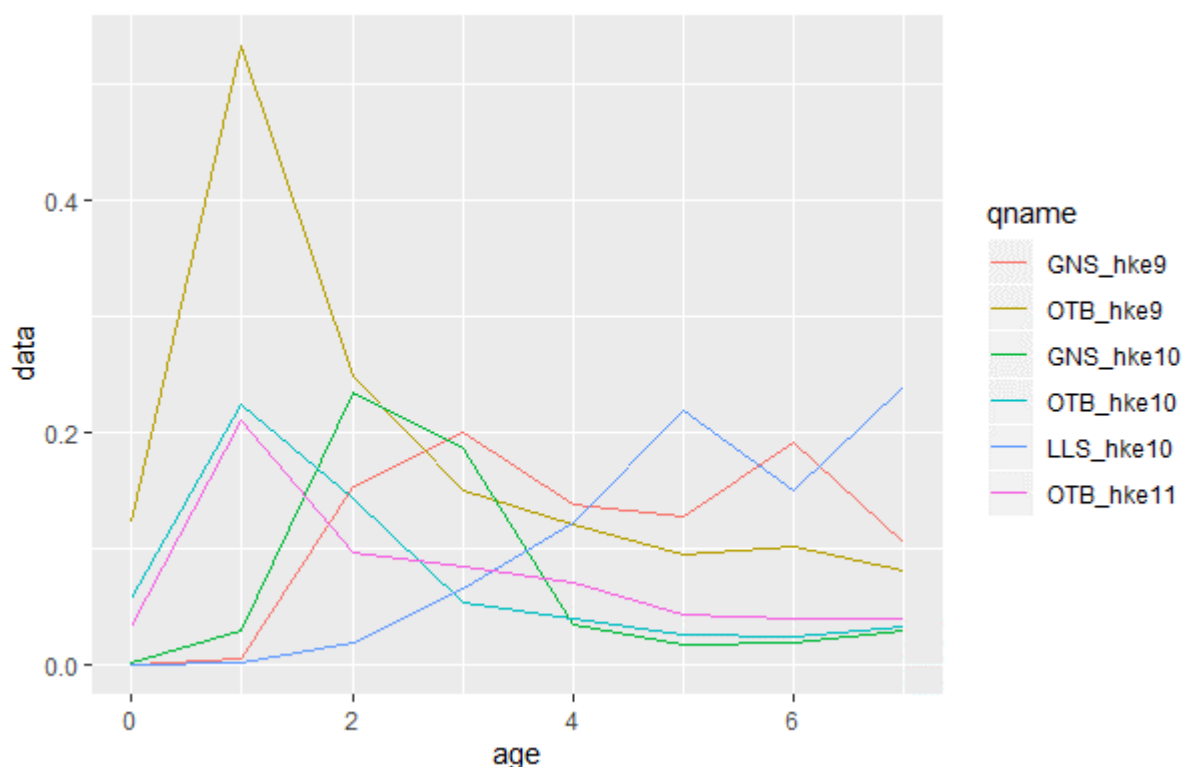


Figure 3.2.8.46. Plots of the partial F-at-age by fleet estimated as average contribution on the whole time series for European hake in GSAs 8, 9, 10 and 11

E. Reference points

The time series is too short to estimate a reliable stock recruitment relationship, therefore reference points are based on equilibrium methods. It was recommended to use $F_{0.1}$ as proxy of F_{MSY} . The library FLBRP available in FLR was used to estimate $F_{0.1}$ from the stock object resulting from the outputs of the a4a assessment. Current F (0.67, estimated as the F_{bar1-3} in the last year of the time series, 2018) is higher than $F_{0.1}$ (0.16), chosen as proxy of F_{MSY} and as the exploitation reference point consistent with high long-term yields, which indicates that European hake stock in GSAs 8, 9, 10 and 11 is over-exploited.

A deterministic short-term prediction for the period 2019 to 2021 was performed using the FLR libraries and scripts, and based on the results of the a4a stock assessment. The input parameters for the deterministic short-term predictions were the same used for the a4a stock assessment and its results. An average of the last three years has been used for weight at age and maturity at age. Also for fishing mortality, the mean F_{bar} in the last three years (2016–2018) of the a4a assessment was used. Recruitment (age 0) showed a general declining trend. Therefore, recruitment for the STF was estimated from the population results as the geometric mean in the period 2011–2018, when MEDITS density index is showing the lowest values (273 296 thousand individuals).

Table 3.2.8.13. Short-term forecast settings for European hake in GSAs 8, 9, 10 and 11

Variable	Value	Notes
Biological parameters		Mean weights at age, maturation at age, natural mortality at age and selection at age, based average of 2016–2018
$F_{ages\ 1-3}$ (2019)	0.73	Mean F 2016–2018 used to give F status quo for 2019
SSB (2019)	3 807	Stock assessment 1 January 2019
R_{age0} (2019, 2020)	273 296	Geometric mean of the time series, years 2011–2018
Total catch (2019)	2 033	Assuming F status quo for 2019

Table 3.2.8.14. Short-term forecast outputs. In different F scenarios for European hake in GSAs 8, 9, 10 and 11

Rationale	Ffactor	Fbar	Catch 2018	Catch 2019	Catch 2020	SSB 2019	SSB 2021	Change_SSB 2019-2021(%)	Change_Catch 2018-2020(%)
High long term yield ($F_{0.1}$)	0.23	0.16	1961.6	2032.6	599.4	3806.8	6137.0	61.2	-69.4
F upper	0.32	0.23	1961.6	2032.6	816.7	3806.8	5807.5	52.6	-58.4
F lower	0.15	0.11	1961.6	2032.6	414.9	3806.8	6419.6	68.6	-78.9
Zero catch	0.00	0.00	1961.6	2032.6	0.0	3806.8	7064.1	85.6	-100.0
Status quo	1.00	0.73	1961.6	2032.6	2168.2	3806.8	3853.7	1.2	10.5
Different Scenarios	0.10	0.07	1961.6	2032.6	275.3	3806.8	6635.1	74.3	-86.0
	0.20	0.15	1961.6	2032.6	535.3	3806.8	6234.9	63.8	-72.7
	0.30	0.22	1961.6	2032.6	780.9	3806.8	5861.5	54.0	-60.2
	0.40	0.29	1961.6	2032.6	1013.1	3806.8	5512.9	44.8	-48.4
	0.50	0.37	1961.6	2032.6	1232.7	3806.8	5187.4	36.3	-37.2
	0.60	0.44	1961.6	2032.6	1440.6	3806.8	4883.4	28.3	-26.6
	0.70	0.51	1961.6	2032.6	1637.4	3806.8	4599.4	20.8	-16.5
	0.80	0.58	1961.6	2032.6	1823.8	3806.8	4334.0	13.8	-7.0
	0.90	0.66	1961.6	2032.6	2000.6	3806.8	4085.8	7.3	2.0
	1.10	0.80	1961.6	2032.6	2327.3	3806.8	3636.5	-4.5	18.6
	1.20	0.88	1961.6	2032.6	2478.4	3806.8	3433.3	-9.8	26.3
	1.30	0.95	1961.6	2032.6	2621.9	3806.8	3243.0	-14.8	33.7
	1.40	1.02	1961.6	2032.6	2758.3	3806.8	3064.8	-19.5	40.6
	1.50	1.10	1961.6	2032.6	2888.1	3806.8	2897.9	-23.9	47.2
	1.60	1.17	1961.6	2032.6	3011.6	3806.8	2741.4	-28.0	53.5
	1.70	1.24	1961.6	2032.6	3129.3	3806.8	2594.6	-31.8	59.5
	1.80	1.31	1961.6	2032.6	3241.3	3806.8	2457.0	-35.5	65.2
	1.90	1.39	1961.6	2032.6	3348.2	3806.8	2327.9	-38.8	70.7
	2.00	1.46	1961.6	2032.6	3450.2	3806.8	2206.7	-42.0	75.9

3.3. Central Mediterranean

3.3.1. Assessment unit: GSAs 12, 13, 14, 15 and 16

European hake has a wide distribution from coastal grounds to depth up to 1000 m, the larger individuals preferring the deepest waters. The stock structure of European hake in the Strait of Sicily (GSAs 12-16, south-central Mediterranean Sea; see map below) is still under investigation. Levi *et al.* (1994) compared the growth of European hake in the Mediterranean and found a quite similar pattern in individuals from the northern side of the Strait of Sicily (GSAs 15 and 16) and those caught in the Gulf of Gabès (GSA 14). Ben Meriem and Gharbi (1996) indicated a similar historical trend in CPUE in north and south Tunisia (GSAs 12, 13 and 14). Lo Brutto *et al.* (1998) have also found no evidence of genetic subdivision or significant differences in allelic frequencies between samples taken near Sicily and those from the mid-line. More recently, Levi *et al.* (2004) applied electrophoretic, morphometric and growth analyses to test the hypothesis of the existence of a unique stock of European hake in the Strait of Sicily, which includes part of the North African continental shelf off the Tunisian coast and the shelf off the southern Sicilian coast. Milano *et al.* (2014), using genetic markers able to identify fine population structure (SNPs), found a significant difference between European hake inhabiting the western, central and eastern Mediterranean. According to the multidimensional definition of stock followed in the STOCKMED project (Fiorentino *et al.*, 2015), European hake in the Strait of Sicily would belong to a single a population unit, extending from the Ligurian-North Tyrrhenian Sea (GSA 9) to the eastern Ionian Sea (GSA 19). However, for the purposes of this benchmark assessment, European hake inhabiting GSAs 12, 13, 14, 15 and 16 are considered as belonging to a single stock (Figure 3.3.1.1).

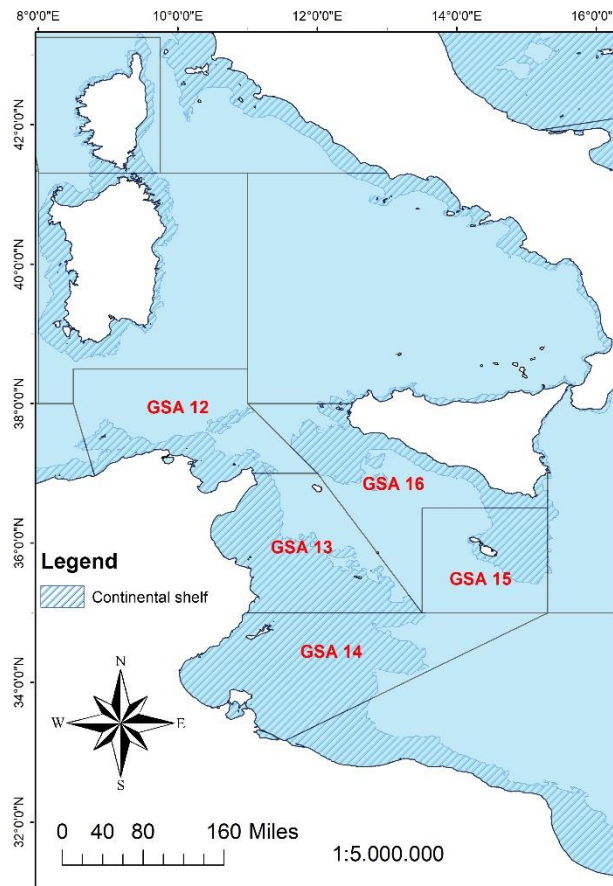


Figure 3.3.1.1. Geographical map of GSAs 12-16

3.3.1.1. Method 1: SS3

Assessment of European hake in GSAs 12-16 was conducted using the stock synthesis (SS) model (Methot and Wetzell, 2013). Stock synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using

inverse Hessian and MCMC methods. The assessment was conducted using the 3.30 version of the stock synthesis software under the Windows platform.

In continuity with previous assessments, an XSA was performed and is reported in section 3.3.2.2.

A. Model assumptions

The assessment model of European hake in GSAs 12-16 is a one area annual model where the population is comprised of 20+ age-classes (with age 20 representing a plus group) with two sexes (male and females are modelled as separated). The model is length based where the numbers at length in the fisheries and survey data are converted into ages using the Von Bertalanffy growth function.

The model starts in 1947 and the initial population age structure was assumed to be in an unexploited equilibrium state, so that the initial fishing mortality was assumed to be about the 10 percent of the average of three initial years (1947–1949) for all fleets. For the Italian-Tunisian passive gear, an initial fishing mortality was not estimated as the fishery was assumed for simplicity to start in the year 1990 and before that period F for that fleet was assumed to be negligible. Fishing mortality was modelled using instantaneous F method (Methot and Wetzel, 2013), which is the preferred method because hybrid F method has high gradients that limit pace of convergence when F is high. Option 5 was selected for the F report basis, this option represents a recent addition to stock synthesis and corresponds to the fishing mortality requested by the International Council for the Exploration of the Sea and GFCM framework (i.e. simple unweighted average of the F of the age classes chosen to represent the F_{bar} [age 1-6]).

B. Spawning stock biomass and recruitment

Spawning biomass was estimated at the beginning of the year and it was considered proportional to fecundity. In the model, the recruitment was assumed that only one single event occurs at the beginning of the year. Recruitment was derived from a Beverton and Holt (BH) stock recruitment relationship (SRR) and variation in recruitment was estimated as deviations from the SRR. Recruitment deviates were estimated for 1984 to 2018 (35 annual deviations). Recruitment deviates were assumed to have a standard deviation (σ_R) of 0.5. For the period 1947–1985, recruitment was derived directly from the SRR and from the initial catches and initial fishing mortality. The reference model assumed a level of steepness (h) of 0.88 for the SRR. Both steepness and σ_R were derived using the likelihood profile function in r4ss.

C. Growth and weights

Growth parameters were fixed for the whole period using values provided by MEDSUDMED working group (Gancitano *et al.*, 2013) (Figure 3.3.1.2). Numbers of fish in age length key (ALK) are used as sample size for each year. The variance in length-at-age was fixed both for older and younger individuals. Length at minimum age (A_{min}) was estimated for both sex within the model. Parameters of the length-weight relationships (a and b) were from Gancitano *et al.* (2013).

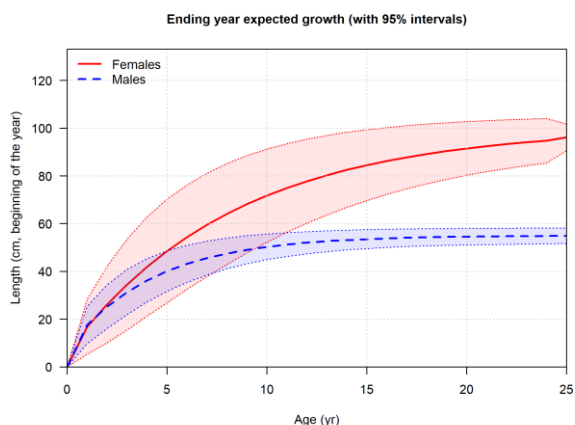


Figure 3.3.1.2. Growth curve used for the entire time series (1947–2018) for European hake in GSAs 12-16

D. Maturity

The values of $L_{50\%}$ and the slope are assumed to be constant for the entire time period. The maturity ogive based macroscopic inspection of the gonads for female indicates that the onset of maturation ($L_{50\%}$) occurs at about 28 cm (Figure 3.3.1.3).

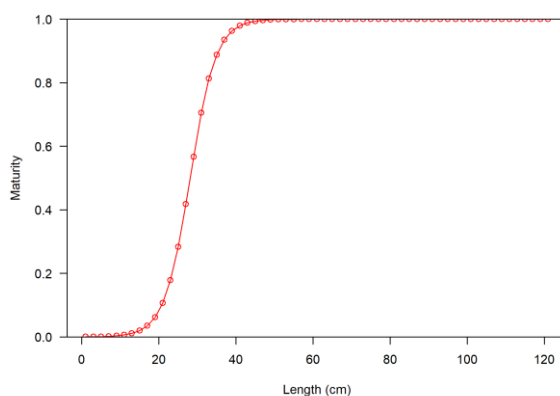


Figure 3.3.1.3. Length-based maturity ogive used for the entire time series (1947–2018) for European hake in GSAs 12-16

E. Natural mortality

Natural mortality at age is assumed to be constant for the entire time series (Figure 3.3.1.4; Table 3.3.1.1). For the assessment, an average of six different methods (Gulland [1987]; Chen and Watanabe [1989]; Lorenzen [1996]; Abella *et al.*, [1997]; Gislason *et al.*, [2008]; and Brodziak *et al.*, [2011]) was used. In particular, two vectors of natural mortality were estimated: one for females and one for males. In order to reduce the number of parameters to be used in the model, natural mortality was set using four breaks: ages 0, 1, 5 and 20, where M for the other ages is simply linearly interpolated using the values estimated for the age breaks.

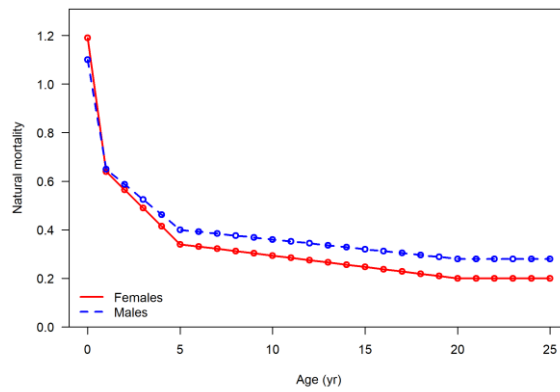


Figure 3.3.1.4. Age-specific natural mortality schedule used in the model for Europeanhake in GSAs 12-16

Table 3.3.1.1. Natural mortality vectors divided by breaks and sex used in the model

Sex	Age 0	Age 1	Age 5	Age 20
F	1.19	0.64	0.34	0.2
M	1.10	0.65	0.40	0.28

F. Selectivity

Fishery selectivity is assumed to be length-specific and time-variant, except for the Tunisian trawlers. For Italian-Maltese trawlers, the time variant parameters were estimated between 2009 and 2018, while for Italian-Tunisian passive gear, they were estimated between 2010 and 2018. Time variant selectivity was assumed due to changes in mesh size for the Italian-Maltese trawlers (Reg. CE 1967/2006) and to different fishing grounds exploited for the Italian-Tunisian passive gear. For all fleets and survey, a double normal selectivity was used, which estimates all parameters with exception of the top value. Years 2014 and 2017 were excluded from the length compositions as those surveys were conducted very late in the year (i.e. November). All data input is summarized in Table 3.3.1.2 while in Table 3.3.1.3 the configuration of the reference model is reported.

G. Samples sizes, CVs, data weighting

For all fleet, the CV of the catches was set to 0.1 until the year 1999, while from 2000 onwards, the CV was set to 0.05. For Italian trawling, and for years from 1981 to 1998, extra variability was included assuming a CV of 0.2 because in this period a large increase in commercial landing was reported, which is considered to be uncertain. No meaningful information is available on the annual sample size associated with age or length distribution data for commercial catches. Therefore, the same value (100) is applied for each fleet in all years. The CV of the MEDITS survey indices was performed according to the following formula (Methot *et al.*, 2019; Stock synthesis manual version 3.30.13, June 2019):

$$\sqrt{(\log_e(1 + (CV)^2))}$$

Where CV is the standard error of the observation divided by the mean value of the observation. Numbers of hauls of the MEDITS survey in each year were used as input for sample.

The relative weighting of the age and length compositions were estimated using the Ianelli method as implemented in r4ss package. The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix, which was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

H. Input data and parameters

a. Landings

The information used for the assessment of European hake in GSAs 12-16 consisted of:

- Italian landings: from 1947 to 2001, hake landings reported by the Italian National Institute of Statistics (ISTAT). From 2002 to 2018, data collected within the EU data collection framework (DCF) were used;
- Italian landings estimated by means of Minipestat catch and effort survey (Andreoli *et al.*, 1995) for the period 1983–1997;
- Tunisian landings: from 1950 to 2018 data provided by the official Tunisian statistics on landings;
- Maltese landings: from 2007 to 2018 data collected within the DCF.

Official Italian catch statistics were discussed during the two previous MEDSUDMED working groups and experts decided to apply a decrement of landings for the period 1983–1997 as adjustment factor on the basis of the values reported by Minipestat sampling collection (Andreoli *et al.*, 1995). Thus, we used two sets of alternative catch configurations, one using the official nominal catches and one with the catch data adjusted on the basis of Minipestat for the period 1983–1997. However, the reference model was based on the Minipestat adjusted data while the official nominal catches were used as an alternative model configuration as the official catches in the period 1983–1997 were considered unrealistically high by the two previous MEDSUDMED working groups.

b. Discards

Information about discards data is available for the Italian and Tunisian trawl fisheries. Discards are sampled by observers on board of commercial fishing vessels and through self-sampling of fishers. Discards were included in the total catches and in the catch at length of the Italian and Tunisian trawlers matrix while for the other fleets we assumed that the discards were negligible and all fish caught was landed.

c. Age and length composition of commercial catch

ALK information is used in the assessment for the period from 2004 to 2018. ALK have been used to estimate length at minimum age (Amin) and population dynamics of the stock as ALK do not inform only growth parameters but also contains information on class strength and mortality. Data on length compositions of the catches in GSAs 12-16 are available from 2007 onwards (see Tables 3.3.1.2 and 3.3.1.3 for details). Data on length compositions of the catches of the Italian fixed nets start from 2007. For Italian trawlers, we used length composition data from 2009–2018 as for those years both commercial and discards data were available. For Tunisian trawler, we used both commercial and discards data from 2007 to 2018.

In the stock assessment model, catches for some of the fleets were aggregated for simplicity and to improve fitting. In particular, Maltese trawling (less than 1 percent of the total catches) were merged with Italian trawling and Italian fixed nets (less than 1 percent of the total catches) were merged with Tunisian passive gear. Thus, the model includes three main fleets, Italian-Maltese trawling, Tunisian trawling and Italian-Tunisian passive gear. Table 3.3.1.2 reported all the data used in the model.

Table 3.3.1.2. Data used in the assessment model for European hake in GSAs 12-16

Fishery	Data type	Fleet	Period
Italian-Maltese trawlers	Commercial landings (tonnes)	Italian trawlers	1947–2018
		Maltese trawlers	2009–2018
	Discards (tonnes)	Italian trawlers	2009–2018
	Length composition of commercial landings (N thousand)	Italian trawlers	2009–2018
		Maltese trawlers	2009–2018
	Length composition of discards (N thousand)	Italian trawlers	2009–2018
Tunisian trawlers	Commercial landings (tonnes)	Tunisian trawlers	1950–2018
	Length composition of commercial landings (N thousand)	Tunisian trawlers	2007–2018
	Discards (tonnes)	Tunisian trawlers	2007–2018
Italian-Tunisian passive gear	Commercial landings (tonnes)	Italian fixed nets	2004–2018
		Tunisian passive gear	2014–2018
	Length composition of commercial landings (N thousand)	Italian fixed nets	2010–2018
		Tunisian passive gear	2010–2018

I. Survey data

Stock abundance indices are available from the MEDITS survey carried out in GSA 16 and conducted mainly in the third quarter of the year. Data on biomass index and length composition are available from 1994. However, length composition data of the years 2014 and 2017 were excluded by the model because the surveys were conducted in the fourth quarter of the year. MEDITS of GSA 15 was excluded because the time series started in 2004 and therefore merging the two series would need a standardisation procedure.

J. Parameters

Table 3.3.1.3 reported the parameters configuration of the reference model. The table columns show: i) the number of estimated parameters; ii) the initial values (from which the numerical optimization is started); iii) the intervals allowed for the parameters; iv) the priors used; and v) the maximum likelihood estimation (MLE) parameters estimation. Parameters in bold are set and not estimated by the model.

Table 3.3.1.3. Settings of the stock synthesis assessment model for European hake in GSAs 12-16.

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)
<u>Natural mortality</u> (age classes 0, 1, 5, 20)		Females: 1.19, 0.64, 0.34, 0.20 Males: 1.10, 0.65, 0.40, 0.28			
<u>Stock and recruitment</u>					
$Ln(R_0)$	1	12.5	(10, 15)	No_prior	12.63
<i>Steepness (h)</i>		0.88			
<i>Recruitment variability (σ_R)</i>		0.50			
Ln (Recruitment deviation): 1947 - 2018	72				
<i>Recruitment autocorrelation</i>		0			
<u>Growth</u>					

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)
L_{inf} (cm)		Females: 100 Males: 55			
K		Females: 0.12 Males: 0.23			
L at minimum age (0.5 years) t_0	1	Females: 11.6 Males: 12.7	F (10, 15) M (10, 15)		
CV of young individuals		Females: 0.37 Males: 0.25			
CV of old individuals		Females: 0.03 Males: 0.03			
<u>Weight (kg) at length (cm)</u>					
A		Females: 5.4e-06 Males: 6e-06			
B		Females: 3.08 Males: 3.05			
<u>Maturity</u>					
Length (cm) at 50% mature		28.1			
Slope of the length at maturity ogive		-0.3			
<u>Initial fishing mortality</u>					
Fishery one	1	0.01	(0, 1.5)	No_prior	0.007
Fishery two	1	0.01	(0, 1.5)	No_prior	0.00025
<u>Selectivity (double normal)</u>					
Fishery one					
Peak	1	20	(3, 35)	No_prior	16.24
Asc-width	1	2.0	(-2, 6)	No_prior	2.20
Desc-width	1	6	(5, 8)	No_prior	5.64
Fishery two					
Peak	1	20	(10, 30)	No_prior	21.93
Asc-width	1	3.0	(0, 6)	No_prior	3.57
Desc-width	1	6.0	(2, 10)	No_prior	7.14
Fishery three					
Peak	1	20	(3, 52)	No_prior	19.20
Asc-width	1	4.0	(0, 10)	No_prior	3.50
Desc-width	1	5.5	(3, 9)	No_prior	5.57
MEDITS survey					
Peak	1	5	(3, 8)	No_prior	3.00 (LO)
Asc-width	1	-9	(-14, 9)	No_prior	-12.73
Desc-width	1	-1	(1, 6)	No_prior	3.48
<u>Catchability</u>					
MEDITS survey					
$\ln(Q)$ – catchability		-3.46414			
Extra variability added to input standard deviation		0.001			

K. Results

a. Selectivity

The selectivity of all fleets is rather well estimated, except for the peak value of the MEDITS Survey (Fig. 102), which is estimated at the lower bound. The estimated time varying selectivity for OTB_ITA_MALTA and Pas_gears_TUN_ITA shows a variable trend with no particular pattern for OTB_ITA_MALTA but an increase in selectivity for Pas_gears_TUN_ITA (e.g. larger fish are being more targeted in the latest years). This temporal shift in selectivity is likely the result of both an increased use of longlines and the exploitation of deeper fishing grounds by the Tunisian fleet in the last three years.

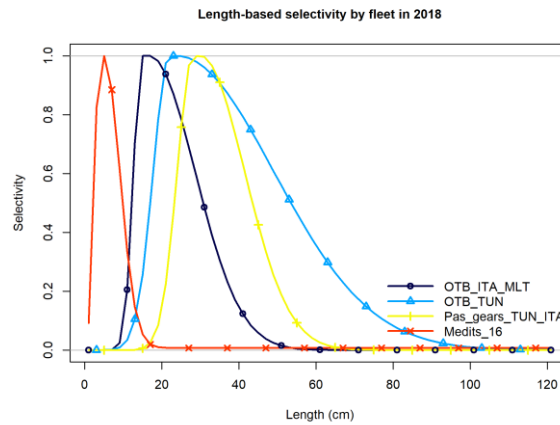


Figure 3.3.1.5. Length based selectivity by fleet for European hake in GSAs 12-16

b. Model fitting

The fitting of the model was good, with the length compositions rather well reconstructed (Figure 3.3.1.6). The residuals are quite low, mostly between -4 and 4, and without particular patterns (Figure 3.3.1.6). Only in 2018 for the Pas_gears_TUN_ITA, residuals are larger for some length classes. In particular, the model underestimates the fraction specimens below 20 and larger of 50 cm.

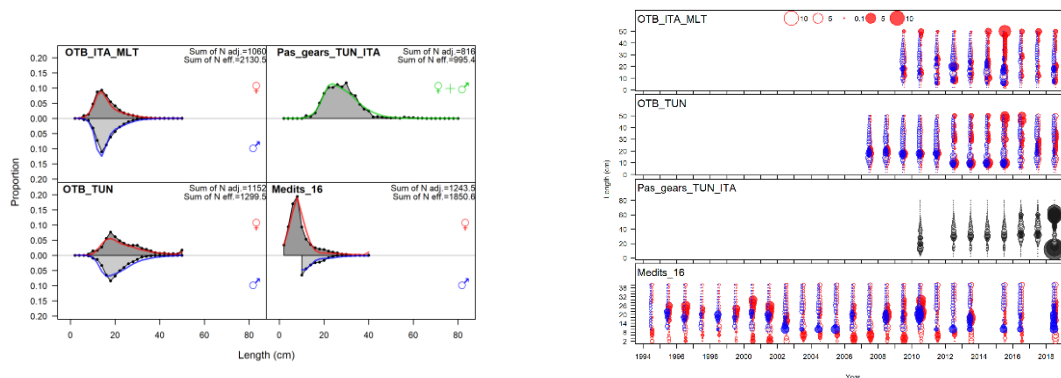


Figure 3.3.1.6. Model fits to length composition data (left) and residuals of fits to length composition data for the different fleets (right) for European hake in GSAs 12-16

c. Biomass index fitting

Overall, the model provides a good fit to the trends in the MEDITS CPUE index (Figure 3.3.1.7). The model fit to the MEDITS survey index was good except for 2005, which was underestimated in all models.

A non-random pattern of residuals may indicate that some heteroscedasticity is present, or that there is some leftover serial correlation (serial correlation in sampling/observation error or model misspecification). Several well-known nonparametric tests for randomness in a time-series include: the runs test, the sign test, the runs up and down test, the Mann-Kendall test, and Bartel's rank test (Gibbons and Chakraborti, 1992).

We used two runs test (JABBA and ordinary runs test) to evaluate whether residuals of the surveys and the length frequency distributions were normally distributed or/and had time trends. These tests have been used recently to diagnose fits to indices and other data components in other assessment models (e.g. SEDAR 40, 2015; Winker *et al.*, 2018). The results of the runs test are presented in Figures 3.3.1.8 and 3.3.1.9.

The JABBA runs test indicated that the fit of the CPUE index was good because no residuals were larger than 1 and the root mean square error (RMSE) is less than 30 percent, indicating a random pattern of the surveys residuals and the length frequency distributions. The JABBA plot is considered as a tool for identifying trends in residuals and if the standard deviation is tight on a given year, this means the fleets are in agreement, even if not fitting well, which is a useful diagnostic. Its purpose is to visualize multiple residuals at once, pick up on periods of substantial data conflicts (width of boxes) and systematic departures in median residuals (loess). In this case, as we have only one survey, the RMSE is the only useful metric. On the contrary, the ordinary runs test was not passed for the MEDITS survey residuals, likely due to the 2005 MEDITS estimate, while the runs tests were passed for all length frequency distributions.

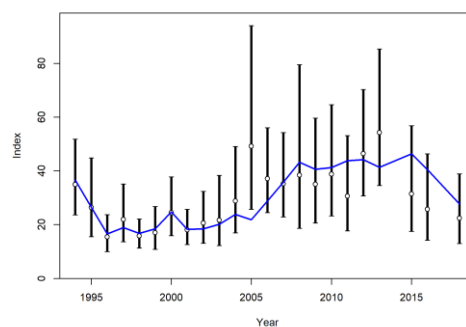


Figure 3.3.1.7. Model fits to MEDITS survey biomass index for European hake in GSAs 12-16

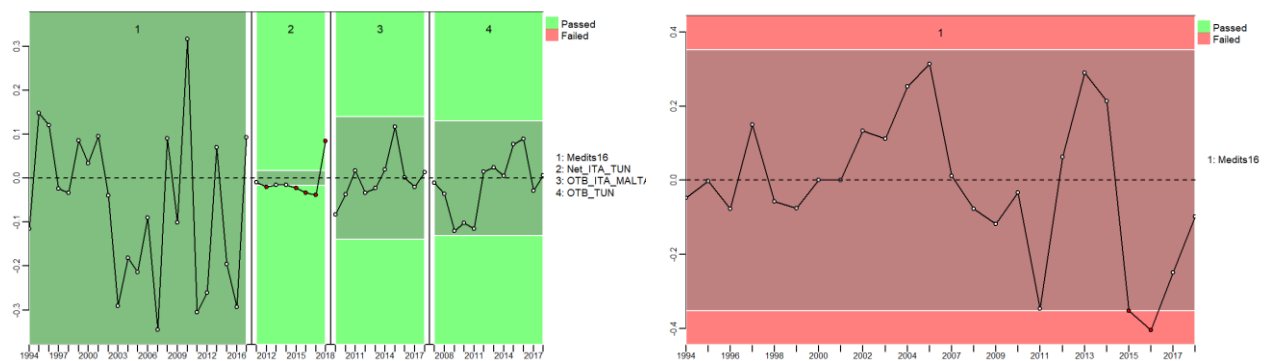


Figure 3.3.1.8. Residuals from ordinary runs test analyses for European hake in GSAs 12-16 with MEDITS length distributions (left) and MEDITS biomass index (right)

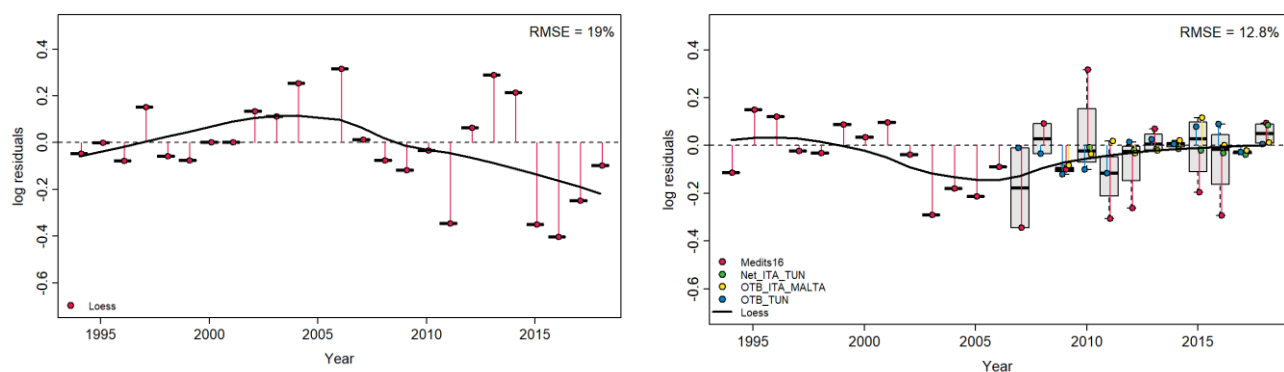


Figure 3.3.1.9. Residuals from the JABBA runs test analyses for European hake in GSAs 12-16 with the MEDITS biomass index (left) and MEDITS length distributions (right)

d. Trends in SSB, F and R of the reference model

The stock status and the trends in SSB, R and F of the reference model based on the MLE are showed in Figure 3.3.1.10. The SSB has been declining since the beginning of the time series in parallel with the development of the fisheries for European hake in GSAs 12-16. SSB is estimated to be below BMSY since the middle of the 1980s. A slight recovery in SSB in recent years has been estimated since the lowest value was observed around 2000, although SSB has started to decline again in the last two years. Fishing mortality (F) has increased markedly since 1970s, with a peak in the end of the 1990s. Thereafter, F has declined to a lower level but it is estimated to above FMSY since the beginning of the 1980s. Recruitment (R) has been declining in concomitance to the decline in SSB and no large year classes has been observed in the latest years, with the last four year classes being the lowest observed over the entire time series (Figure 3.3.1.10). Interestingly, the development of the SSB is mirroring very closely the development of the fleet capacity of the main fleet (i.e. the Italian trawlers), which increased from just after the Second World War to the middle of the 1980s and decreased thereafter (Ben-Yehoyada *et al.*, 2016).

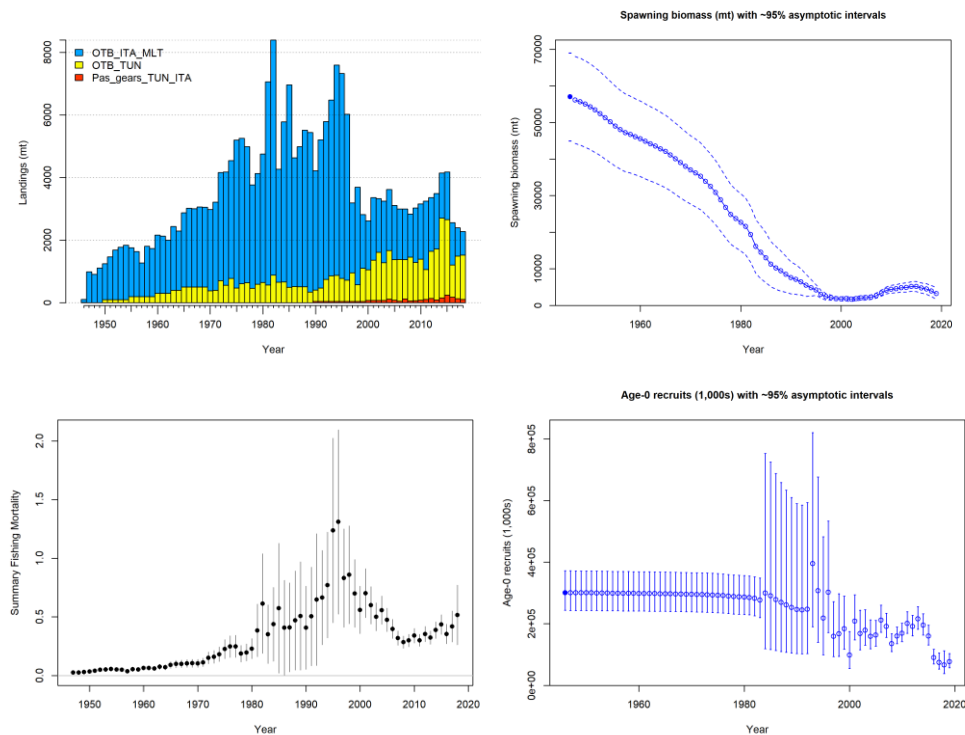


Figure 3.3.1.10. Summary of the stock assessment with SSB, F and R with 95 percent confidence intervals and landings by fleet (in tonnes) for European hake in GSAs 12-16

L. Diagnostic, comparison between model runs, sensitivity analysis

a. Jittering

Jittering test was performed with 200 runs and considering a 10 percent of jitter of the initial parameters, which means that a small random jitter is added to the initial parameter values. Starting values are jittered based on a normal distribution based on the pr (PMIN) = 0.1 percent and the pr (PMAX) = 99.9 percent.

The 200 iterations of the jitter test for global convergence resulted in 194 converged model runs, among these 128 model runs with a minimum total likelihood value ± 10 likelihood units to that of the base case model run. Six model runs failed to converge (Figure 3.3.1.11). All model runs with a minimum total likelihood value ± 10 likelihood units to that of the base case model run, resulted in similar time series of spawning biomass, fishing mortality and number of recruits at age zero (Age-0 recruits). Values obtained were within the asymptotic 95 percent confidence intervals obtained for the base case model run. Results of the converged jitter runs showed that estimating the peak parameter in the MEDITS survey selectivity made the model slightly more unstable (Figure 3.3.1.12). For this reason, another jitter (100 iterations) was performed fixing the value of the peak in the MEDITS survey selectivity at same value of the estimated by the model. Results showed that this improved the stability of the model (Figure 3.3.1.12). In addition, no local minima are observed as no runs have a likelihood lower than the reference run. It is however important to stress that the absence of a local minima when running jittering is not a guarantee that the model is not indeed stuck in a local minimum, although its absence reduced the risks that this occurs (Subbey, 2018).

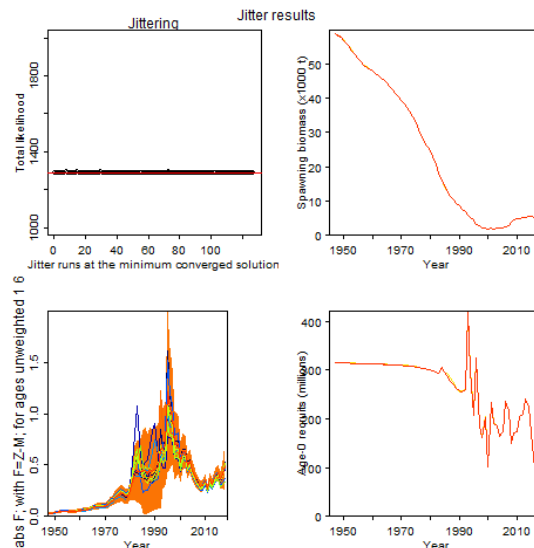


Figure 3.3.1.11. Results from jitter, using 200 iterations, estimated MEDITS selectivity peak and an average jitter of 10 percent for European hake in GSAs 12-16

The figure shows 128 model runs with a minimum total likelihood value ± 10 likelihood units to that of the base case model run.

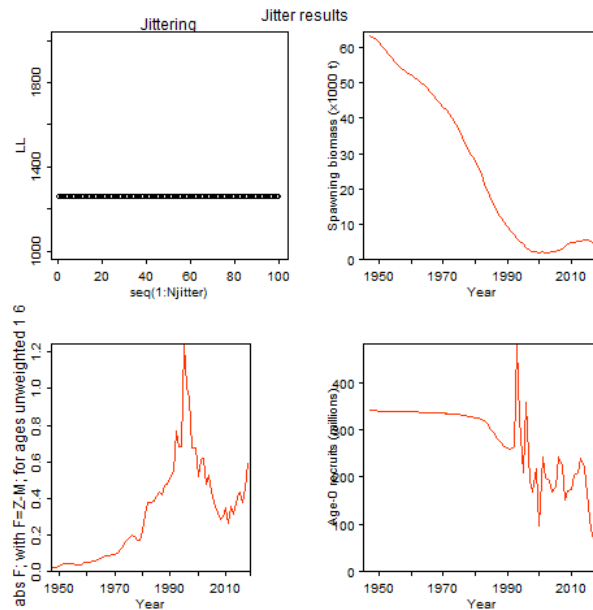


Figure 3.3.1.12. Results from jittering with MEDITS selectivity peak using 100 iterations and an average jitter of 10 percent for European hake in GSAs 12-16 with in the upper left, the total likelihood (LL) values of the 100 iterations

b. Retrospective analysis

The retrospective analysis was conducted with the reference model for the last three years of the assessment time horizon to evaluate whether there were any strong changes in model results. Given that the variability of Mohn's index (as defined in Hurtado-Ferro *et al.*, 2014) depends on life history, and that the statistic appears insensitive to F , Hurtado-Ferro *et al.* (2014) proposed the following rule of thumb when determining whether a retrospective pattern should be addressed explicitly: values of Mohn's index higher than 0.20 or lower than -0.15 for longer-lived species (upper and lower bounds of the 90 percent simulation intervals for the flatfish base case), or higher than 0.30 or lower than -0.22 for shorter-lived species (upper and lower bounds of the 90 percent simulation intervals for the sardine base case) should be cause for concern and taken as indicators of retrospective patterns. However, Mohn's index values smaller than those proposed should not be taken as confirmation that a given assessment does not present a retrospective pattern, and the choice of 90 percent means that a "false positive" will arise 10 percent of the time. In both cases, model misspecification would be correctly detected more than half the time. The retrospectives of the reference model were rather stable (Figure 3.3.1.13). The estimated Hurtado-Ferro (2014) variant of the Mohn's indices was just outside the bound of the recommended values for SSB (0.21).

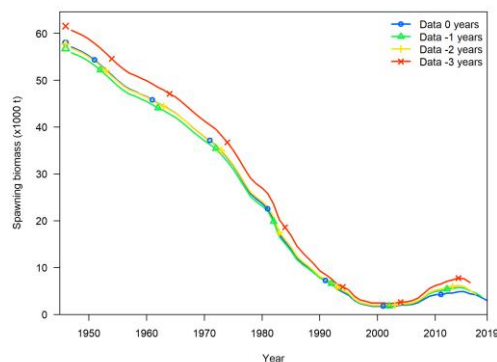


Figure 3.3.1.13. Retrospective analyses of the reference model with the MEDITS selectivity peak fixed for European hake in GSAs 12-16

c. Markov chain Monte Carlo

We ran a Markov chain Monte Carlo (MCMC) run using the random walk metropolis method with 100 000 iterations, with no burn-in period and thinning each 100 iterations. Parameters with a large estimated standard deviation in reference model based on MLE were fixed at the estimated value. These were only the first (peak) and the second parameter (ascendant width) of the MEDITS survey. The results showed that the MCMC is rather similar to the MLE estimated, which is an indication of the robustness of the model (Figure 3.3.1.14).

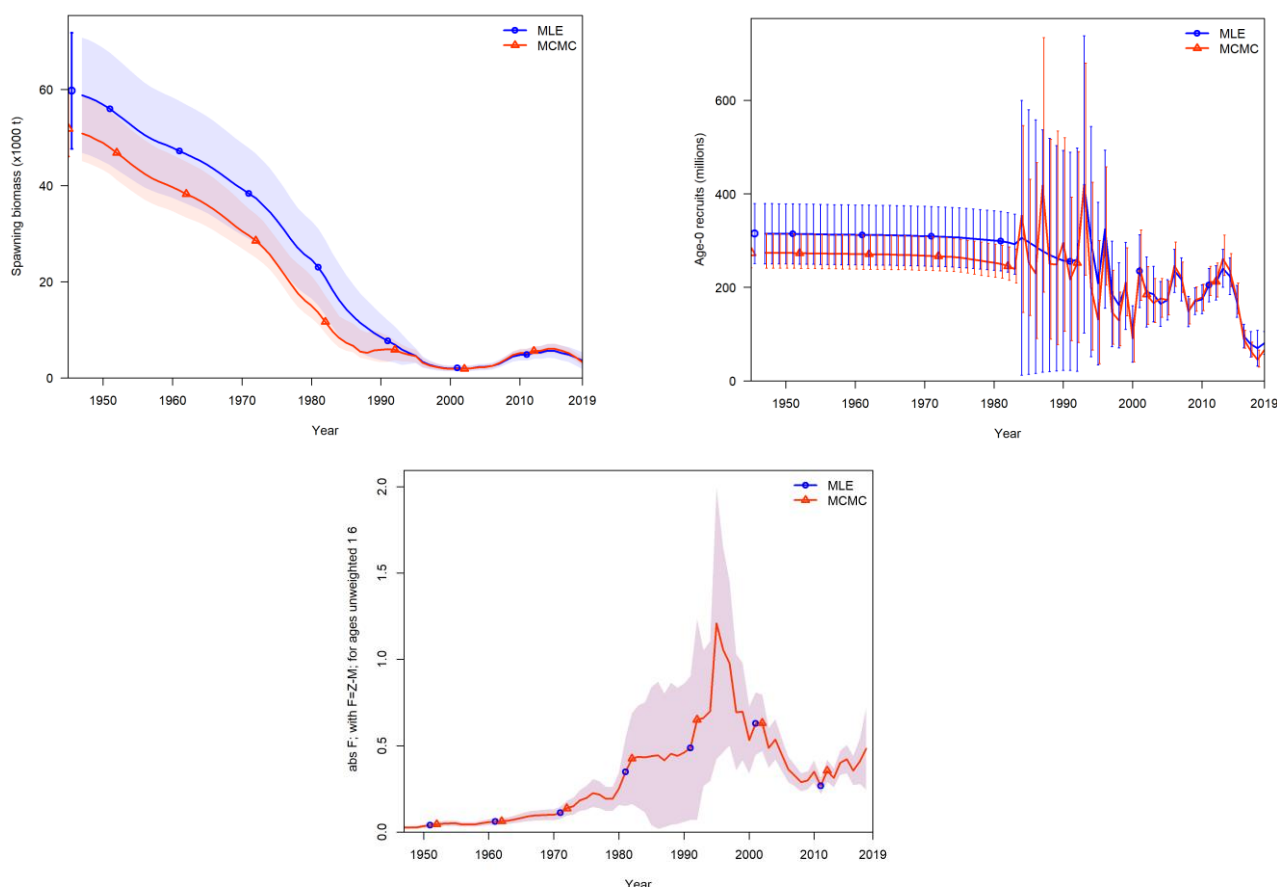


Figure 3.3.1.14. Results of the MCMC analysis in terms of SSB, R and F compared to the MLE model for European hake in GSAs 12-16

d. Age-structured production model

In some integrated stock assessments, the index of abundance provides almost no information on population scale. Consequently, the estimates of the model outputs rely almost completely on the size- and age-composition data and model structure. Maunder and Piner (2015) proposed a diagnostic tool that can be used to evaluate the information content of data about absolute abundance and assess whether the model is correctly specified. This diagnostic consists of comparing the results of an age-structured production model (ASPM) to those from a model estimating all of the model parameters and fitting to all the data (e.g., an integrated analysis). It is inferred that a production function is apparent in the data when the catch data explain indices with good contrast (e.g. declining and increasing trends), therefore providing evidence that the index is a reasonable proxy of stock trend. If the ASPM cannot mimic the index, then either the stock is recruitment-driven, catch levels have not been high enough to have a detectable impact on the population, the model is incorrect, or the index of relative abundance is uncertain or not proportional to abundance. Thus, ASPM is able to evaluate if variations in predicted population dynamics are mainly informed by the relative abundance indices and catches, and governed by the underlying surplus production function and process error or instead are driven by changes in recruitment or other biological characteristics of the stock (growth, M, maturity etc.).

To perform the ASPM diagnostic test, we had to change the original model parameterization. SS can behave like an ASPM (Methot and Wetzel, 2013) when the parameters of the selectivity curve are fixed at those

estimated from the fully integrated model, the annual recruitment deviates are not estimated (fixed at zero so that recruitment follows the stock-recruitment relationship), and the age- and size-composition data are not used for parameter estimation. The results from the ASPM should be similar to those from the fully integrated model if the size- and age-composition data are not informing absolute abundance or the trend in abundance and there is no strong pattern in recruitment. The ASPM test (Maunder and Piner, 2015) appears to have promise in detecting systems dynamic misspecification (h and M), where the runs test showed lower power, and ASPM showed good power. For European hake in GSAs 12-16, a production relationship was evident in the assessment models, with ASPM results leading to very similar estimates of SSB and SSB₂₀₁₈ compared to the correspondent fully integrated model (Figure 3.3.1.15).

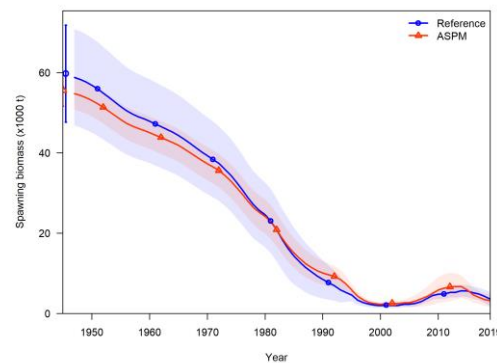


Figure 3.3.1.15. Results of the ASMP analysis in terms of SSB compared to the MLE model for European hake in GSAs 12-16

e. Exploratory runs

Using as baseline the reference model, ten different models were explored. The alternative configuration detected are reported in Table 3.3.1.4. The modifications compared to reference model regarded:

- data input:
 - official landings were used from model 1 to model 8 (see 3.3.1.1) and official landings based on the Minipestat adjusted were used in the model 9 and 10, for year 1983–1997;
 - ALK were only used in models 3 and 4; and
- parameters: different configuration of growth, selectivity, steepness, M, recruitment and weighting method were used.

Table 3.3.1.4. Alternative model runs with different configurations for European hake in GSAs 12-16

Id	Landing	Growth	Selectivity	ALK	Steepness	M	Sig maR	Other modifica tion
Model 1 NOITANET	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time invariant	Yes	0.88	Using growth from last assessment	0.5	
Model 2 NOITANET 099	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time invariant	Yes	0.99	Using growth from last assessment	0.5	
Model 3 NOALK	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time invariant	No	0.88	Using growth from last assessment	0.5	
Model 4 NOALK_09 9	Official	Parameter used in the last assessment	Time invariant	No	0.99	Using growth	0.5	

Id	Landing	Growth	Selectivity	ALK	Steepness	M	Sig maR	Other modifica tion
		of European hake GSAs 12-16 (2016)				from last assessment		
Model 5 RAMP	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time invariant	Yes	0.88	Using growth from last assessment	0.5	Recruit ment deviatio n is set consider ing the ramp method (Methot and Taylor, 2011)
Model 6 TVSEL_IAN	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time varying	Yes	0.88	Using growth from last assessment	0.5	Iannelli weightin g method
Model 7 TVSEL_IAN_082	Official	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time varying	Yes	0.82 (Myers <i>et al.</i> , 1999)	Using growth from last assessment	0.5	Iannelli weightin g method
Model 8 VarGR	Official	Estimated	Time invariant	Yes	0.99	Using growth from last assessment	0.5	
Model 9 PEST_TVSEL_IAN_082	Official adjusted	Parameter used in the last assessment of European hake GSAs 12-16 (2016)	Time varying	Yes	0.82 (Myers <i>et al.</i> , 1999)	Using growth from last assessment	0.5	Iannelli weightin g method
Model 10 PEST_TVSEL_IAN_Gr	Official adjusted	Parameter reported by CNR IAMC 2007	Time varying	Yes	0.88	Using growth CNR IAMC 2007	0.5	

The main results in terms of likelihood component, parameter values and derived model quantities for the alternative model configurations are reported in Table 3.3.1.5. The first five alternative models generally did not improve the likelihood or convergence of the model, or the fits to different data sources, compared to the reference run. On the contrary, NOALK runs and official adjusted with alternative growth achieved values of AIC lower than reference model but similar values of final convergence. In addition, comparing the estimated catches of models that used the official landings with the reference one, larger differences are evident between observed and expected catches for the time series from 1981 to 1998, suggesting a very likely overestimate of the official landings for this period (Figure 3.3.1.16) and supporting the assumption of the MINIPSTAT estimates in the reference model.

Table 3.3.1.5. Likelihood component, parameter values and derived model quantities for the alternative model configurations for European hake in GSAs 12-16

	Reference model	Model 9	Model 10	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
AIC	3032	3092	2881	3912	3970	2741	2707	3943	3063	3054	3173
deltaAIC	0	60	-151	880	938	-291	-325	911	31	22	141
Survey likelihood											
Medits	-26	0	0	-5	-8	-10	-8	-11	-2	-3	-7
Length likelihood											
ALL	733	-34	30	-444	-450	-416	-383	-445	-4	-13	-247
OTB_ITA	106	0	3	-69	-70	-57	-55	-69	0	0	-57
OTB_TUN	207	-2	9	-5	-7	18	16	-4	-1	-4	-10
Net_TUN	114	0	3	-132	-133	-112	-115	-133	-2	-3	-117
Medits	306	-31	15	-239	-240	-266	-230	-239	-1	-6	-63
Age likelihood											
OTB_ITA	565	5	45	11	18	NA	NA	2	7	17	176
Derived quantities											
SB0	56384	69052	41519	92793	47029	97854	44404	110863	76880	92362	50781
SSB_2018	3823	4158	2325	3356	4656	1788	565	2881	3246	4194	935
F_2018	0.52	0.54	0.58	0.47	0.34	0.69	1.45	0.44	0.47	0.45	0.58
F_MS _Y	0.29	0.25	0.30	0.27	0.47	0.28	0.46	0.25	0.28	0.25	0.31
SSB_MS _Y	10745	15331	8093	18149	4121	18522	5615	22651	14899	20524	8028

The values in the likelihood component of each model indicate changes in likelihood units compared to the reference model. Values +/- 2 likelihood units are considered significantly different.

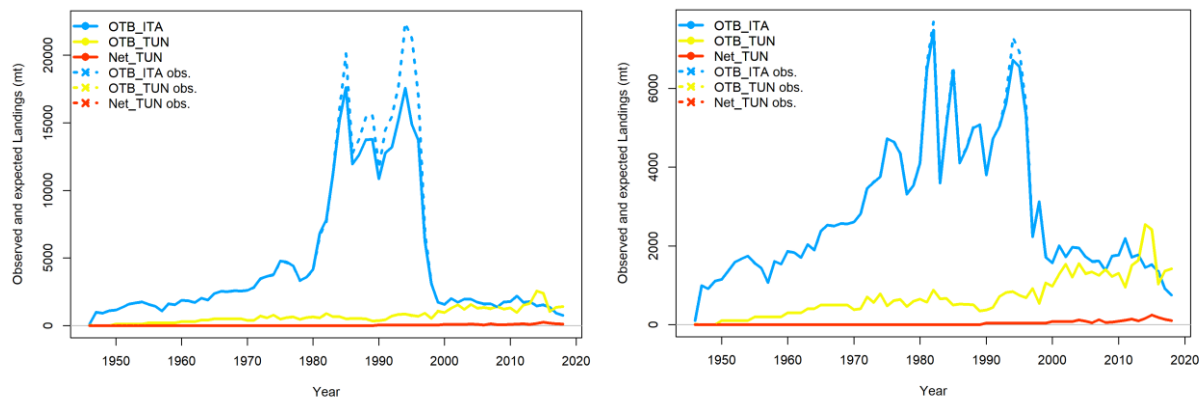


Figure 3.3.1.16. Comparison between observed and expected catches of European hake in GSAs 12-16 in the two alternative series of landings for years 1981–1998 with the catches used in the reference model (PEST) (right) and the Italian official catches for the Italian trawlers, which have been used in the last three models reported in Table 3.3.1.4 as an alternative data configuration (left)

For more details, see section 3.3.1.1

Finally, the median trend with the 95 percent confidence intervals of SSB/SSB_{MSY} and F/F_{MSY} for the aggregated 10000 estimates of 2018 stock status of the 11 model options is shown in Figure 3.3.1.17. All different model configurations median estimate for 2018 are in the red quadrant of the kobe plot, with the exception of model 2 (NOITANET099).

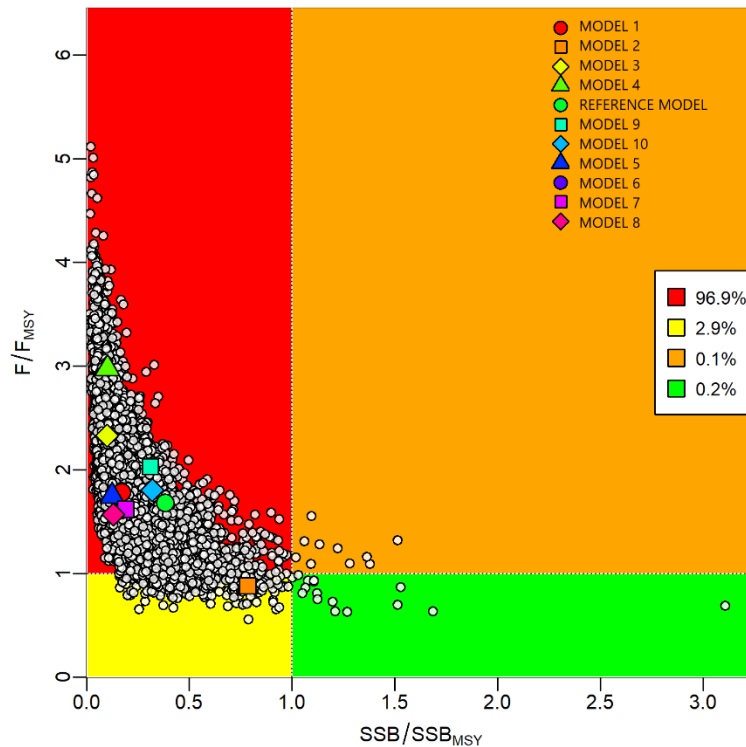


Figure 3.3.1.17. Aggregated assessment Kobe plot for European hake in GSAs 12-16

The coloured points represent stock status estimates from the 11 model options. The white points represent the aggregated 10000 estimates of 2018 stock status from the multinomial approximation from the mean and variance-covariance of the 11 model options. The legend indicates the estimated probability of the stock status being in each of the Kobe quadrant.

3.3.1.2. Method 2: extended survivor analysis

In continuity with previous assessments of European Hake conducted in this area continuously since 2014 with XSA, an additional run of the XSA model was performed as implemented in the FLR (fisheries libraries in R). Although results are reported here, only the SS3 model was presented as candidate model for the benchmark.

The XSA assessment was carried out using official trawl catch data (landings and discards, EU DCF) collected in GSAs 15-16 and GSAs 12-14 (Tunisia) in the period 2007–2018. The XSA was tuned using MEDITS survey data (2007–2018) from GSAs 15 and 16. The natural mortality M was estimated by Prodbiom's method. The annual size of the landings, as well as MEDITS data were converted into the number at age by knife edge slicing.

A. Model assumptions

Darby and Flatman (1994) outlined the XSA algorithm as performing the following steps: i) a cohort analysis of the total catch-at-age data to produce estimates of population abundance-at-age, and total fishing mortalities; ii) adjustment of the CPUE values for the period of fishing defined using the alpha and beta parameters in the fleet tuning file, into CPUE values that would have been recorded if the fleet had fished only at the beginning of the year. The adjusted values are directly comparable with the population abundances at the beginning of the year; iii) calculation of fleet-based estimates of population abundance-at-age from the adjusted CPUE values and fleet catchabilities; and iv) calculation of a least squares estimate (weighted mean) of the terminal population (survivors at the end of the final assessment year) for each cohort in the tuning range using the fleet-derived estimates of population abundance-at-age. These terminal populations are used to initiate the cohort analysis in the next iteration. The process iterates until the convergence criteria described for *ad hoc* tuning are achieved. Various options are available for catchability analysis, time series weighting and shrinkage of the weighted estimates.

B. Input data and parameters

The information used for the assessment of European hake in GSAs 12-16 was kept constant in respect of previous years' XSA assessments and consisted of:

- catch at length and landings data from Italy and Malta collected according to the field data collection framework (DCF) from 2007 to 2018;
- catch at length and landings data from Tunisia provided by the official Tunisian landing statistics;
- MEDITS survey in GSAs 15 and 16 as tuning data;
- biological parameters: $L_{\infty}=100$, $k=0.116$, $t_0=-0.6$, $a=0.004$, $b=3.15$ for combined sexes from average SAMED (2002) / Ben Meriem (unpubl.); and
- natural mortality M estimated by Prodbiom method.

Table 3.3.1.6. Catch matrix in N by year and age in thousands

	0	1	2	3	4	5	6	7	8
2007	241.5	23 788.4	4 736.2	890.8	181.8	64.9	62.6	12.8	10.6
2008	193.6	19 434	4 982.3	1 057.8	182.7	50.6	39.1	13	10.6
2009	930.8	27 041.7	5 428.8	1 066.4	3 31.7	159.1	139.2	42.5	19
2010	608.3	19 881	6 121	1 327.2	3 16.2	230.1	128.3	43.1	18.3
2011	877.4	25 951.4	5 182.4	1 383.4	309.1	194.1	101.4	39.6	21
2012	1 766.6	15 950.4	7 402.7	1 833.8	434	172.2	92.6	94.7	77.5
2013	1 904.3	15 593.8	8 189.3	2 016.8	501.7	190.4	87.6	88.7	74.5
2014	2 720.2	17 303.9	8 964.3	2252	558.8	219.1	112.3	127.2	113.2
2015	2 351.6	13 638.5	7 393	2 284.9	555.2	633.1	309.6	99.9	157.8
2016	706.1	12 531.1	8 216	2 170.8	843.6	774.2	447.1	162.4	190.6
2017	406.4	17 969.2	8 937.8	2 037.2	273.1	212.9	122.4	9.6	5.9
2018	3 840.1	14 080.4	11 690.5	2 894.9	899.3	137.6	15.4	10.6	3.3

Table 3.3.1.7. Catch matrix in weight (kg) by year and age

	0	1	2	3	4	5	6	7	8
2007	0.0143	0.0562	0.1668	0.4016	0.7317	1.1926	1.6269	2.2206	2.9616
2008	0.0148	0.0609	0.1692	0.4054	0.7179	1.0784	1.5968	2.1848	3.1838
2009	0.0112	0.0446	0.1405	0.3222	0.5959	0.9241	1.3058	1.7189	2.3680
2010	0.0116	0.0518	0.1524	0.3464	0.6384	0.9606	1.4257	1.8321	2.3534
2011	0.0126	0.0484	0.1505	0.3308	0.6166	0.9071	1.3642	1.7640	2.4476
2012	0.0093	0.0517	0.1434	0.3159	0.5776	0.9043	1.3274	1.6908	2.0393
2013	0.0093	0.0526	0.1418	0.3145	0.5749	0.8750	1.2976	1.6416	1.9507
2014	0.0096	0.0544	0.1456	0.3156	0.5832	0.9000	1.3471	1.6916	1.9906
2015	0.0091	0.0448	0.1389	0.3062	0.5682	0.8418	1.2393	1.7000	1.9081
2016	0.0148	0.0427	0.0907	0.2379	0.3168	0.3570	0.5383	0.7675	0.7976
2017	0.0074	0.0341	0.0989	0.2160	0.4044	0.6251	0.8985	1.8363	0.0305
2018	0.0037	0.0254	0.0774	0.1909	0.3208	0.5171	0.8624	1.0590	1.3381

Table 3.3.1.7. Tuning data by year and age in thousands (density indices were raised to the whole GSAs 15 and 16 areas assuming the same catchability)

	Tuning data at age								
	0	1	2	3	4	5	6	7	8
2007	42.44	4.67	0.75	0.22	0.11	0.04	0.02	0.01	0.003
2008	19.64	8.18	1.16	0.26	0.08	0.03	0.02	0.02	0.011
2009	27.55	6.51	1.24	0.31	0.11	0.04	0.02	0	0.001
2010	7.21	5.91	2.04	0.36	0.11	0.04	0.01	0.01	0.008
2011	20.8	3.38	0.76	0.27	0.1	0.06	0.03	0.02	0.009
2012	47.5	5.52	1.18	0.26	0.08	0.04	0.01	0.004	0.004
2013	16.78	11.88	1.57	0.39	0.12	0.06	0.02	0.02	0.011
2014	19.68	10.06	1.06	0.25	0.09	0.06	0.03	0.01	0.02
2015	22.65	6.93	2.36	0.42	0.26	0.14	0.04	0.04	0.02
2016	19.19	9.83	1.64	0.65	0.19	0.11	0.08	0.04	0.03
2017	8.35	8.38	1.47	0.34	0.14	0.08	0.07	0.02	0.01
2018	4.48	6.74	1.8	0.45	0.11	0.04	0.03	0.01	0.01

Table 3.3.1.10. Natural Mortality at age estimated by Prodbiom method

Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1.38	0.56	0.27	0.21	0.19	0.18	0.17	0.16	0.16

Table 3.3.1.10. Proportion of mature specimens by age

*Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
0.01	0.16	0.61	0.93	0.98	1.0	1.0	1.0	1.0

C. Results

As in previous year, the XSA run with shrinkage of 1 and catchability equal to three years was adopted as final model (Figure 3.3.1.18) based on both residuals and retrospective analysis.

Setting parameters of the adopted model

```
xsa_control <- FLXSA.control (x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1, rage=0, qage=4,
shk.n=TRUE, shk.f=TRUE, shk.yrs=1, shk.ages=3, window=100, tsrange=20, tspower=3, vpa=FALSE)
```

The XSA results in terms of SSB and annual recruitment are reported in Table 3.3.1.11. SSB seems to be stable from 2006 to 2011, increases until 2014 and then decreases. Recruitment varies with no clear trend.

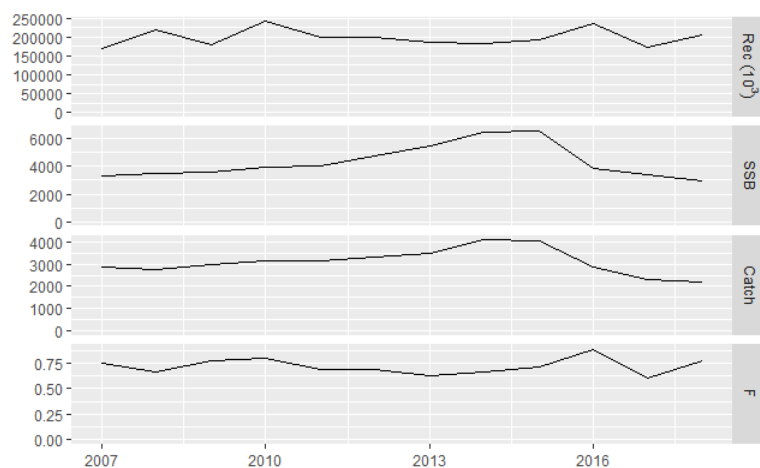


Figure 3.3.1.18. Final XSA model for European hake in GSAs 12-16

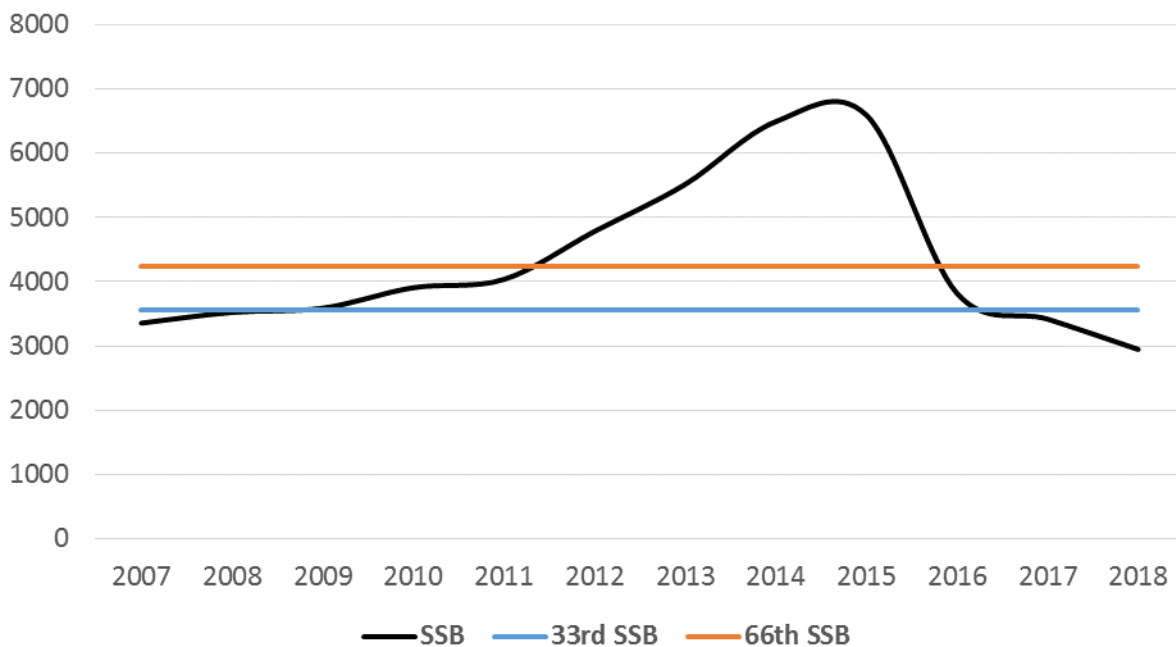
Table 3.3.1.11. XSA estimates of total biomass (TB), spawning stock biomass (SSB) and recruitment

Year	SSB (t)	Recruitment	TB (t)
2007	2 855.1	168 153	8 052.1
2008	3 160.1	217 108	9 145
2009	3 368.3	179 246	7 985.8
2010	3 722	240 594	9 122
2011	3 773.2	197 871	9 384.7
2012	4 533.5	198 135	9 408.8
2013	5 229	183 366	10 094
2014	6 263	184 331	11 130.3
2015	6 485.6	188 777	10 693.6
2016	3681	237 829	9 443.2
2017	3 206.2	180 506	6 958.9
2018	2 871.4	213 140	5 309.7

Fishing mortality values at age are reported in Table 3.3.1.12. $F_{bar (1-5)}$ fluctuates without any trend. The average $F_{bar (1-5)}$ of the last three year (2016–2018) was 0.80 ± 0.25 .

Table 3.3.1.12. F at age by XSA

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
2007	0.003	1.120	1.031	0.836	0.748	0.536	0.536
2008	0.002	0.941	1.065	0.723	0.399	0.466	0.466
2009	0.010	1.068	1.080	0.733	0.525	0.720	0.720
2010	0.005	0.890	1.062	0.936	0.500	0.859	0.859
2011	0.009	0.844	0.836	0.791	0.585	0.652	0.652
2012	0.018	0.558	0.851	0.895	0.624	0.761	0.761
2013	0.021	0.547	0.870	0.629	0.666	0.612	0.612
2014	0.030	0.707	1.005	0.668	0.354	0.687	0.687
2015	0.025	0.512	1.093	0.831	0.339	0.865	0.865
2016	0.006	0.443	0.943	1.363	0.884	1.134	1.134
2017	0.004	0.510	0.922	0.686	0.597	0.565	0.565
2018	0.037	0.531	1.067	0.986	0.765	0.683	0.683

**Figure 3.3.1.19.** Trend of SSB (2007–2018) in GSAs 12-16 estimated by XSA.

The value in the last year is lower than 33th percentile.

D. Robustness analysis

Residuals at age of the MEDITS survey are reported in Figure 3.3.1.20.

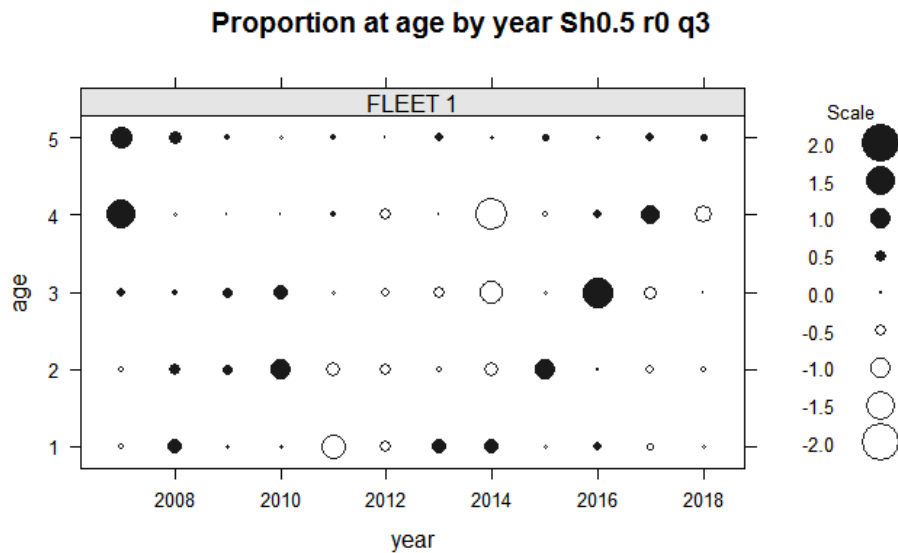


Figure 3.3.1.20. Residual at age of MEDITS survey

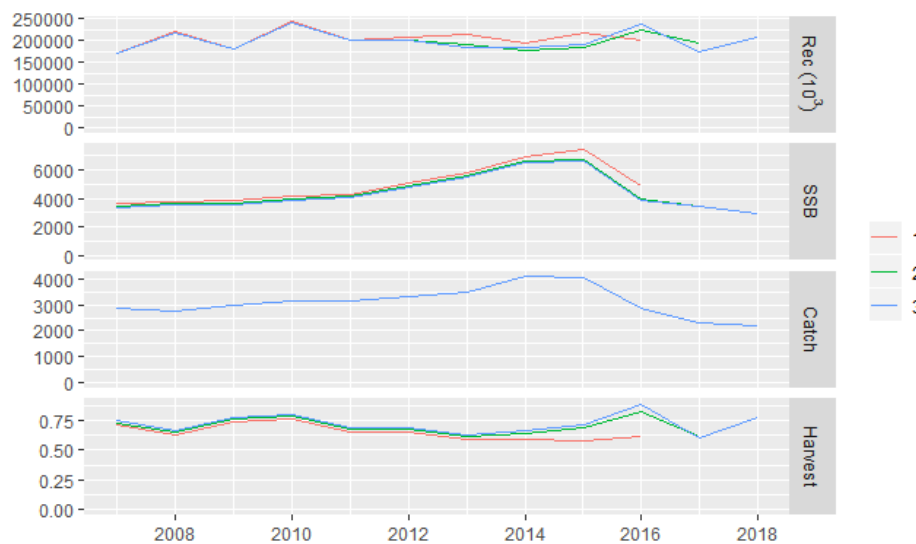


Figure 3.3.1.21. Retrospective analysis

E. Assessment quality

Based on MEDITS residuals and the retrospective analysis, the XSA results appear consistent and in line with the XSA assessment carried out in 2018 (Figure 3.3.1.22). Residuals did not show any trend. Overall diagnostics are acceptable, and the retrospective analysis seems to be consistent.

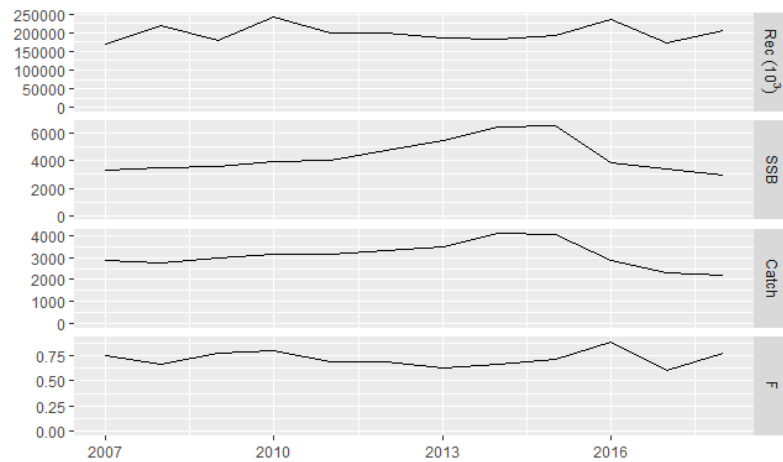


Figure 3.3.1.22. Final XSA model obtained in 2018 for European hake in GSAs 12-16

3.3.1.3. Comparison between model outcomes

The following figures showed the comparison between the two models, namely XSA and SS in terms of SSB and F (Figure 3.3.1.23). However, the SSB estimates from the stock synthesis model refer only to female specimens.

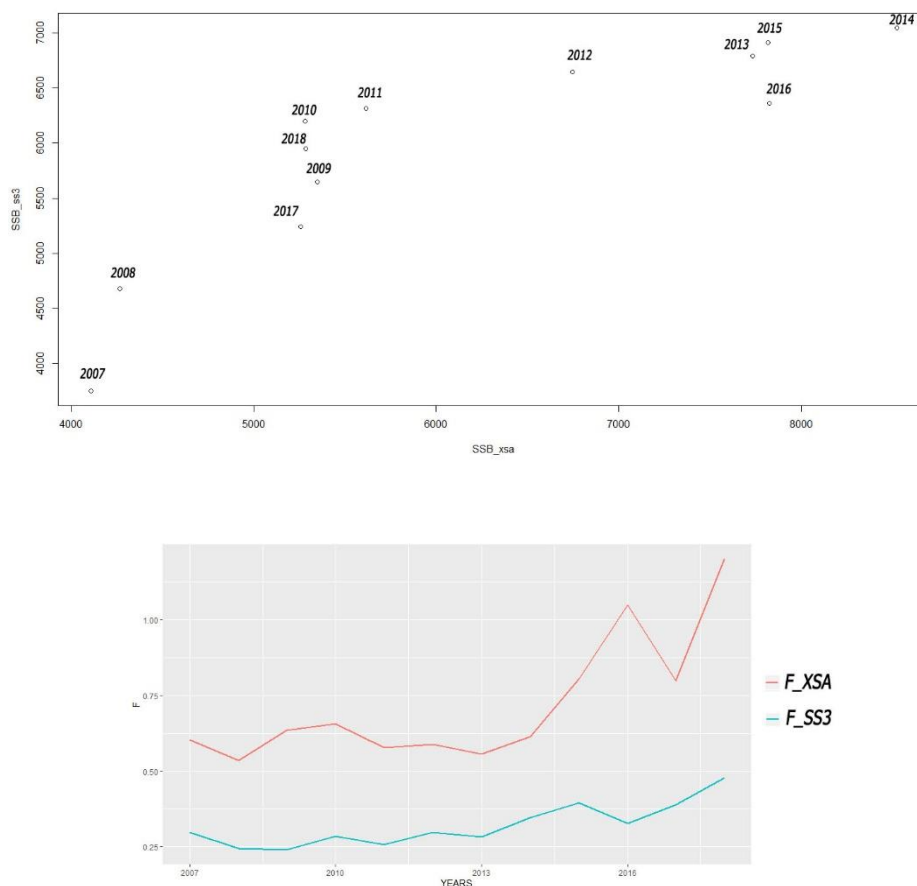


Figure 3.3.1.23. Comparison between stock synthesis (i.e. final model as agreed at the benchmark) and XSA estimates of SSB and F for European hake in GSAs 12-16

3.3.1.4. Final model

The SS3 model was presented as candidate to benchmark for different reasons: i) it is an integrated model that uses all available data, in as raw a form as appropriate, in a single analysis; ii) it treats each fleet separately and allows to specify the different sources of data, providing different uncertainty estimates for each data set; iii) it estimates the selectivity for each fleet allowing to use different types of selectivity curve; and iv) it is able to set time-varying parameters.

During the benchmark session, the MEDITS survey data were corrected because of some minor mistakes. Also, the ALK were used differently from the preliminary reference model developed before the benchmark, and they were inputted as observed separately for females and males to allow the sex ratio to be independent for female and males as suggested by the stock synthesis manual. Therefore, a revised reference model was developed and agreed as the final model for advice. However, it is important to note that the diagnostics presented above is related to the original reference model presented on the first day at the benchmark as the input data are essentially the same as well as the model structure. Only the retrospective diagnostic was rerun, also for the final model configurations as agreed at the benchmark.

In addition, during the benchmark session, alternative model configurations were explored:

- excluding the biomass index for the year 2014 and 2017 for the MEDITS survey;
- reducing the time series of the model starting from 1994; and
- reducing the plus group of the MEDITS length compositions data.

The trends in the derived stock quantities from the alternative configurations tested were very similar to the reference model developed at the benchmark, thus the benchmark group decided to use the reference model developed at the benchmark and described above as the final model for advice. It is also important to note that the overall fit of the preliminary reference model developed before the benchmark is very similar to the final model used for advice.

The results in terms of SSB, R and F of the final model are shown in Figure 3.3.1.24 and Table 3.3.1.13. The retrospective of the final model is shown in Figure 3.3.1.25. The Mohn's rho of the SSB is 0.17 and for F is 0.03, so under the thresholds suggested by Hurtado-Ferro *et al.* (2014). The results are included in Table 3.3.1.13. The model fits reasonably well all data components, except the sex ratio of the fish larger than 35-40 cm for Italian and partially for Tunisian trawler. Attempts were made to improve the fitting of the sex ratio and the best results were obtained estimating the growth parameters of the males only within the model (data not shown). However, the benchmark decided to maintain the above described configuration (i.e. growth parameters of both males and females are estimated outside the model and fixed) for the final model used for advice. All figures not included in this report are available on the GFCM Sharepoint or upon request to the authors.

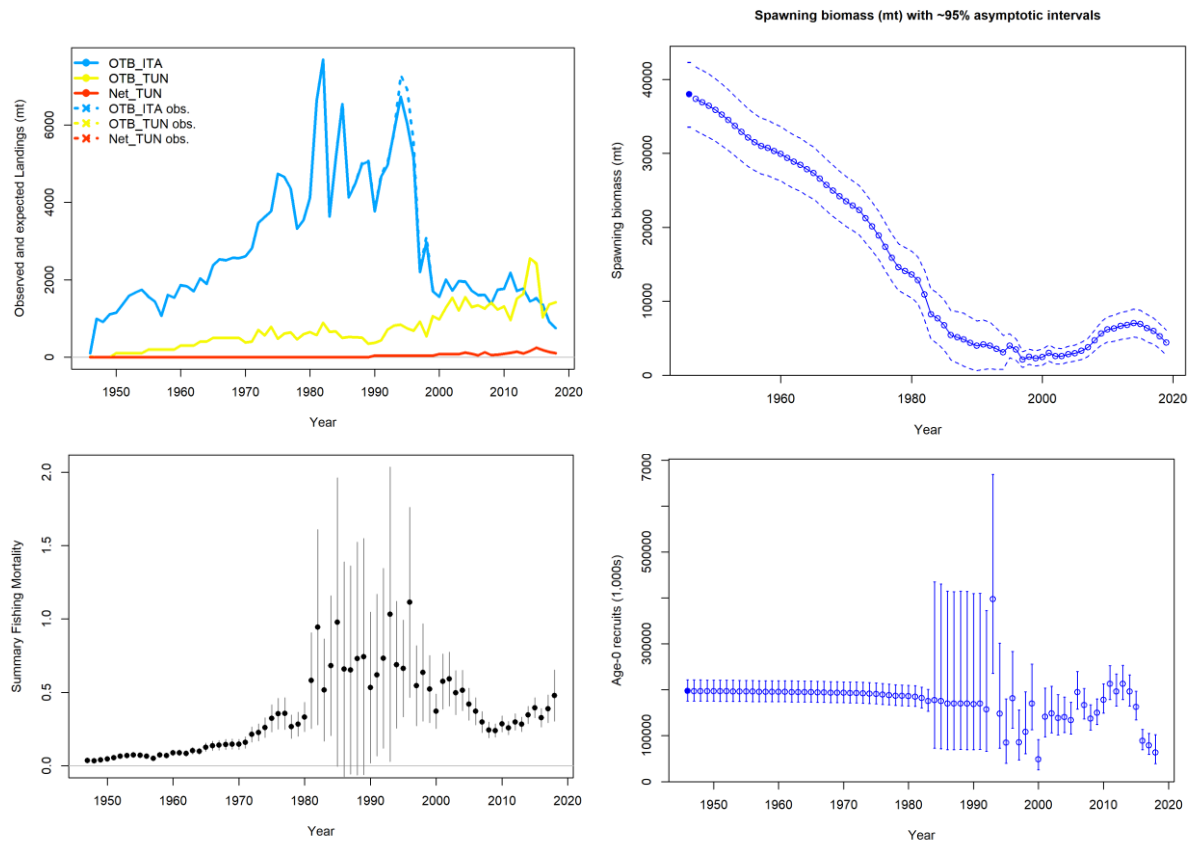


Figure 3.3.1.24. Summary of the stock assessment for the final model agreed at the benchmark for European hake in GSAs 12-16 with SSB, F, R with 95 percent confidence intervals, and catches by fleet (in tonnes)

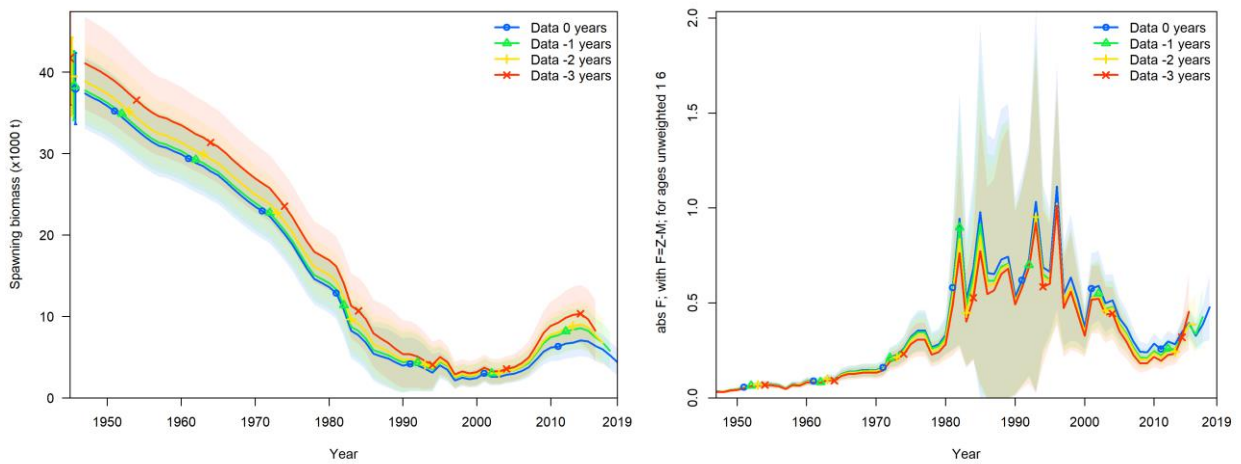


Figure 3.3.1.25. Retrospective analyses of the final model agreed at the Benchmark for European hake in GSAs 12-16

Table 3.3.1.13. Summary table of the final model agreed at the benchmark for European hake in GSAs 12-16 (landings, discards and SSB in tonnes; recruitment in 1000s individuals)

Years	Landings estimated	Landings observed	Observed discard	F	sd	Recruitment	sd	SSB	sd
1947	990	990		0.034	0.004	197185	11740	37368	2206
1948	910	910		0.032	0.004	197096	11738	36889	2199
1949	1109	1109		0.040	0.005	197007	11735	36417	2181
1950	1246	1246		0.046	0.005	196895	11730	35845	2157
1951	1464	1464		0.055	0.006	196768	11724	35214	2128
1952	1686	1686		0.065	0.008	196618	11717	34497	2096
1953	1772	1772		0.069	0.008	196445	11710	33700	2062
1954	1840	1840		0.073	0.009	196263	11701	32905	2025
1955	1761	1761		0.070	0.008	196080	11691	32137	1988
1956	1635	1635		0.066	0.007	195916	11681	31478	1953
1957	1273	1273		0.051	0.006	195784	11673	30967	1924
1958	1811	1811		0.072	0.008	195722	11666	30735	1902
1959	1735	1735		0.070	0.008	195604	11661	30296	1887
1960	2163	2163		0.088	0.010	195503	11657	29930	1872
1961	2132	2132		0.088	0.010	195343	11652	29371	1859
1962	2000	2000		0.083	0.009	195189	11647	28848	1845
1963	2437	2437		0.103	0.012	195063	11641	28435	1830
1964	2293	2293		0.098	0.011	194873	11636	27830	1818
1965	2879	2879		0.126	0.014	194708	11630	27328	1803
1966	3027	3027		0.137	0.016	194443	11625	26553	1791
1967	3005	3005		0.139	0.016	194139	11618	25716	1775
1968	3067	3067		0.145	0.017	193838	11609	24933	1758
1969	3059	3059		0.147	0.018	193530	11600	24180	1741
1970	2985	2985		0.146	0.018	193235	11590	23496	1724
1971	3216	3216		0.159	0.020	192976	11580	22927	1709
1972	4173	4172		0.213	0.026	192681	11570	22308	1696
1973	4186	4185		0.227	0.030	192120	11562	21214	1683
1974	4553	4552		0.260	0.034	191501	11551	20121	1670
1975	5212	5210		0.323	0.047	190720	11540	18882	1656
1976	5269	5267		0.353	0.053	189617	11535	17359	1646
1977	5003	5002		0.355	0.055	188345	11521	15864	1631
1978	3780	3779		0.267	0.041	187090	11500	14606	1616
1979	4139	4138		0.282	0.042	186528	11454	14100	1612
1980	4773	4772		0.332	0.051	185926	11425	13594	1612
1981	7203	7201		0.580	0.166	184953	11423	12840	1617
1982	8572	8575		0.944	0.340	181849	11560	10876	1692
1983	4303	4306		0.516	0.178	175679	12101	8239	1731
1984	5845	5855		0.682	0.243	177701	85522	7684	1757
1985	7039	7062		0.978	0.501	175655	84632	6750	1720
1986	4651	4665		0.658	0.373	170059	81613	5412	1703
1987	4993	5014		0.652	0.362	169916	81318	5108	1776
1988	5499	5531		0.729	0.405	170354	81524	4809	1824
1989	5401	5443		0.743	0.410	169764	81425	4351	1783
1990	4182	4213		0.532	0.262	168950	80432	3973	1702
1991	5139	5199		0.618	0.281	169812	80496	4134	1700
1992	5715	5795		0.732	0.313	157203	72733	3992	1605
1993	6692	6646		1.032	0.512	397123	107581	3560	1416
1994	7605	8178		0.688	0.220	148185	55598	3094	1166
1995	6819	7715		0.663	0.168	84697	33827	3974	814
1996	5883	6281		1.113	0.330	181402	41830	3454	732
1997	3164	3241		0.545	0.140	85731	26710	2113	539
1998	3547	3696		0.634	0.169	108673	33234	2484	517
1999	2807	2829		0.522	0.116	169835	35889	2272	521
2000	2611	2618		0.371	0.060	48984	16102	2432	552
2001	3365	3368		0.574	0.096	141153	26565	2992	553
2002	3335	3332		0.591	0.094	148566	25593	2577	548
2003	3246	3240		0.497	0.077	138753	22095	2551	526
2004	3629	3618		0.513	0.070	140297	19669	2838	545
2005	3106	3101		0.420	0.056	133588	17542	2973	560
2006	2994	2980		0.371	0.047	194772	20858	3281	589
2007	2991	2984		0.298	0.037	166426	16757	3753	634
2008	2839	2825		0.244	0.027	137412	13925	4681	715
2009	3034	3032	185	0.240	0.023	149768	14112	5651	808
2010	3166	3161	243	0.285	0.028	178081	16179	6197	867
2011	3245	3239	902	0.257	0.023	212746	18787	6316	902
2012	3363	3361	297	0.298	0.028	196574	17782	6646	929
2013	3497	3497	204	0.282	0.025	212791	18898	6792	950
2014	4158	4138	47	0.345	0.030	195931	17245	7047	960
2015	4184	4185	109	0.394	0.035	162851	15861	6913	958
2016	2557	2565	134	0.327	0.032	88894	11245	6364	939
2017	2400	2399	61	0.388	0.048	79039	11584	5953	906
2018	2270	2274	18	0.478	0.089	63585	15711	5242	869
2019								4397	858

A. Reference points

Reference points estimated by the model were $F_{MSY}=0.29$ and $SSB_{MSY} = 7021$.

Current F (0.48, estimated as the F_{1-6} in the last year of the time series, 2018) is higher than F_{MSY} indicating that European hake stock in GSAs 12, 13, 14, 15 and 16 is over-exploited ($F/F_{MSY} = 1.66$). Moreover, the model estimates a SSB (2019, that correspond to 1 January) of 4 397 tonnes.

Finally, the final results of the model accepted in the benchmark session are reported in the following table.

Table 3.3.1.14. Reference points of the final model

$F_{current} (SS3)$	0.48
F_{MSY}	0.29
$F_{current}/F_{MSY}$	1.66
Current SSB (tonnes)	4 397
SSB_{MSY}	7 021
$SSB_{current}/SSB_{MSY}$	0.63

European hake in GSAs 12-16 is overexploited and in overexploitation.

B. Short-term forecast

The short-term projections are made with stock synthesis using the reference model using MCMC. Recruitment in the forecast period was decided to be set to the average of the last 10 years for which recruitment deviations are estimated in the stock synthesis model. Probabilistic forecasts were used. In this approach, catch and SSB levels corresponding to different catch options are calculated as in typical deterministic short term forecast but using MCMC to make it possible to also include the most correct associated probability of the SSB to be below biomass reference points, for each year of forecast. Therefore, an MCMC with 1 100 000 iterations, no burn-in and 100 000 thinning was run for the different levels of assumed catches in 2020 and 2021, assuming catches in 2019 (i.e. intermediate year) equal to catches in 2018. Recruitment was set at the mean of the last five years to take into account the recent downward trend in recruitment as estimated by the model. Figures 3.3.1.26 and 3.3.1.27 show the kobe plot of the stochastic forecast for 2021 and 2022 conducted applying different fishing TAC levels (TAC at 0, 30 percent, 50 percent, 70 percent and 100 percent of the catches in 2018). The results show that to reduce F to F_{MSY} with 50 percent probability, a reduction in catches between 30 and 50 percent of the current catches is necessary. However, even with zero catches, the probability of the SSB to be above B_{MSY} in the forecast period is null (Tables 3.3.1.15 and 3.3.1.16).

Table 3.3.1.15. Probability of F to fall below F_{MSY} between 2020 and 2022 for European hake in GSAs 12-16 at different levels of catches expressed as percentage of the reduction of present catches in 2020, 2021 and 2022

TAC Year	2020	2021	2022
0	100	100	100
30	100	100	100
50	47	100	100
70	1	54	100
100	0	0	0

Table 3.3.1.16. Probability of SSB to be above B_{MSY} between 2020 and 2022 for European hake in GSA 12-16 at different level of catches reduction in 2020 and 2021

TAC Year	2020	2021	2022
0	0	0	0
30	0	0	0
50	0	0	0
70	0	0	0
100	0	0	0

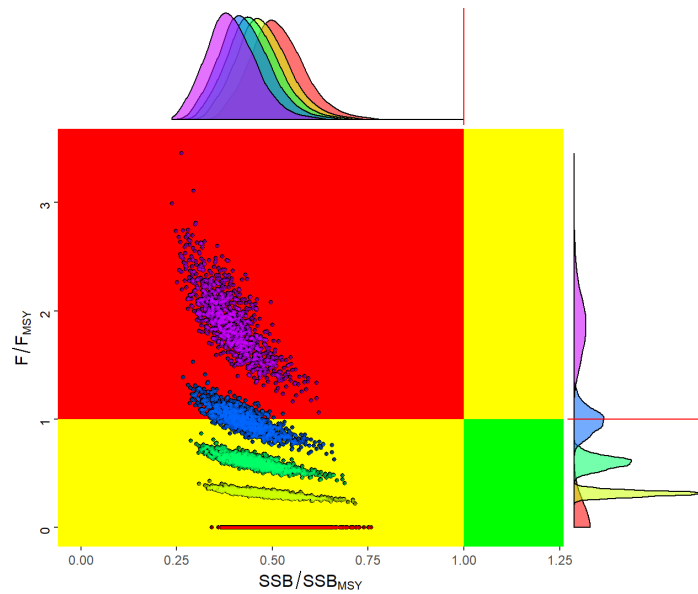


Figure 3.3.1.26. Kobe plot of the stochastic forecast for 2021 for European hake in GSAs 12-16

The plot was conducted applying different fishing catch options (i.e. catch at 0 purple, 30 percent blue, 50 percent green, 75 percent yellow and 100 percent red of the catches in 2018), shown in y-axis. The x-axis shows the corresponding SSB relative to B_{MSY} , while the y-axis shows corresponding F relative to F_{MSY} .

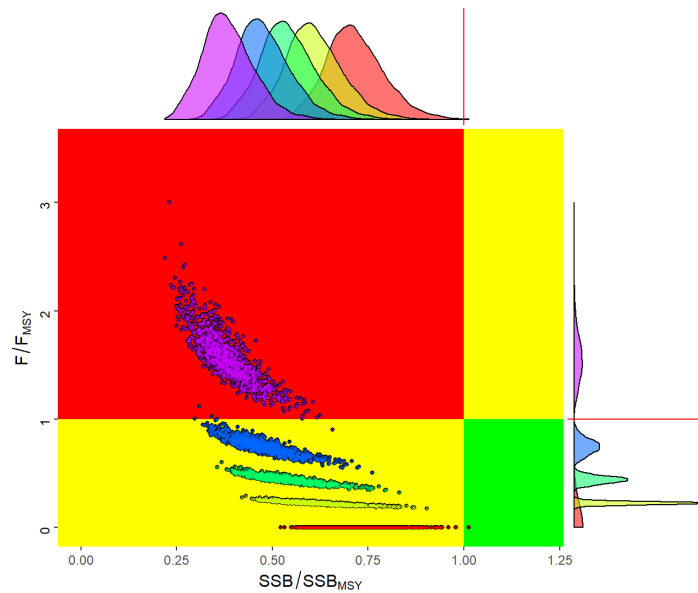


Figure 3.3.1.27. Kobe plot of the stochastic forecast for 2022 for European hake in GSAs 12-16

The plot was conducted applying different fishing catch options (i.e. catch at 0 purple, 30 percent blue, 50 percent green, 75 percent yellow and 100 percent red of the catches in 2018), shown in y-axis. The x-axis shows corresponding SSB relative to B_{MSY} , while the y-axis shows corresponding F relative to F_{MSY} .

Table 3.3.1.17. Short-term forecast table for European hake in GSAs 12-16 (with catch percentage expressing the proportion of the catches estimated for 2018)

Catch %	year	SSB	Catch	F
0	2020	3048	0	0.00
0	2021	3588	0	0.00
0	2022	4990	0	0.00
30	2020	3048	682	0.17
30	2021	3322	682	0.09
30	2022	4246	682	0.07
50	2020	3048	1137	0.29
50	2021	3148	1137	0.17
50	2022	3768	1137	0.13
70	2020	3048	1592	0.44
70	2021	2982	1592	0.29
70	2022	3310	1592	0.22
100	2020	3048	2274	0.70
100	2021	2738	2274	0.54
100	2022	2661	2274	0.45

3.3.2.Assessment unit: GSA 19

Following the twenty-first SAC meeting (Egypt, June 2019), the benchmark stock assessment of European hake was carried out assuming the stock was in the boundaries of the Western Ionian Sea (GSA 19). European hake represents one of the most important demersal species in terms of landings and income in GSA 19, especially for longlines (20 percent of the European hake landing), gillnets and trammel nets (20 percent of the European hake landing), but also for trawlers (60 percent).

3.3.2.1. Growth and maturity

Biological information on growth von Bertalanffy parameters, maturity at length, length-weight relationship was derived from the DCF (2002–2018).

The information from the ALK derived from DCF data was also used; after checking that mean length at age is consistent along the years, a consolidated ALK was derived and used in the assessment analyses (Figure 3.3.2.1).

The natural mortality vector was estimated as an average of different methods (Gislason; Prodbiom revised version with unique solution; Chen and Watanabe; Brodziak, 2011 and 2012;and Lorenz and Gulland), consistently with the approach used in the benchmark assessment of European hake in the Adriatic Sea in 2019.

Table 3.3.2.1. Maximum size, size at first maturity and size at recruitment

Somatic magnitude measured (LT, LC, etc)			TL	Units	Cm
Sex	Fem	Mal	Combined	Reproduction season	December-November
Maximum size observed	89			Recruitment season	
Size at first maturity	33-34	18		Spawning area	
Recruitment size to the fishery			4-5	Nursery area	On the shelf between Otranto and Santa Maria di Leuca, around the Amendolara Bank, in the Gulf of Squillace and offshore Siracusa (MEDISEH MAREA project).

Table 3.3.2.2. M vector and proportion of matures by size or age (combined)

Size/Age	Natural mortality	Proportion of matures
0	1.27	0.03
1	0.69	0.33
2	0.45	0.57
3	0.34	0.92
4	0.28	0.99
5	0.24	0.98
6	0.22	1.00
7+	0.20	1.00

Table 3.3.2.3. Growth and length weight model parameters

		Sex				
		Units	Female	Male	Combined	Years
Growth model	L_{∞}		111	73		2002-2018
	K		0.10	0.15		2002-2018
	t_0	cm	-0.60	-0.73		2002-2018
	Data source	DCF				
Length weight relationship	a		0.0055	0.005		2002-2018
	b		3.1	3.04		2002-2018
	M (scalar)					
	sex ratio (% females/total)					

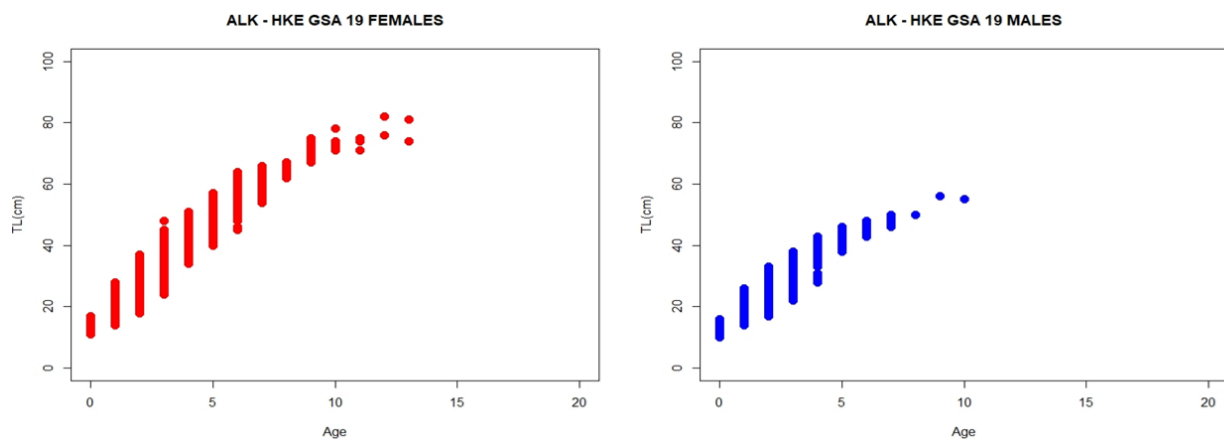


Figure 3.3.2.1. Consolidated age-length key for European hake in GSA 19

The natural mortality vector was derived as an average of different methods for estimating the natural mortality at age (Table 3.3.2.4 and Table 3.3.2.5). The revised version of Abella *et al.* (1998), that is Martiradonna (2012) was used.

Table 3.3.2.4. Natural mortality vectors estimated with different models, and average M vector for females

age	Gislason et al., 2010	Abella et al., 1998 (2009)	Chen & Watanabe, 1989	Brodziak et al., 2011	Brodziak et al., 2012	Gulland, 1987	Lorenz 1996	Mean
0.5	2.69	1.71	0.96	1.01	0.43	1.20	1.50	1.36
1.5	1.19	0.88	0.68	0.61	0.26	0.56	0.97	0.74
2.5	0.63	0.60	0.44	0.41	0.18	0.31	0.69	0.46
3.5	0.45	0.46	0.33	0.34	0.14	0.22	0.57	0.36
4.5	0.34	0.38	0.27	0.28	0.12	0.17	0.49	0.30
5.5	0.27	0.32	0.23	0.25	0.10	0.14	0.43	0.25
6.5	0.23	0.28	0.21	0.22	0.09	0.12	0.39	0.22
7.5	0.20	0.25	0.19	0.20	0.09	0.10	0.37	0.20
8.5	0.18	0.23	0.17	0.19	0.08	0.09	0.35	0.19
9.5	0.16	0.21	0.16	0.18	0.08	0.09	0.33	0.17
10.5	0.15	0.20	0.15	0.17	0.07	0.08	0.31	0.16
11.5	0.14	0.18	0.15	0.16	0.07	0.07	0.30	0.15
12.5	0.13	0.17	0.14	0.16	0.07	0.07	0.29	0.15
13.5	0.12	0.16	0.14	0.15	0.06	0.07	0.28	0.14
14.5	0.12	0.16	0.13	0.14	0.06	0.06	0.27	0.14
15.5	0.11	0.15	0.13	0.14	0.06	0.06	0.27	0.13
16.5	0.11	0.14	0.13	0.14	0.06	0.06	0.26	0.13
17.5	0.10	0.14	0.12	0.14	0.06	0.06	0.26	0.12
18.5	0.10	0.13	0.12	0.13	0.06	0.05	0.25	0.12
19.5	0.10	0.13	0.12	0.13	0.06	0.05	0.25	0.12
20.5	0.09	0.13	0.12	0.13	0.05	0.05	0.24	0.12

Table 3.3.2.5. Natural mortality vectors estimated with different models, and average M vector for males

age	Gislason et al., 2010	Abella et al., 1998 (2009)	Chen & Watanabe, 1989	Brodziak et al., 2011	Brodziak et al., 2012	Gulland, 1987	Lorenz 1996	Mean
0.5	2.08	1.71	0.89	0.55	0.24	1.35	1.40	1.17
1.5	0.99	0.88	0.65	0.34	0.14	0.62	0.93	0.65
2.5	0.61	0.60	0.44	0.23	0.10	0.33	0.71	0.43
3.5	0.42	0.46	0.35	0.18	0.08	0.24	0.58	0.33
4.5	0.33	0.38	0.29	0.15	0.07	0.19	0.51	0.27
5.5	0.29	0.32	0.26	0.13	0.06	0.15	0.47	0.24
6.5	0.25	0.28	0.23	0.12	0.05	0.13	0.43	0.21
7.5	0.22	0.25	0.22	0.11	0.05	0.11	0.40	0.19
8.5	0.20	0.23	0.20	0.10	0.04	0.10	0.38	0.18
9.5	0.19	0.21	0.19	0.10	0.04	0.09	0.37	0.17
10.5	0.18	0.20	0.18	0.09	0.04	0.08	0.36	0.16
11.5	0.17	0.18	0.18	0.09	0.04	0.08	0.35	0.15
12.5	0.16	0.17	0.17	0.08	0.04	0.07	0.34	0.15
13.5	0.15	0.16	0.17	0.08	0.03	0.07	0.33	0.14
14.5	0.15	0.16	0.16	0.08	0.03	0.07	0.33	0.14
15.5	0.15	0.15	0.16	0.08	0.03	0.06	0.33	0.14
16.5	0.15	0.14	0.16	0.08	0.03	0.06	0.33	0.14
17.5	0.15	0.14	0.16	0.07	0.03	0.06	0.33	0.13
18.5	0.15	0.13	0.16	0.07	0.03	0.06	0.33	0.13
19.5	0.15	0.13	0.15	0.07	0.03	0.06	0.33	0.13
20.5	0.15	0.13	0.15	0.07	0.03	0.05	0.33	0.13

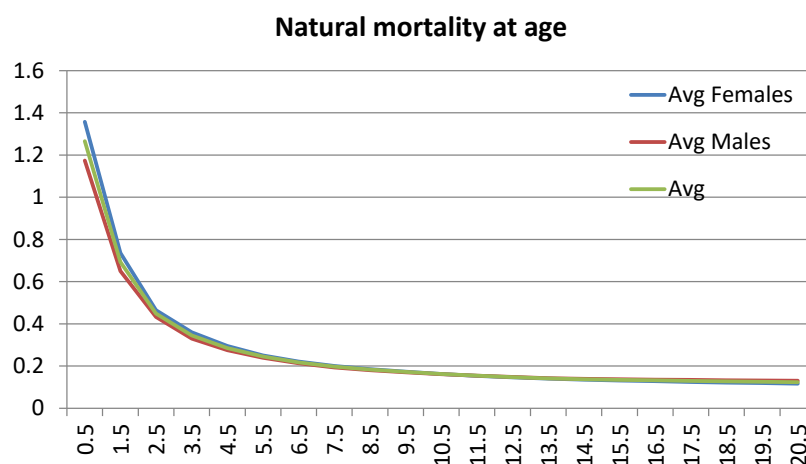


Figure 3.3.2.2. Natural mortality vectors for females (average of the different methods in Table 3.3.2.4), males (average of the different methods in Table 3.3.2.5) and average of the two sexes

3.3.2.2. Fisheries information

A. Description of the fleet

As an average along the years, the longlines represent about 20 percent of the European hake landings, while the gillnets and trammel nets represent together around 20 percent, and the trawlers make up for about 60 percent.

Table 3.3.2.6. Composition of the fleet exploiting the stock according the GFCM fleet segmentation <http://www.fao.org/gfcm/activities/fisheries/fleet/segmentation/en/>

Area	Country	Trawlers 6-12 m (T-10)	Trawlers 12-24 m (T-11)	Trawlers > 24 m (T-12)	Small-scale vessel with engine using passive gear < 6 m (P-05)	Small-scale vessel with engine using passive gear 6-12 m (P- 06)	Small-scale vessel with engine using passive gear 12-24 m (P- 07)	Longliners 12-24 m (L-03)	Total
GSA 19	Italy ¹	21	228	11	294	592	5	86	1237

¹ Fisheries and Maritime Affairs' Fleet Register, 2018

Table 3.3.2.7. Catch, bycatch, discards and effort by operational unit in the reference year

Operational Units*	Fleet (n° of boats)*	Catch (t or kg of the species assessed)	Other species caught (names and weight)	Discards (species assessed)	Discards (other species caught)	Effort (units)
T10+T11+T12	260			12		
[P05+P06]	891			0		
L03	86			0		
Total	1 237			12		

*Fisheries and Maritime Affairs' Fleet Register, 2018

B. Historical trends

The time series of landings for European hake in the area used in the assessment were from the DCF and cover the years 2002–2018. Being the first two years quite different from the rest of the time series, and lacking the longliners in the same years, the assessment was carried out from 2004. The discards data were available for 2006 and 2009–2018. In the years where the information on the discards was not available, it was derived multiplying the ratio between discards and landings on the years 2006 and 2009 by the landings of the lacking years (Figure 3.3.2.3). After the peak in 2006 and a decrease until 2012, the landings time series show a trend quite stable until 2018. Even the discards show stability from 2010 onwards. The average proportion among the different types of gear is 40 percent, 20 percent and 20 percent respectively for OTB, GNS and GTR, and LLS.

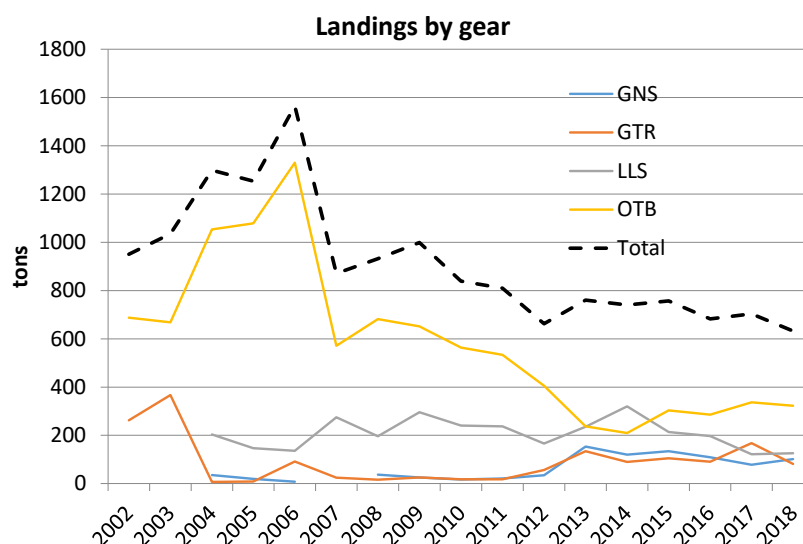


Figure 3.3.2.3. Landings of European hake in GSA 19 by gear (in tonnes)

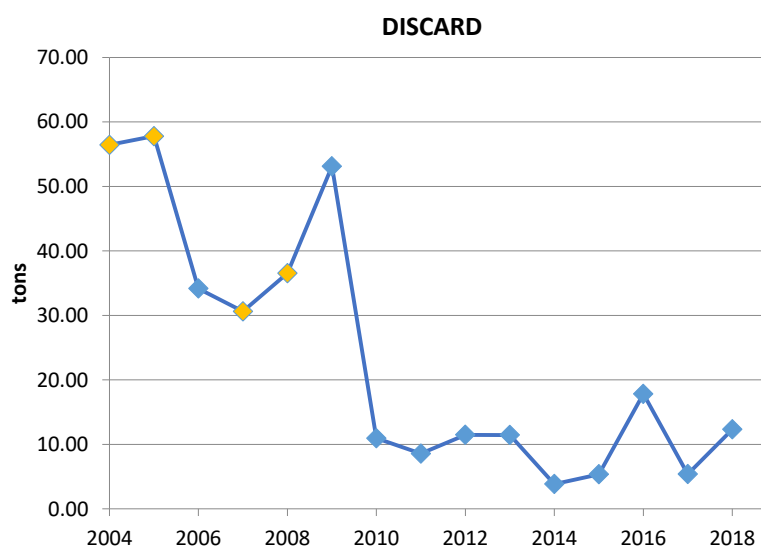


Figure 3.3.2.4. Discard (trawlers) of European hake in GSA 19 by gear (in tonnes)

Figures 3.3.2.5 to 3.3.2.8 show the different fractions of the population that are targeted by the different types of gear: longlines mean size in the catch is around 35-40 cm, the trawlers catches are more concentrated on smaller sizes (about 18-20 cm), while gillnets and trammel nets have their bulk around 20 cm.

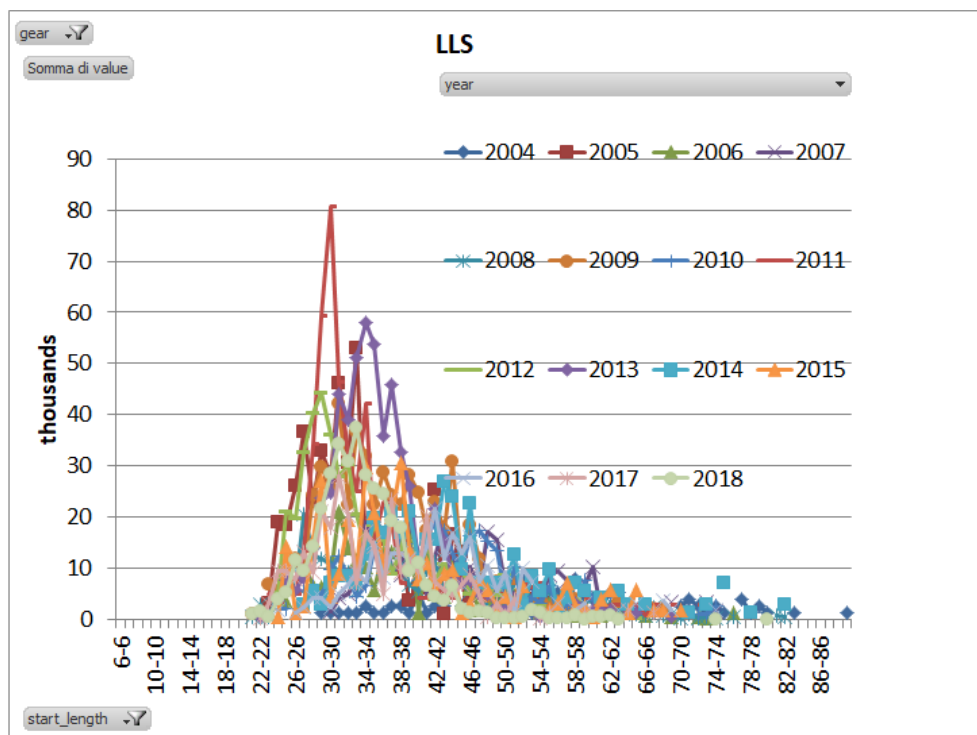


Figure 3.3.2.5. Length-Frequency distributions of longlines (landings) for European hake in GSA 19

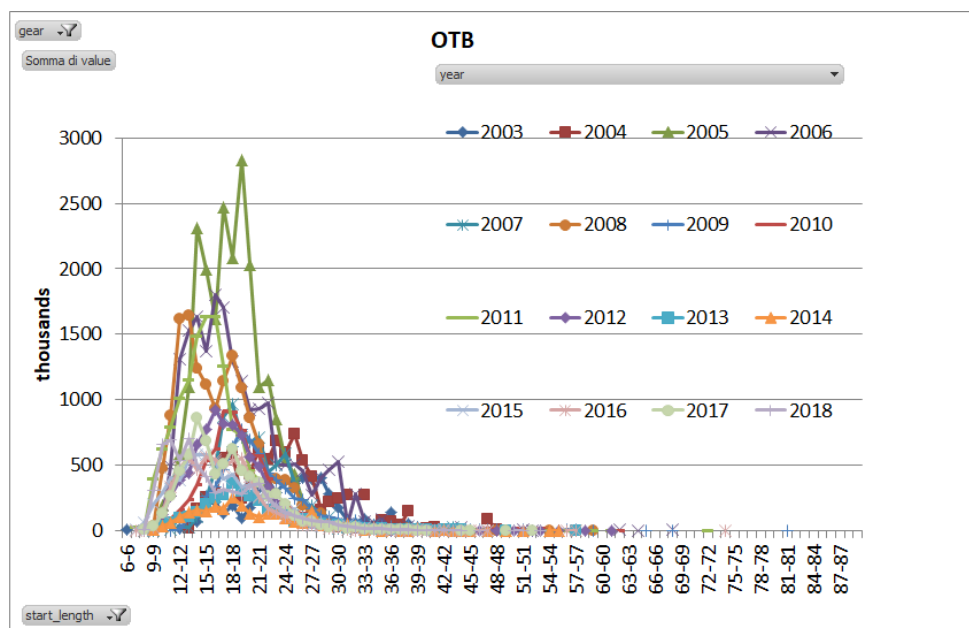


Figure 3.3.2.6. Length-Frequency distributions of trawlers (landings) for European hake in GSA 19

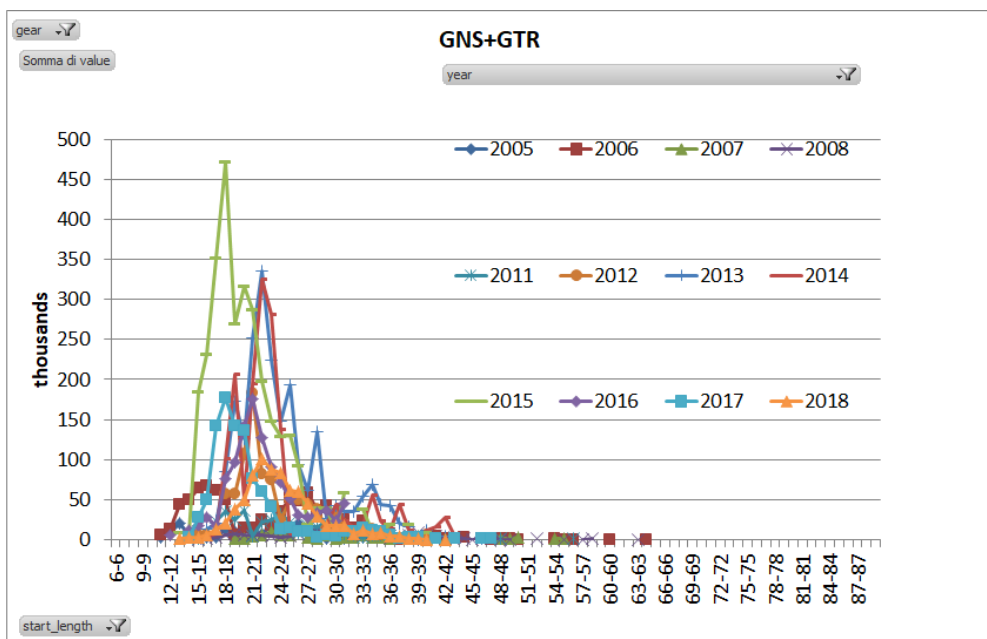


Figure 3.3.2.7. Length-Frequency distributions of gillnets and trammel nets (landings) for European hake in GSA 19

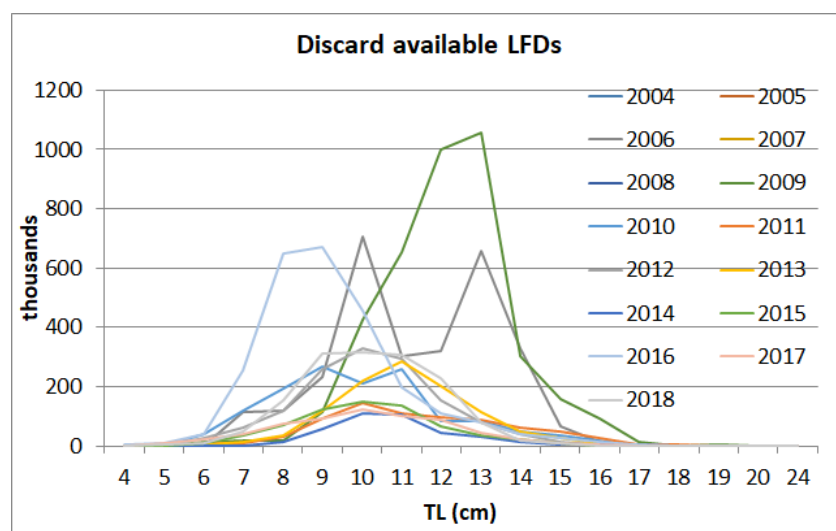


Figure 3.3.2.8. Length-Frequency distributions of trawlers (discards) for European hake in GSA 19

3.3.2.3. Management regulations

In Italy, management regulations are based on technical measures, closed number of fishing licenses for the fleet and area limitation (distance from the coast and depth). In order to limit the over-capacity of the fishing fleet, the Italian fishing licenses have been fixed since the late 1980s and the fishing capacity has been gradually reduced. Other measures on which the management regulations are based pertain to technical measures (mesh size), minimum landing sizes (EC 1967/06) and seasonal fishing ban. Regarding small-scale fishery management, regulations are based on technical measures related to the height and length of the gear as well as the mesh size opening, minimum landing sizes and number of fishing licenses for the fleet. In 2008, a management plan was adopted that foresaw the reduction of fleet capacity associated with a reduction of the time at sea. Also, there is a protected marine area at Porto Cesareo, covering an area of 16 654 hectares (the third largest in Italy). A marine protected area had been established in 1997. Recreational fishery using no more than five hooks is allowed. Since June 2010, the rules implemented in the EU regulation (EC 1967/06) regarding the codend mesh size and the operative distance of fishing from the coasts are enforced.

3.3.2.4. Reference points

Table 3.3.2.8. List of reference points and empirical reference values previously agreed (if any)

Indicator	Limit reference point/ empirical reference value	Value	Target reference point/ empirical reference value	Value	Comments
B					
SSB					
F			0.16	F _{0.1}	STECF EWG 17-15
Y					
CPUE					
Index of biomass at sea					

3.3.2.5. Fisheries independent information

A. MEDITS trawl survey

The sampling design is random stratified with a number of hauls by stratum proportional to stratum surface.

Data were assigned to strata based upon the shooting position and average depth (between shooting and hauling depth). Only those hauls noted as valid were used in the analysis, including stations with no catches (zero catches are included).

The abundance and biomass indices by GSA were calculated through stratified means (Cochran, 1953; Saville, 1977). The variation of the stratified mean is then expressed as coefficient of variation respect to the mean.

The catchability is assumed equal to 1.

The survey time was quite stable along the years (varying from June to August), except in 2017 when the survey was carried out between October and December.

B. Direct methods: trawl-based abundance indices

Table 3.3.2.9. MEDITS trawl survey basic information

Survey	MEDITS GSA 19	Trawler/RV	PEC
Sampling season	Summer		
Sampling design	Stratified sampling design with the number of hauls proportionate to the strata surface		
Sampler (gear used)	GOC 73		
Codend mesh size as opening in mm	20 mm		
Investigated depth range (m)	10-800 m		

Table 3.3.2.10. MEDITS trawl survey sampling area and number of hauls

Stratum	Total surface (km ²)	Trawlable surface (km ²)	Swept area (km ²)	Number of hauls
10-50 m	2 124			9
50-100 m	1 701			8
100- 200 m	2 664			10
200- 500 m	4 355			14
500- 800 m	5 503			29
Total (10- 800 m)	16 347			70



Figure 3.3.2.9. Map of MEDITS hauls' positions in GSA 19

The indices by stratum show that the species is more distributed in the area between 50 and 500 m.

Table 3.3.2.11. Trawl survey abundance and biomass results

Depth Stratum	Years	kg per km ²	CV	N per km ²	CV
10-50 m	2018	4.6	76.7	86.7	70.2
50-100 m	2018	29.5	65.7	775.3	59.7
100-200 m	2018	46.9	36.7	1618.3	57.2
200- 500 m	2018	40.6	25.8	781.7	63.4
500- 800 m	2018	8.9	22.0	11.0	21.7
Total 10-800m)	2018	25.1	17.9	567.6	36.4

C. Direct methods: trawl-based length and age structure of population at sea

The standardized LFDs from MEDITS trawl survey are shown in Figure 3.3.2.10. These LFDs were age sliced by the deterministic age slicing applying the parameters reported in the section 2.2. The maturity scale used for the maturity stages of this species is MEDITS scale (Medits Handbook 2017, version 9).

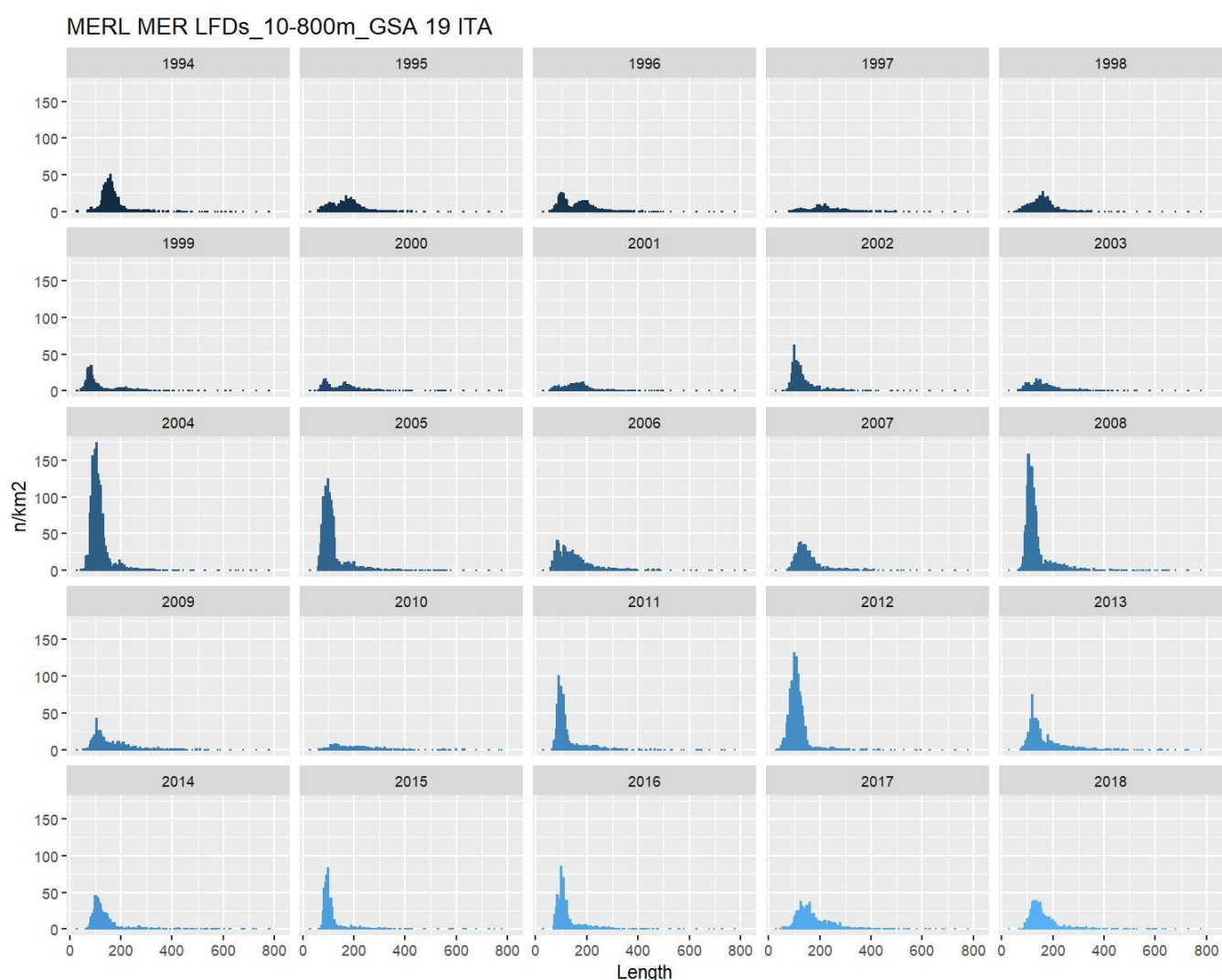


Figure 3.3.2.10. MEDITS survey indices (N/km^2) by length (the catchability is assumed equal to 1)

D. Direct methods: trawl-based recruitment analysis

The recruitment of European hake is continuous. In the MEDISEH project the recruitment threshold was estimated equal to 13.2 cm, using MEDITS data, while it was observed that the smallest individuals present in the catch are about 5 cm-sized. A recruitment index (N/km^2) was estimated and reported in Table 3.3.2.13 and Figure 3.3.2.11, where the recruits are defined as the individuals smaller than 13 cm. Peaks in recruitment were observed in the years 2004, 2005, 2008 and 2012.

Table 3.3.2.12. MEDITS trawl surveys: recruitment analysis summary

Survey	MEDITS	Trawler/R V	PEC
Survey season	Summer		
Codend mesh size as opening in mm			
Investigated depth range (m)	10-800 m		
Recruitment season and peak (months)			
Age at fishing-grounds recruitment			
Length at fishing-grounds recruitment	4-5 cm first lengths in the fishery, 13 cm threshold for recruitment phase defined in MEDISEH project.		

Table 3.3.2.13. MEDITS trawl surveys: recruitment index

Years	Area in km ²	N of recruit per km ²	CV
1994	16 347	79.3	36.0
1995	16 347	113.0	53.2
1996	16 347	195.4	58.7
1997	16 347	18.7	59.1
1998	16 347	101.9	35.9
1999	16 347	237.9	59.4
2000	16 347	101.5	51.8
2001	16 347	70.2	37.4
2002	16 347	347.8	32.6
2003	16 347	82.0	46.1
2004	16 347	1 373.7	46.9
2005	16 347	1 073.1	32.5
2006	16 347	333.4	47.0
2007	16 347	232.9	43.3
2008	16 347	987.9	47.5
2009	16 347	225.3	66.7
2010	16 347	40.7	46.8
2011	16 347	578.0	92.8
2012	16 347	1 132.9	44.8
2013	16 347	283.1	55.9
2014	16 347	324.2	62.6
2015	16 347	442.7	65.1
2016	16 347	506.6	51.4
2017	16 347	197.1	46.1
2018	16 347	185.2	58.5

MERLMER GSA19 (abundance of recruits)_10-800 m

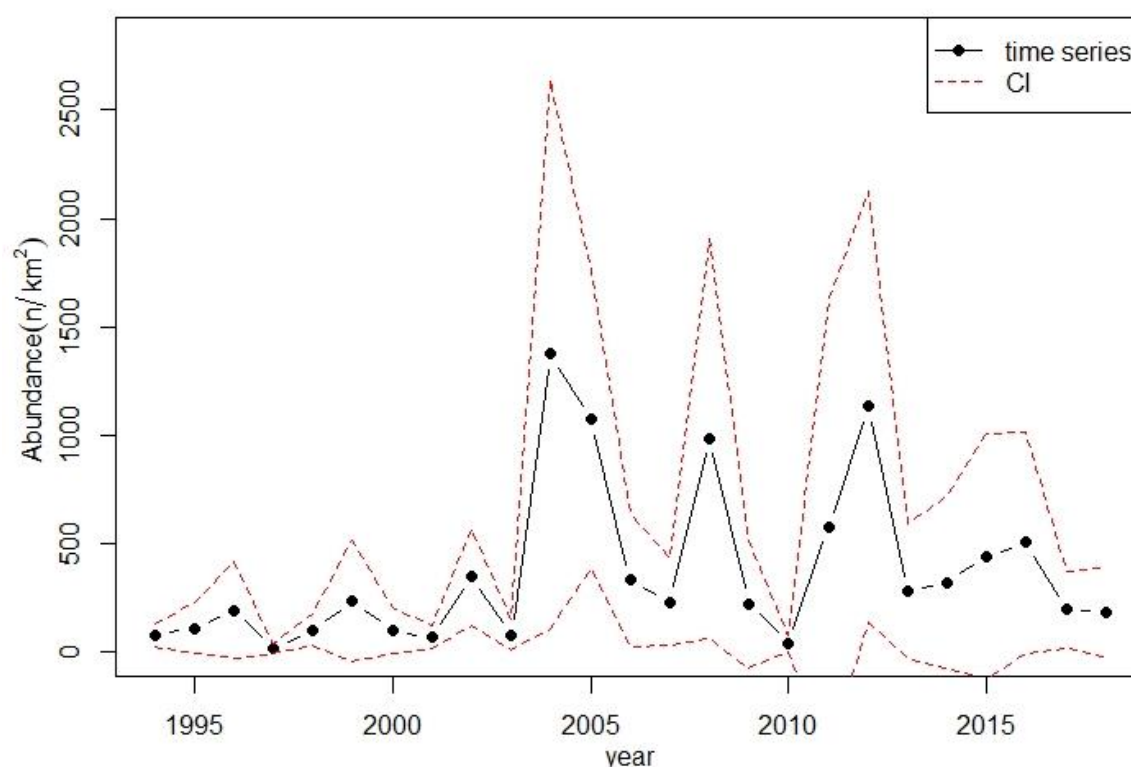


Figure 3.3.2.11. MEDITS trawl surveys: recruitment index with CI (red dotted lines)

E. Direct methods: trawl-based spawner analysis

Due to the poor presence of individuals longer than 40 cm in the MEDITS survey, the MEDITS project could not identify a suitable threshold for spawners for this species in the area. A spawner index (N/km^2) was in any case estimated and reported in Table 3.3.2.15, defining as spawners the individuals > 33 cm, that is the size at first maturity of females from DCF biological data.

European hake is a multiple spawner; the spawner index does not show any particular peak in the trend. Despite of this, it should be considered that individuals of length greater than 40 cm are poorly sampled, thus this index should be considered with caution.

Table 3.3.2.14. MEDITS trawl surveys: spawners analysis summary

Survey	MEDITS	Trawler/RV	PEC
Survey season	Survey season		
Investigated depth range (m)	10-800 m		
Spawning season and peak (months)	December-November		

Table 3.3.2.15. MEDITS trawl surveys: spawner index

Years	Area in km ²	N of recruit per km ²	CV
1994	16 347	3.8	26.1
1995	16 347	4.3	35.1
1996	16 347	5.7	22.3
1997	16 347	6.3	28.3
1998	16 347	2.2	33.5
1999	16 347	4.3	38.7
2000	16 347	3.0	25.8
2001	16 347	4.6	27.0
2002	16 347	2.8	42.2
2003	16 347	4.4	30.8
2004	16 347	4.5	28.6
2005	16 347	10.1	17.5
2006	16 347	8.4	21.1
2007	16 347	8.1	37.6
2008	16 347	10.1	17.7
2009	16 347	12.2	17.9
2010	16 347	6.8	17.9
2011	16 347	4.8	22.5
2012	16 347	3.3	26.1
2013	16 347	10.6	20.3
2014	16 347	11.3	18.8
2015	16 347	6.0	19.6
2016	16 347	3.8	30.4
2017	16 347	10.1	23.9
2018	16 347	8.8	16.6

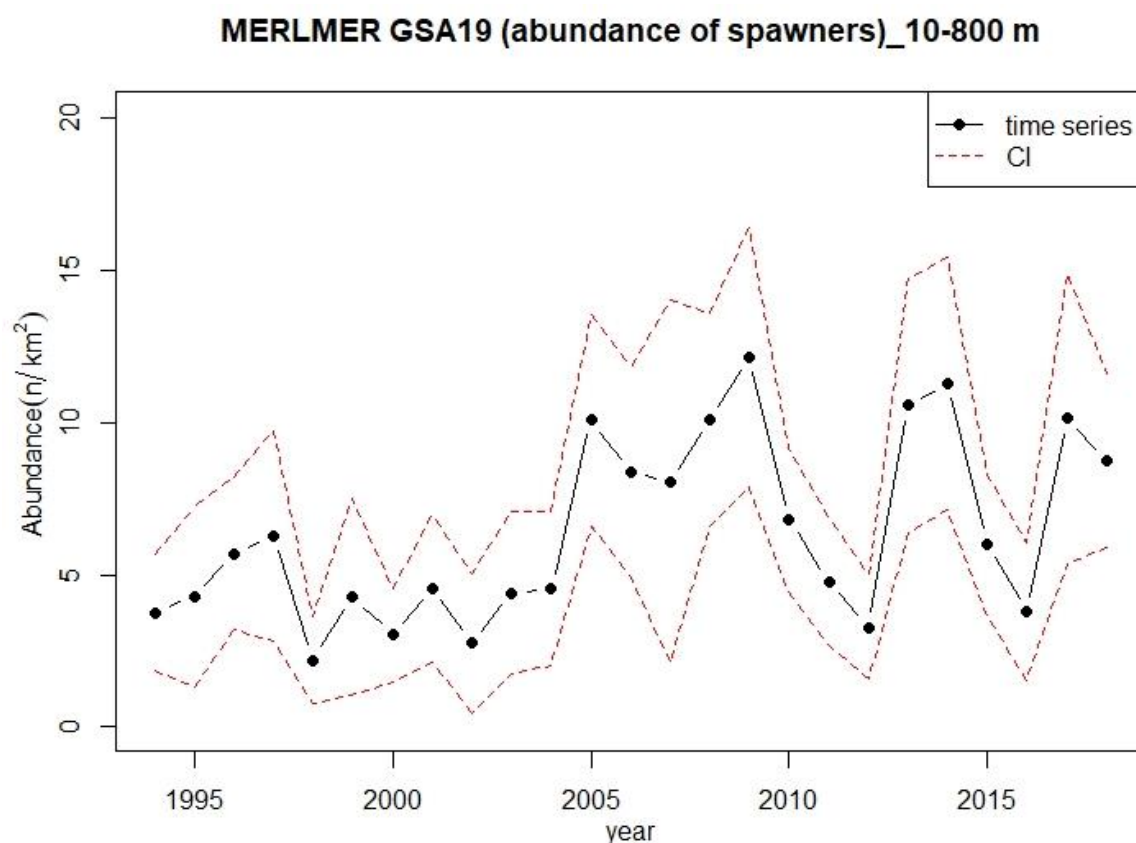


Figure 3.3.2.12. MEDITS trawl surveys: spawners index

3.3.2.6. Spatial distribution of the resources

The MEDISEH project identified the main nurseries in the area, being located on the shelf between Otranto and Santa Maria di Leuca, around the Amendolara Bank, in the Gulf of Squillace and offshore Siracusa. Spawning areas were not identified.

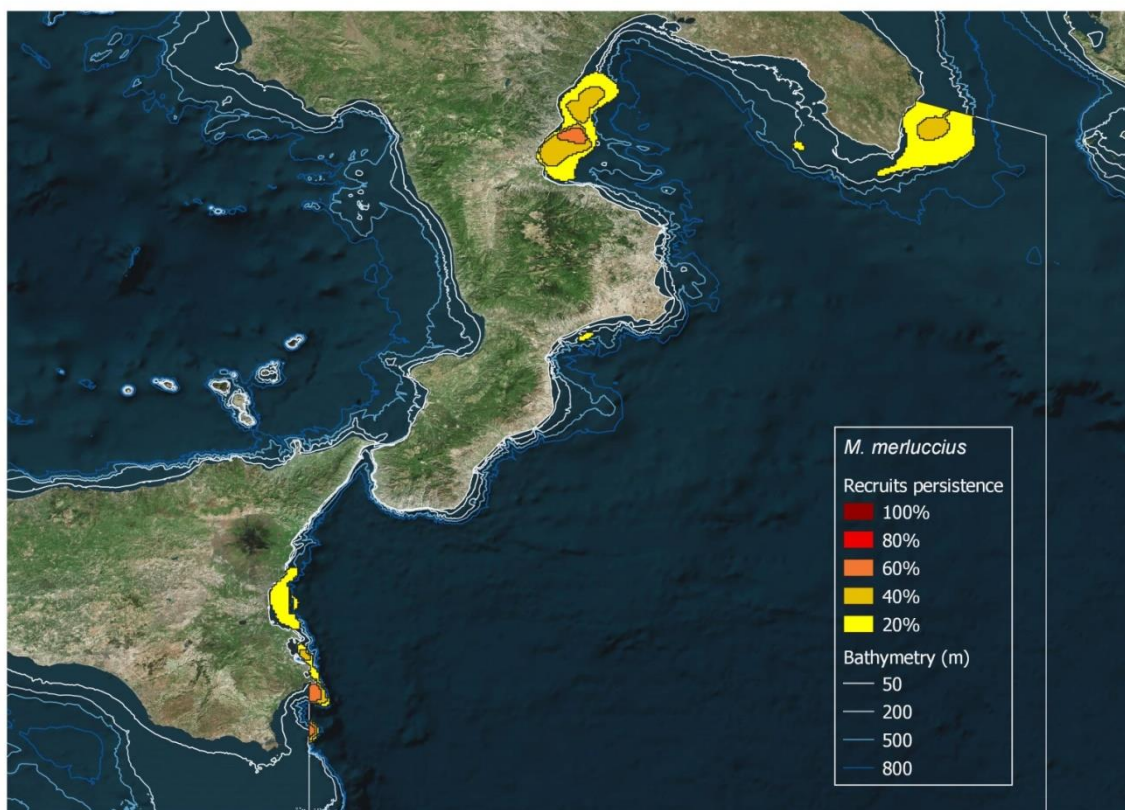


Figure 3.3.2.13. Nursery areas of European hake in GSA 19

A. Historical trends

The density index shows a trend significantly increasing (Spearman's rho 0.455, pvalue<0.05), while the biomass index does not show any significant trend.

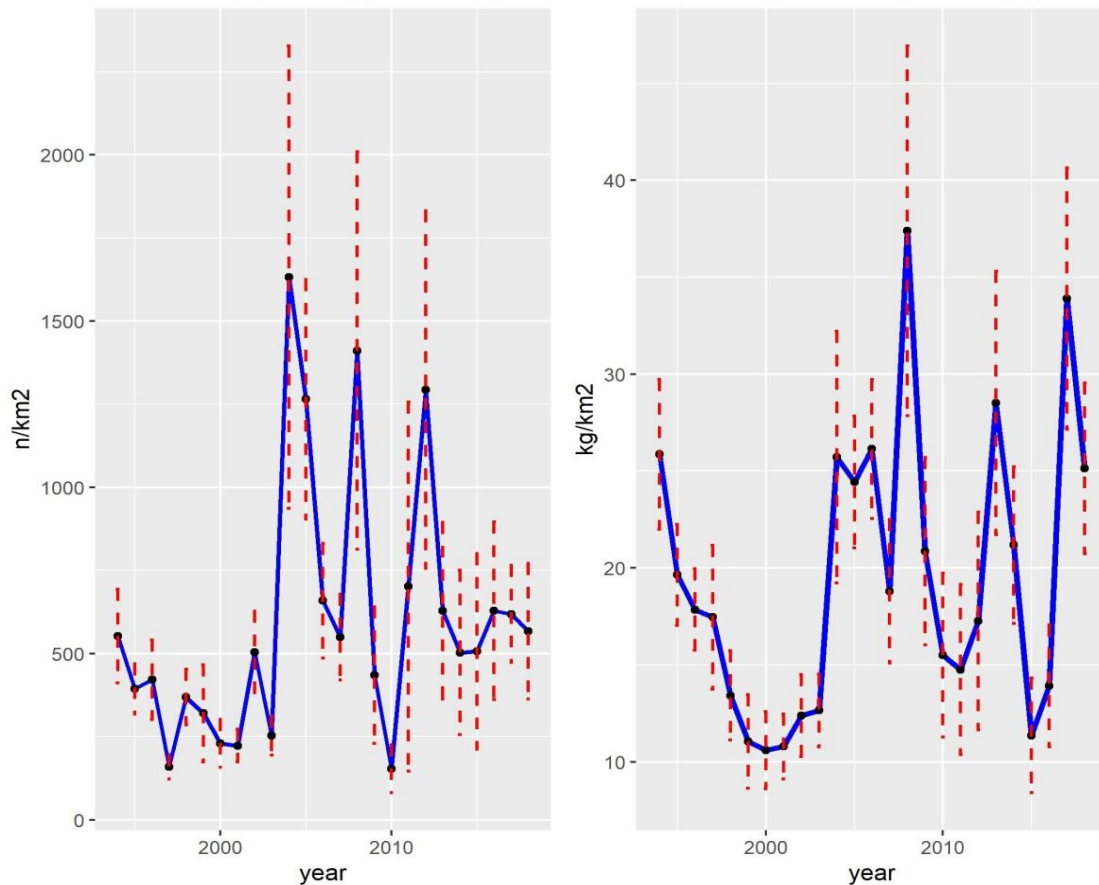


Figure 3.3.2.14. Density (right) and biomass (left) indices from MEDITS trawl survey

3.3.2.7. Ecological information

A. Protected species potentially affected by the fisheries

No analysis was carried out on this aspect.

B. Environmental indexes

No analysis was carried out on this aspect.

3.3.2.8. Stock assessment

The stock assessment was carried out using two different approaches to derive the catch at age matrices (for catch and for survey): deterministic age sling and consolidated ALK. The two sexes were sliced separately, according to the growth parameters and the ALK by sex, and then summed up.

A. Statistical catch at age

A statistical catch-at-age assessment was carried out for this stock, using the assessment for all initiative (a4a) method (Jardim *et al.*, 2015). The a4a method utilizes catch-at-age data to derive estimates of historical population size and fishing mortality. Model parameters estimated using catch-at-age analysis are done so by working forward in time and analyses do not require the assumption that removals from the fishery are known without error.

B. Model assumptions

The assessment was carried out using the period 2004–2018 for catch data and survey index for the ages 0 to 7+. Concerning the F_{bar} , the age range used was 0-4 age groups, being the age range more represented in the catch and in the F at age.

C. Scripts

A model selection procedure was performed taking into account statistical measures (AIC, BIC) and model diagnostics (residuals, retrospective) and fitting.

The sub-models explored are:

F sub-models:

- `fmod1 <- ~ s(age, k=5) + s(year, k = 7) + te(age, year)`
- **`fmod2 <- ~ s(age, k=5)+s(year, k=7) + s(year, k=7, by=as.numeric(age==0))`**

Q sub-models:

- `qmod1 <- list(~factor(replace(age,age>2,2)))`
- **`qmod2<- list(~factor(age))`**
- `qmod3<-list(~1)`

SR sub-models:

- `srmod1 <- ~factor(year)`
- `srmod2 <- ~s(year,k=7)`
- **`srmod3 <- ~geomean(CV=0.2)`**
-

In bold are reported the sub-models returning the best fit.

D. Input data and parameters

The catch at age matrices derived from age slicing (growth parameters in Section 2.2) and from ALK are reported in Tables 3.3.2.17 and 3.3.2.18.

According to the consistency of catch at age and index at age (Figure 3.3.2.15 and 3.3.2.16), the age slicing methods were retained for the benchmark assessment.

Table 3.3.2.16. Maturity and natural mortality vectors by age used in the assessment

	0	1	2	3	4	5	6	7+
Maturity	0.03	0.33	0.57	0.92	0.99	0.98	1.00	1.00
M	1.27	0.69	0.45	0.34	0.28	0.24	0.22	0.20

Table 3.3.2.17. Catch at age matrix of catch (including discards) derived using age slicing

Years	Age							
	0	1	2	3	4	5	6	7+
2004	5 115	5 143	2 224	438	127	32	21	49
2005	12 598	13 641	675	116	60	7	3	1
2006	11 353	8 781	2 886	335	82	35	10	23
2007	3 259	5 889	744	176	104	67	35	27
2008	10 749	6 669	785	192	59	33	21	23
2009	4 694	4 743	1 223	437	173	61	26	17
2010	3 480	4 783	596	245	135	120	30	16
2011	9 487	4 553	888	196	55	45	20	23

Years	Age							
	0	1	2	3	4	5	6	7+
2012	4 994	4 834	777	180	64	34	11	1
2013	1 975	3 469	1 040	544	92	16	5	10
2014	1 232	2 609	610	372	151	58	30	31
2015	4 687	4 829	709	254	45	20	18	23
2016	5 744	3 615	446	151	94	44	9	13
2017	4 169	4 057	498	193	44	10	3	3
2018	5 608	2 834	838	246	28	8	2	2

Table 3.3.2.18. Catch at age matrix of catch (including discards) derived using ALK

Years	Age							
	0	1	2	3	4	5	6	7+
2004	3 977	3 994	3 628	1 155	246	66	27	55
2005	7 153	15 770	3 740	334	79	17	6	1
2006	6 808	10 764	4 239	1 452	153	48	17	24
2007	2 284	4 969	2 410	358	139	65	47	28
2008	7 666	8 066	2 214	383	112	39	27	26
2009	3 613	4 304	2 241	786	284	85	38	22
2010	2 119	5 001	1 510	371	215	113	51	24
2011	5 334	7 788	1 433	523	89	43	30	26
2012	2 924	5 705	1 685	402	120	39	16	6
2013	1 391	2 763	1 882	847	220	29	10	10
2014	789	2 083	1 332	499	241	73	38	37
2015	2 863	5 252	1 805	475	120	27	19	25
2016	4 287	4 103	1 232	277	129	51	18	16
2017	2 432	4 738	1 348	333	98	19	5	4
2018	4 570	2 867	1 501	520	89	12	5	2

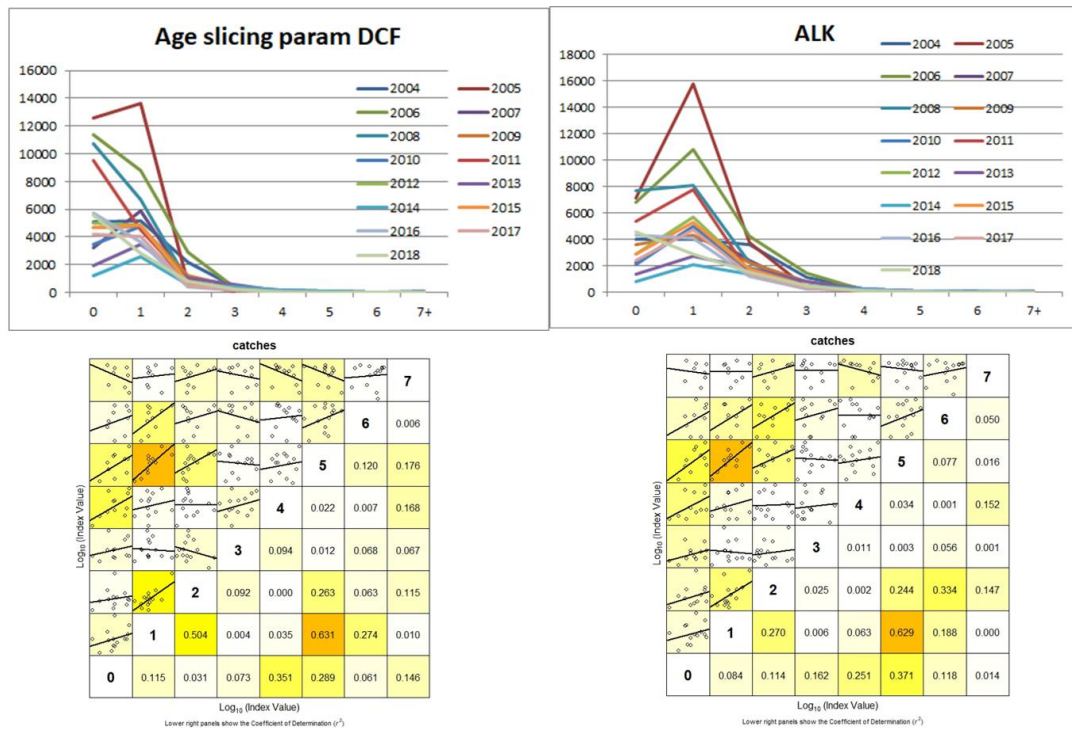


Figure 3.3.2.15. Comparison of the two methods for deriving the catch at age, with consistency plots

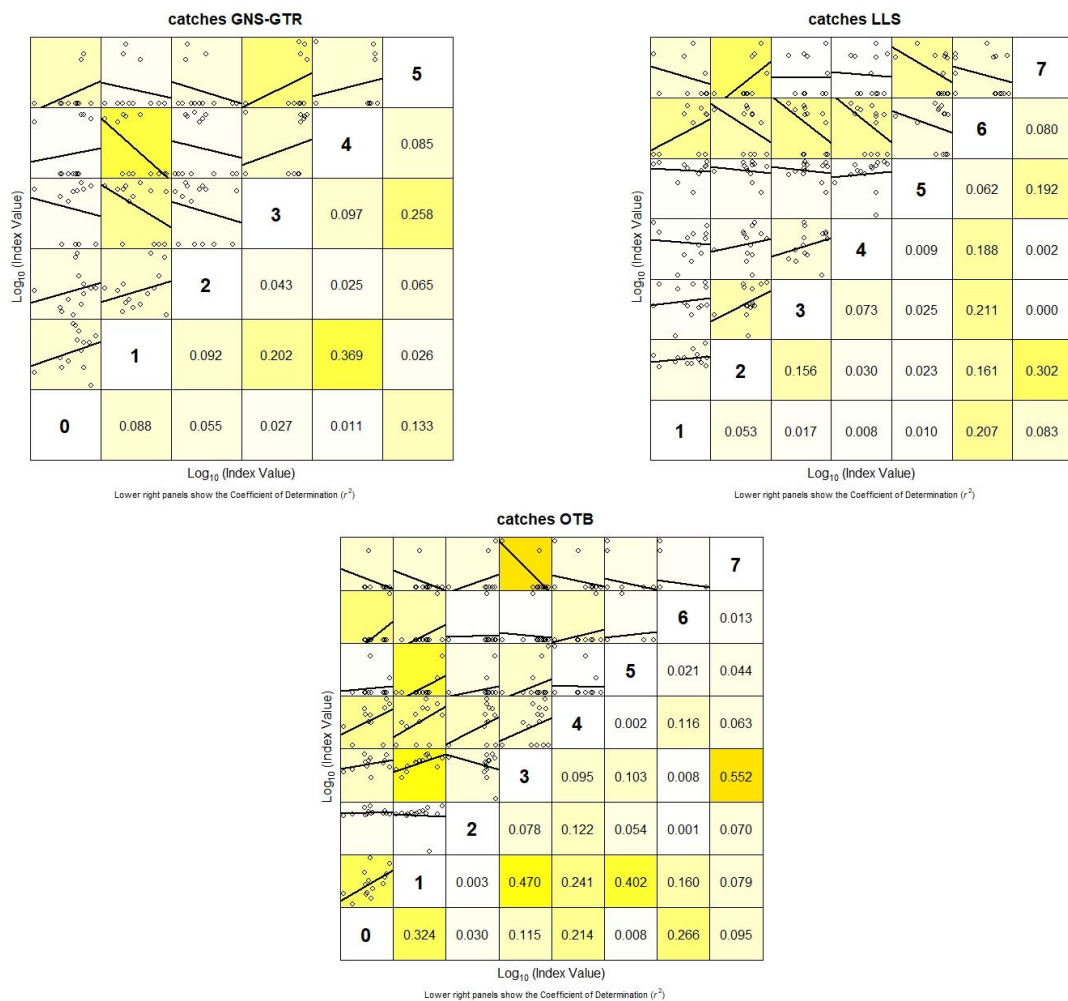


Figure 3.3.2.16. Consistency plots by gear

E. Tuning data

Table 3.3.2.19. Index at age matrix of survey derived using age slicing (the index until age 4 was used, because the other age classes are poorly represented).

Years	Age							
	0	1	2	3	4	5	6	7+
2004	1 487	96	18	4	2	0	0	1
2005	1 089	109	23	8	2	2	0	0
2006	442	162	30	8	4	1	0	0
2007	395	125	19	11	1	1	0	0
2008	1 212	148	37	8	3	1	1	1
2009	281	114	22	13	3	1	0	0
2010	64	54	24	7	1	0	1	1
2011	606	70	15	2	1	1	0	0
2012	1 193	27	12	3	1	0	0	0
2013	430	146	36	11	3	1	0	1
2014	422	49	17	6	4	2	1	1
2015	459	31	7	6	2	0	0	0
2016	541	65	16	2	2	1	0	0
2017	340	203	55	10	4	1	0	0
2018	363	163	27	11	1	1	0	0

Table 3.3.2.20. Index at age matrix of survey derived using ALK (the index until age 4 was used, because the other age classes are poorly represented).

Years	Age							
	0	1	2	3	4	5	6	7+
2004	1 397	187	36	10	2	0	0	1
2005	1 081	125	40	13	4	2	1	1
2006	358	227	51	17	4	2	0	1
2007	263	239	29	15	4	1	0	0
2008	1053	271	65	16	3	1	1	2
2009	236	132	45	16	5	1	0	0
2010	45	57	34	13	2	1	1	2
2011	583	76	34	6	1	1	0	1
2012	1 154	115	17	5	1	0	0	0
2013	310	228	62	22	4	1	0	1
2014	343	122	18	10	5	2	2	3
2015	445	35	14	8	2	1	1	1
2016	513	77	30	6	2	1	0	1
2017	223	278	90	20	5	1	1	1
2018	216	285	44	18	3	1	1	1

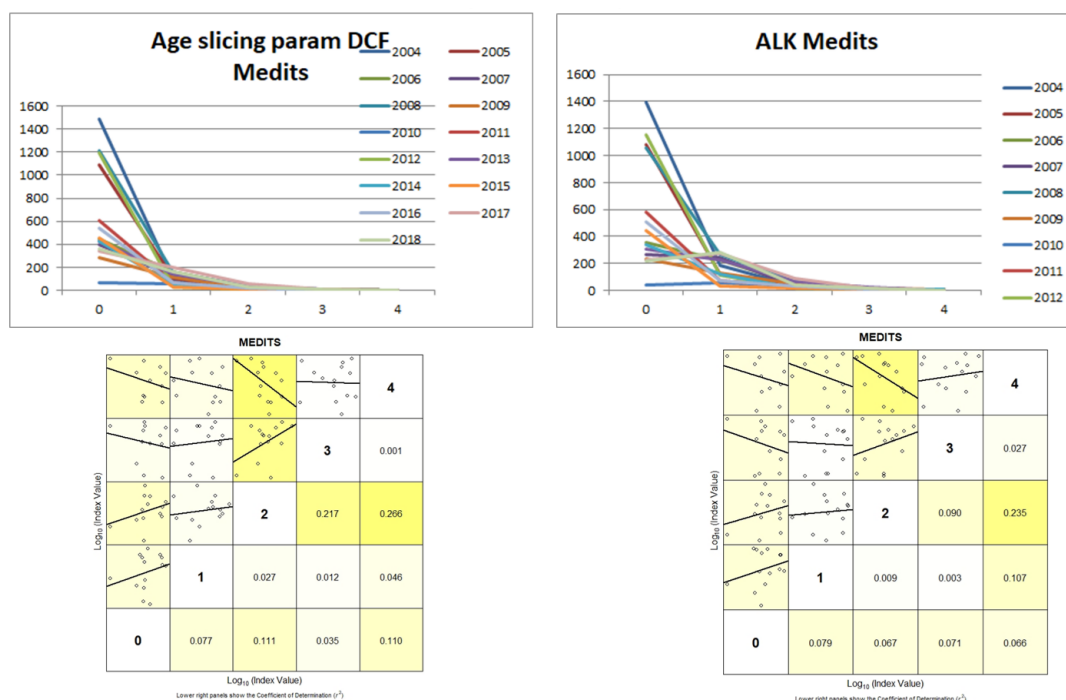


Figure 3.3.2.17. Comparison of the two methods for deriving the index at age, with consistency plots

F. Results

The performances of the 18 explored models were analyzed (Table 3.3.2.21), together with the retrospective analysis and the residuals. Considering the prevailing criterion of decreasing selectivity of the survey towards older ages and that the statistics that were quite comparable compared to model 18, model 15 has been selected.

The summary of this fit was reported in Table 3.3.2.22. The partial F by gear was estimated splitting the total F through the proportion in numbers of individuals by gear.

Table 3.3.2.21. Exploration of the performances of the 18 a4a models

fit	F sub-model	Q sub-model	SR sub-model	nopar	nlogl	maxgrad	nobs	gcv	nlogl_comp1	nlogl_comp2	nlogl_comp3
1	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(replace(age, age>2, 2)))	~factor(year)	57.0	128.65	0.0000052	195	0.60	72.73	55.92	
2	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(replace(age, age>2, 2)))	~s(year, k=7)	49.0	132.10	0.0000007	195	0.61	73.53	58.57	
3	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(replace(age, age>2, 2)))	~geomean(CV=0.2)	58.0	128.13	0.0000008	195	0.61	75.58	56.98	-4.42
4	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(age))	~factor(year)	59.0	128.32	0.0000026	195	0.56	73.78	54.54	
5	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(age))	~s(year, k=7)	51.0	131.69	0.0000023	195	0.57	74.23	57.45	
6	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~factor(age))	~geomean(CV=0.2)	60.0	127.00	0.0000110	195	0.55	75.99	55.96	-4.95
7	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~1)	~factor(year)	55.0	130.53	0.0000054	195	0.63	74.15	56.38	
8	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~1)	~s(year, k=7)	47.0	133.88	0.0000024	195	0.63	74.79	59.09	
9	~s(age, k=5) + s(year, k=7) + te(age, year)	list(~1)	~geomean(CV=0.2)	56.0	130.04	0.0000026	195	0.64	77.19	57.31	-4.46
10	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(replace(age, age>2, 2)))	~factor(year)	43.0	140.83	0.0000027	195	0.51	85.19	55.65	
11	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(replace(age, age>2, 2)))	~s(year, k=7)	35.0	143.42	0.0000006	195	0.51	85.78	57.64	
12	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(replace(age, age>2, 2)))	~geomean(CV=0.2)	44.0	137.94	0.0000032	195	0.50	86.66	57.12	-5.85
13	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(age))	~factor(year)	45.0	140.34	0.0000014	195	0.51	85.08	55.26	
14	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(age))	~s(year, k=7)	37.0	142.91	0.0000006	195	0.51	85.68	57.22	
15	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~factor(age))	~geomean(CV=0.2)	46.0	137.50	0.0000001	195	0.50	86.60	56.73	-5.82
16	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~1)	~factor(year)	41.0	141.86	0.0000002	195	0.52	85.48	56.38	
17	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~1)	~s(year, k=7)	33.0	144.48	0.0000009	195	0.52	86.19	58.30	
18	~s(age, k=5) + s(year, k=7) + s(year, k=7, by=as.numeric(age==0))	list(~1)	~geomean(CV=0.2)	42.0	138.82	0.0000038	195	0.50	87.05	57.74	-5.96

Table 3.3.2.22. Summary statistics of fit 15

Year	Recruitment (thousands)	F(0-4)	SSB (tonnes)	Catch in tonnes (est)	Catch in tonnes (obs)
2004	72 345	0.85171	1 304.57	1 253.84	1 257.51
2005	61 463	0.69083	1 166.21	1 065.37	1 010.34
2006	60 319	0.621	1 197.63	973.48	948.75
2007	49 288	0.62717	1 289.15	969.06	944.18
2008	48 937	0.69013	1 314.18	960.63	929.29
2009	44 356	0.74286	1 220.31	961.31	955.03
2010	43 965	0.72472	1 048.82	828.37	827.16
2011	48 474	0.65401	959.61	725.73	725.32
2012	45 008	0.59688	1 003.29	705.79	714.67
2013	35 546	0.61005	1 056.07	748.78	747.3
2014	37 667	0.68406	1 056.34	774.19	779.63
2015	50 982	0.73156	990.64	774.45	747.22
2016	56 468	0.65505	947.6	785.65	683.35
2017	49 051	0.47809	1 051.29	701.41	528.93
2018	47 324	0.30872	1 321.27	536.87	453.12

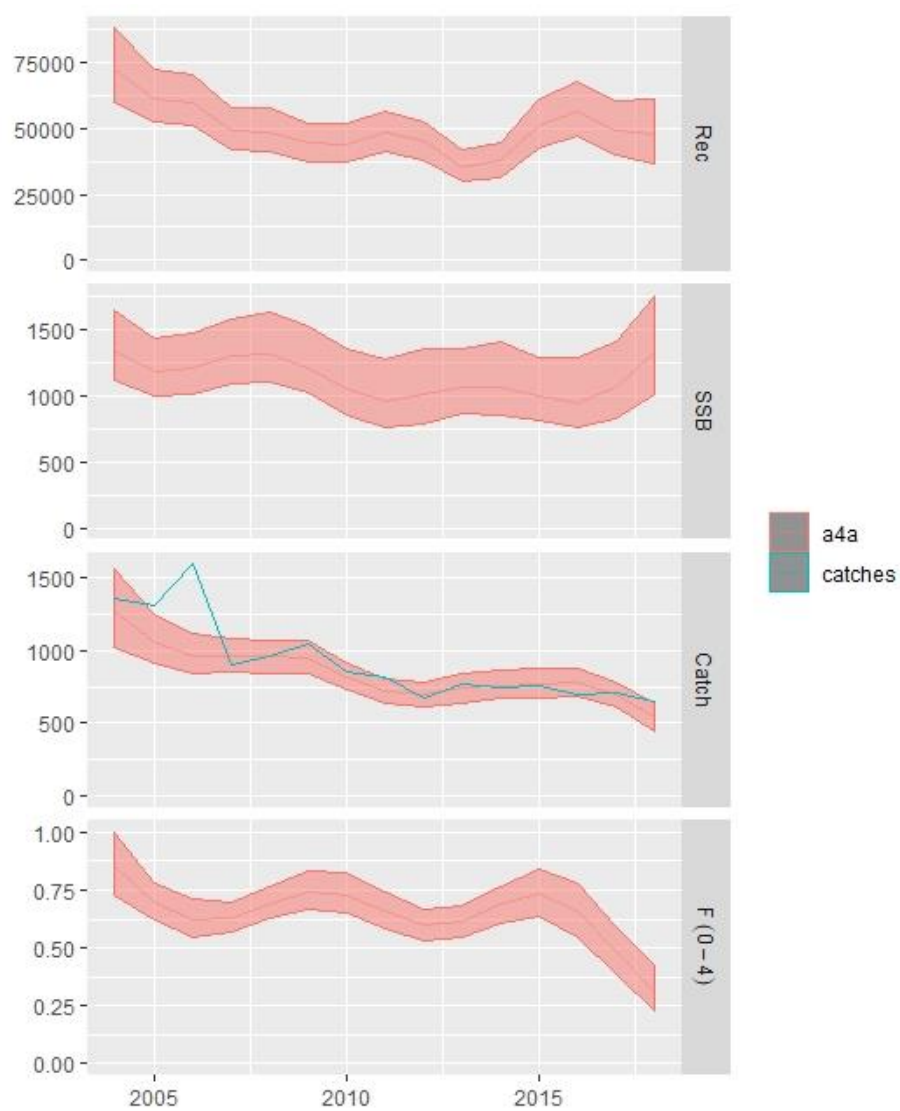


Figure 3.3.2.18. Stock summary with uncertainty (the turquoise line representing the observed catches)

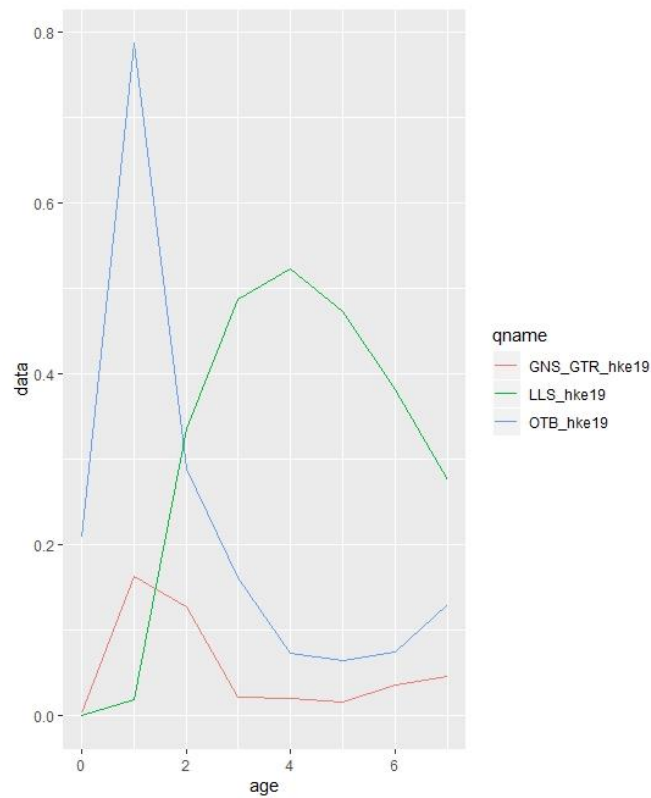


Figure 3.3.2.19. Partial F by gear

G. Retrospective analysis, comparison between model runs, sensitivity analysis

The retrospective analysis as well as the plot of residuals did not show any signal of instability or trend (Figures 3.3.2.20 and 3.3.2.21).

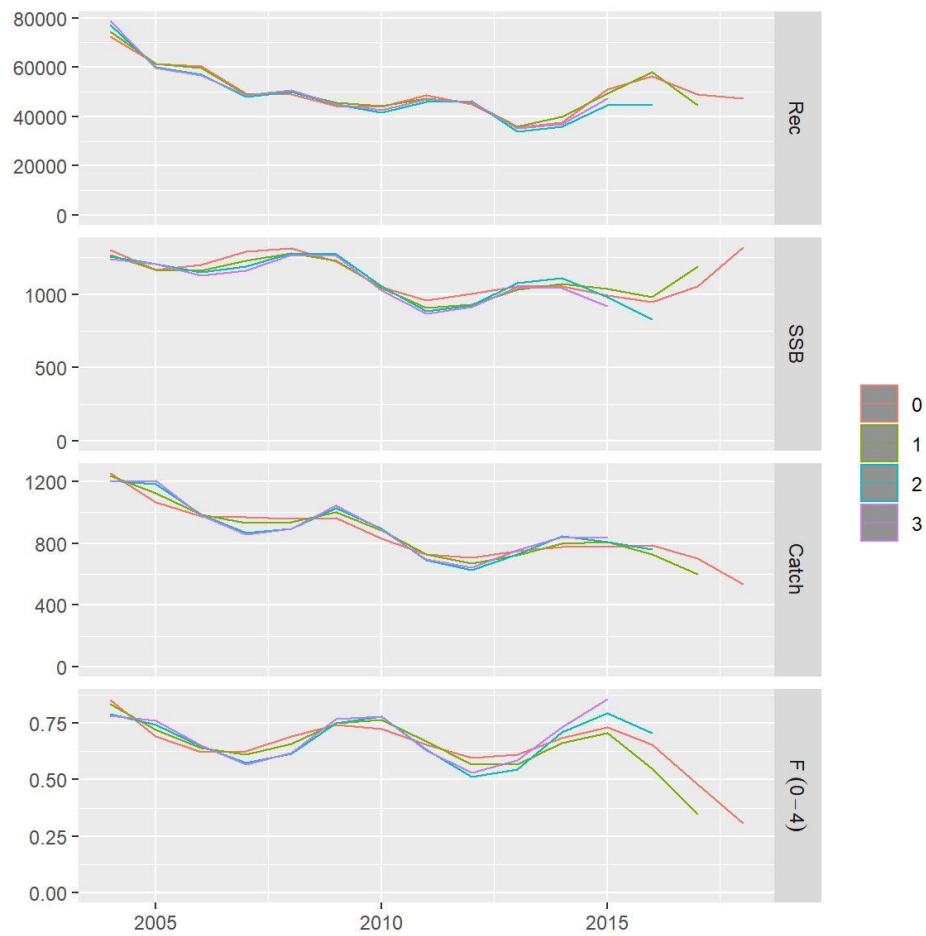


Figure 3.3.2.20. Retrospective analysis of the selected run (15)

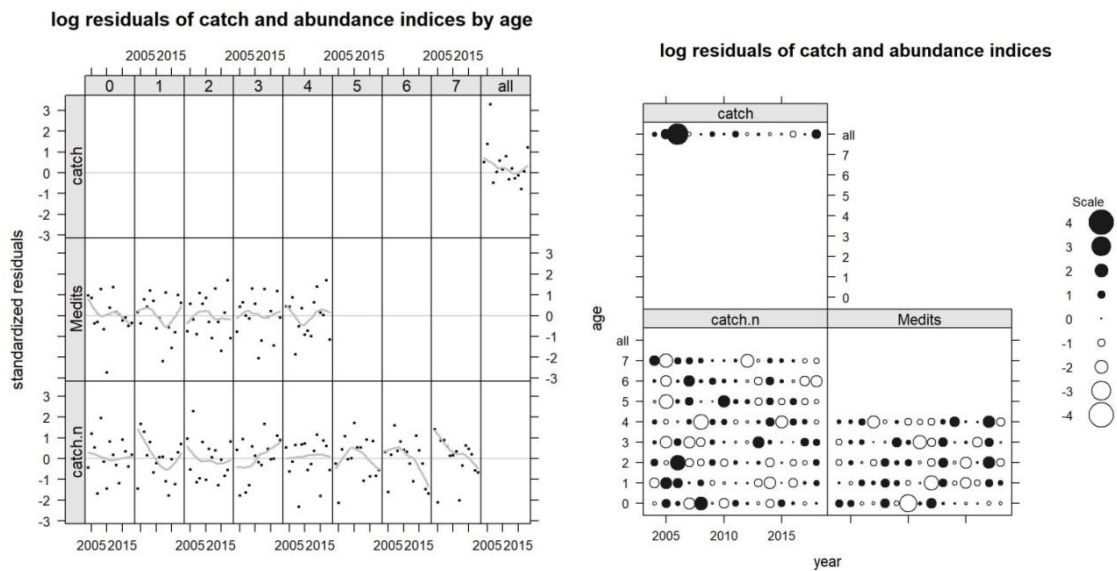


Figure 3.3.2.21. Residuals of the selected run (15)

H. Assessment quality

Considering the sensitivity analysis carried out, the retrospective analysis and the residuals diagnostic, the group agreed that the assessment results can be considered quite reliable, to be endorsed as benchmark assessment.

3.3.2.9. Stock predictions

A. Short-term predictions

Being the time series too short to estimate a reliable stock recruitment relationship, the group agreed to estimate the reference points on the basis of equilibrium methods, using $F_{0.1}$ as a proxy of F_{MSY} . The FLBRP library was used to estimate $F_{0.1}$ from the stock object resulting from the outputs of the a4a assessment, assuming a geometric mean on the whole time series as recruitment function. Current F (0.31, estimated as the last value, 2018) is higher than $F_{0.1}$ (0.13), chosen as proxy of F_{MSY} and as the exploitation reference point consistent with high long-term yields, which indicates that the European hake stock in GSA 19 is overexploited (Figure 3.3.2.22).

A deterministic short-term prediction for the period 2019 to 2021 was performed using the FLR libraries and scripts, starting from the results of the selected a4a stock assessment. The input parameters for the deterministic short-term predictions were the same used for the a4a stock assessment and its results. An average of the last three years has been used for weight at age, maturity at age and recruitment, while the mean F_{bar} (2018) from the a4a assessment was used (because showing a decreasing trend).

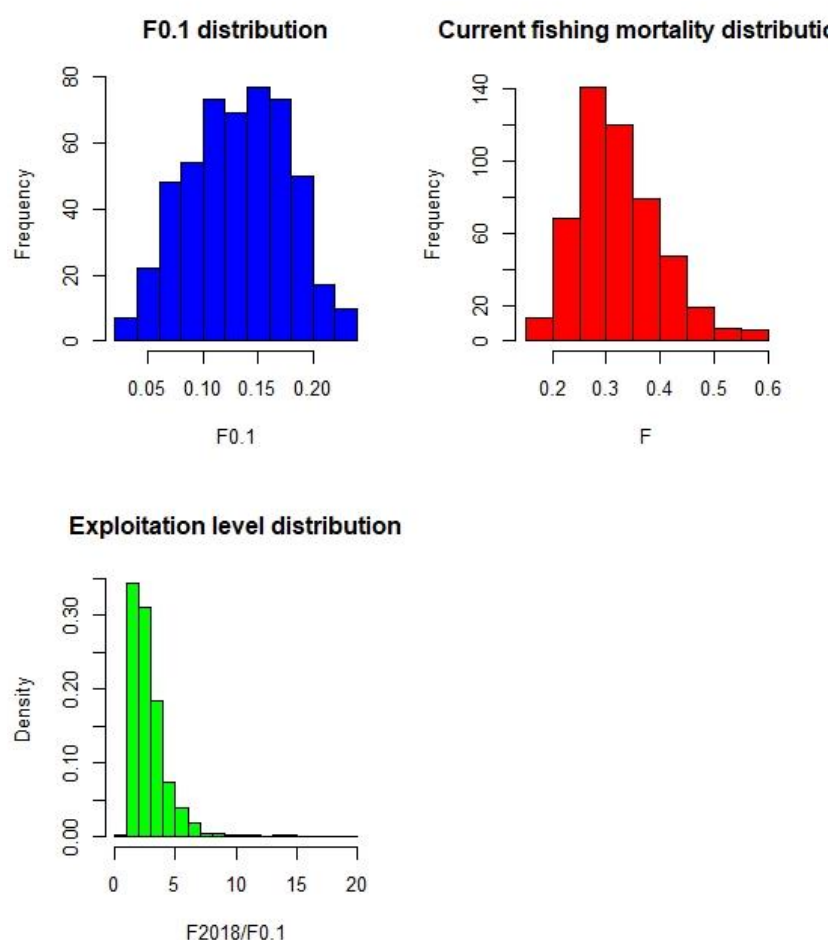


Figure 3.3.2.22. Reference points and F current with uncertainty

The results of short term predictions show that a decrease in fishing mortality at F0.1 level would produce an increase in the SSB of 85 percent from 2019 to 2021 and a decrease in the 30 percent of the catch from 2020 to 2018.

Table 3.3.2.23. Short-term forecast settings for European hake in GSA 19

Variable	Value	Notes
Biological parameters		Mean weights at age, maturation at age, natural mortality at age and selection at age, based average of 2016–2018
F _{ages 1-3} (2019)	0.31	Value of 2018
SSB (2019)	1 873	Stock assessment 1 January 2019
R _{age0} (2019, 2020)	50 948	Average years 2016–2018
Total catch (2019)	671	Assuming F status quo for 2019

Table 3.3.2.24. Short-term forecast outputs in different F scenarios for European hake in GSA 19.

Rationale	Ffactor	Fbar	Catch2020	SSB2021	SSB_change_2019-2021(%)	Catch_change_2018-2020(%)
High long term yield (F0.1)	0.43	0.13	373	3470	85.32	-30.55
F upper	0.60	0.19	512	3288	75.59	-4.62
F lower	0.29	0.09	260	3619	93.28	-51.63
Zero catch	0.00	0.00	0	3964	111.68	-100.00
Status quo	1.00	0.31	804	2910	55.39	49.71
Different Scenarios	0.10	0.03	92	3842	105.17	-82.95
	0.20	0.06	180	3724	98.88	-66.40
	0.30	0.09	267	3610	92.79	-50.33
	0.40	0.12	350	3500	86.90	-34.74
	0.50	0.15	432	3393	81.21	-19.61
	0.60	0.19	510	3290	75.70	-4.92
	0.70	0.22	587	3190	70.37	9.35
	0.80	0.25	661	3094	65.21	23.20
	0.90	0.28	734	3000	60.22	36.65
	1.10	0.34	872	2822	50.72	62.40
	1.20	0.37	938	2738	46.20	74.73
	1.30	0.40	1002	2656	41.82	86.70
	1.40	0.43	1065	2577	37.59	98.34
	1.50	0.46	1126	2500	33.49	109.64
	1.60	0.49	1184	2425	29.52	120.63
	1.70	0.52	1242	2354	25.68	131.31
	1.80	0.56	1298	2284	21.97	141.69
	1.90	0.59	1352	2217	18.37	151.78
	2.00	0.62	1404	2151	14.88	161.59

3.3.3. Assessment unit: GSA 20

3.3.3.1. Method 1: Surplus production model with SPiCT

Stock assessment was based on a surplus production model that was implemented with the SPiCT package (Pedersen and Berg, 2017) in R environment (R core team 2017). SPiCT does a state-space implementation of the Pella-Tomlinson surplus production model in continuous time, which assumes that both the biomass (process equation) and survey index equation (observation equation) are subject to errors. Additionally, SPiCT assumes that the catch equation is subject to error.

A. Model assumptions

Surplus production models aim to predict the biomass and exploitation level of stocks in cases where catch-at-age data are not available. The data required to fit the model are a time series of catches and a time series of CPUE or abundance indices. The model assumes that the rate of change of the total biomass is a function of the net biomass added or removed from the population through the processes of recruitment, growth and

natural mortality (surplus production) and the biomass removed through fishing (the catch). The surplus production is the result of a constant density-independent growth rate, r (which incorporates recruitment, growth and natural mortality) and a density-dependent term that reduces the rate of growth when the biomass approaches the carrying capacity, K . The catch removed from the population is assumed to be proportional to the current biomass, B , and the fishing mortality, F . A second equation links the survey abundance index time series with the biomass equation, assuming that the abundance index is proportional to the biomass through a constant coefficient q that represents the catchability.

B. Input data and parameters

The input data are the time series of landings from 1990–2018 and a time series of abundance indices from the MEDITS trawl survey (1994–2018) (Table 3.3.3.1). The abundance index time series has a number of missing values, i.e. years when the sampling did not take place. Initially, the fits were performed using default SPiCT parameterization. Then, to improve the assessments, a number of different model fits were investigated, exploring all possible combinations of two factors: i) use a prior for the shape parameter n (lognormally distributed with mean $\log(n) = \log(2)$, and standard deviation of 0.4); and ii) use a prior for the growth rate r (lognormally distributed with mean $\log(r) = \log(0.53)$, and standard deviation of 0.4). The prior mean estimate of growth rate r was taken from FishBase.

Table 3.3.3.1. Landings and abundance index by year for European hake in GSA 20

Year	Landings (tonnes)	Abundance index
1990	377.2	NA
1991	607.1	NA
1992	816.6	NA
1993	1 759.2	NA
1994	1 718.9	21.13
1995	1 486.5	69.35
1996	1 151.4	30.87
1997	1 145.0	23.94
1998	777.6	14.92
1999	665.9	13.93
2000	598.9	30.05
2001	612.8	31.54
2002	760.2	NA
2003	692.3	36.52
2004	777.2	42.36
2005	876.3	68.75
2006	1 234.5	52.06
2007	1 229.2	NA
2008	1 458.4	45.31
2009	1 247.1	NA
2010	1 067.7	NA
2011	923.9	NA
2012	962.1	NA
2013	1 025.9	NA
2014	638.3	34.13
2015	425.7	NA
2016	509.3	44.15
2017	685.3	NA
2018	998.3	45.88

C. Results

From the four models tested (default, prior in n , prior in r , and prior in n and r), the model with prior in n and r passed all seven criteria of the SPiCT checklist, although all models converged returning similar qualitative results. Hence focusing on the model with prior in n and r hereafter, the model exhibited relatively lower variability in the fits of relative biomass and relative fishing mortality (top row of Figure 3.3.3.1) compared to the other models. The fit of the production curve appeared satisfactory, although not covering a wide range of B/K , and the Kobe plot showed that the stock was overfished in the 1995–2005 period, but is currently underfished (bottom row of Figure 3.3.3.1). In specific, the SPiCT assessment estimated that the biomass in 2018 was around 1.5 of B_{msy} , and that fishing mortality was around 0.5 of F_{msy} (Table 3.3.3.2).

The model exhibited satisfactory behavior in the diagnostics. The posterior distributions for the parameters estimated using priors were narrower than their prior distributions, indicating that the empirical data were informative for these estimates (Figure 3.3.3.2). The diagnostic tests for the one-step-ahead residuals of both the catch and index fits did not show any residual mean different from zero, no empirical autocorrelation in the residuals, and no normality departure in the distribution of the residuals (Figure 3.3.3.3).

Table 3.3.3.2. Mean estimates of parameters and reference points, and low–high ends of their 95 percent CI

Variable	Estimate	Low	High
n	1.559	0.863	2.815
r	0.618	0.337	1.132
K	5914	3694	9468
B_{msy}	2665	1576	4505
F_{msy}	0.40	0.24	0.66
MSY	1055	949	1172
$BB_{msy}(2018)$	1.504	1.060	2.134
$FF_{msy}(2018)$	0.536	0.336	0.856

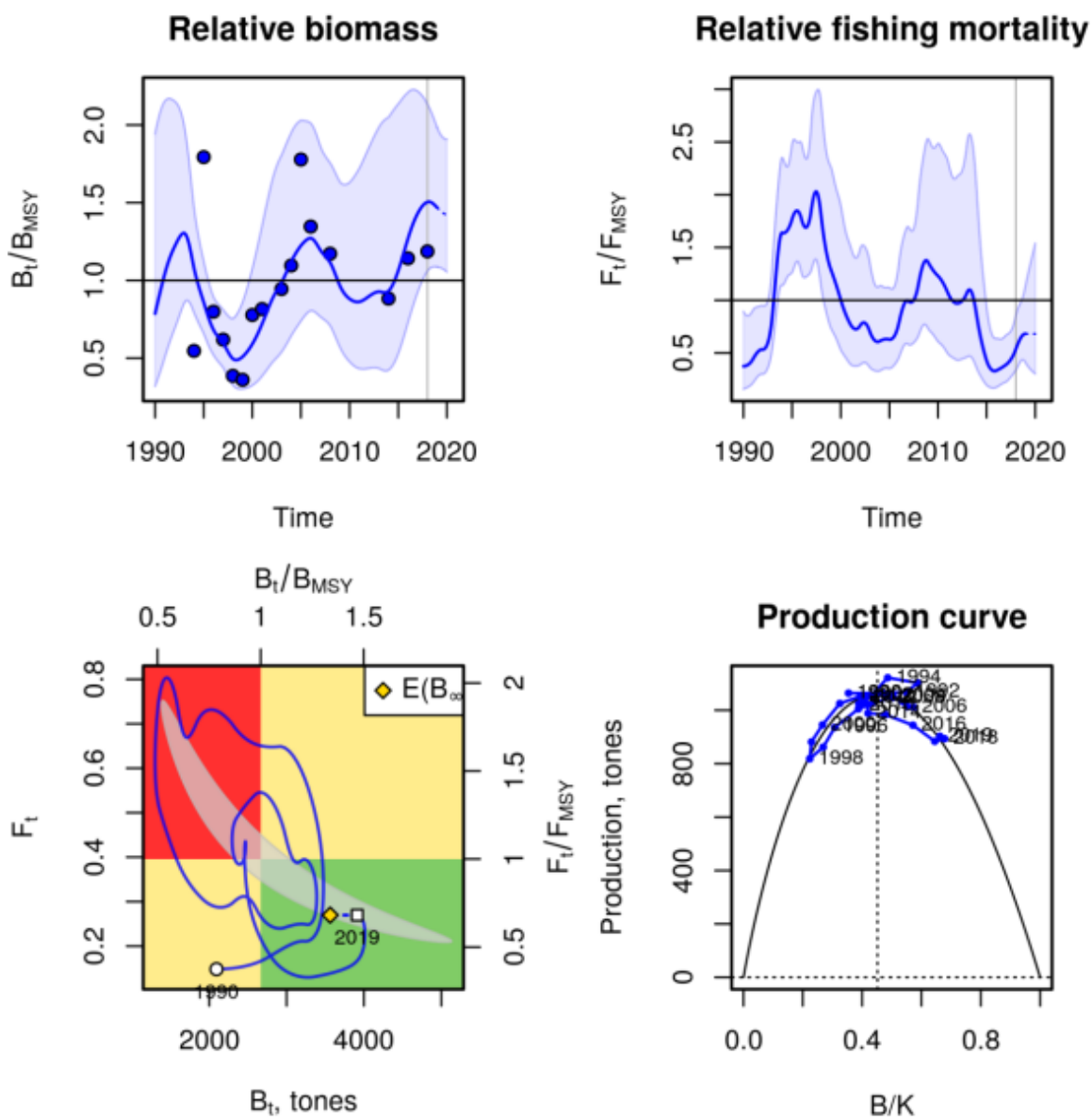


Figure 3.3.3.1. Stock assessment fits for European hake in GSA 20

The top row shows the median (blue solid line) of relative biomass and relative fishing mortality with 95 percent CI (blue shaded region) and the bottom row shows the Kobe plot of fishing mortality versus biomass (left), and the fitted production curve (right).

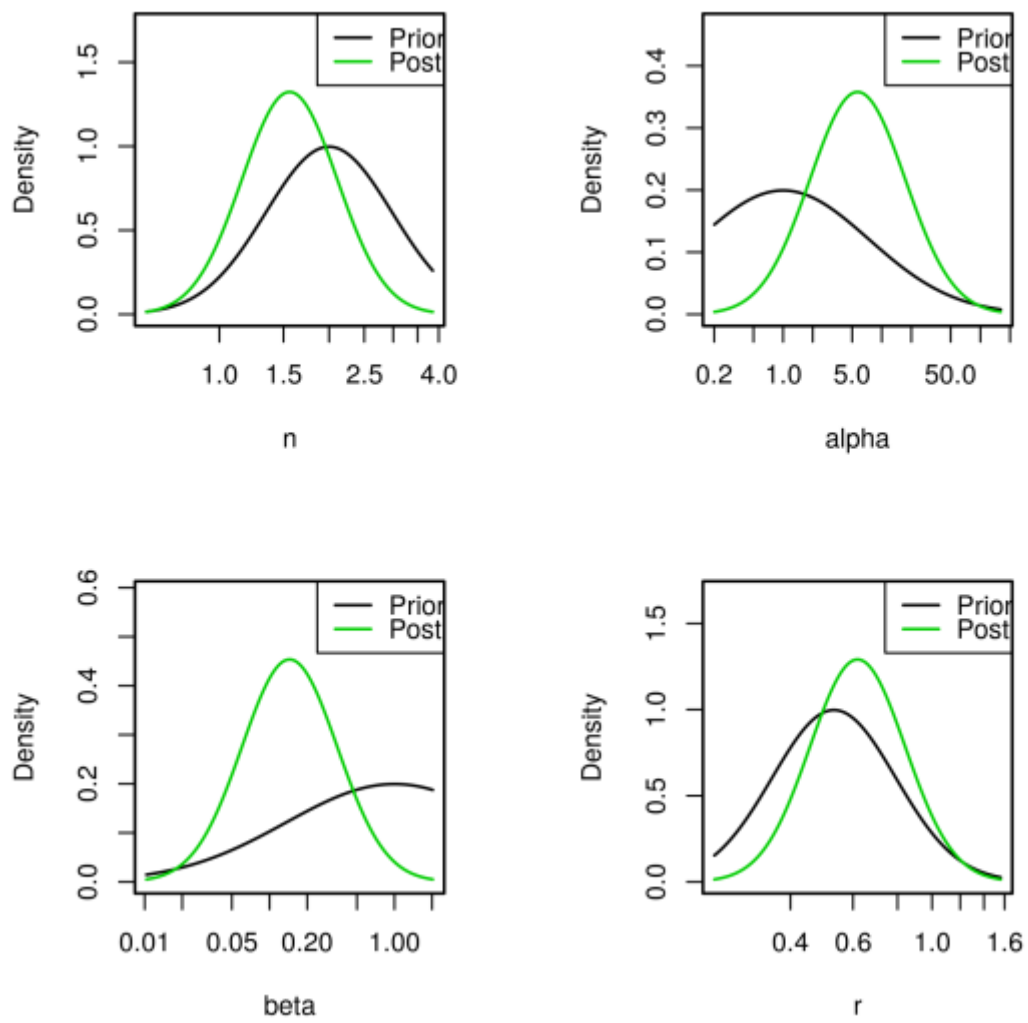


Figure 3.3.3.2. Prior–posterior distributions of all parameters that were estimated using priors

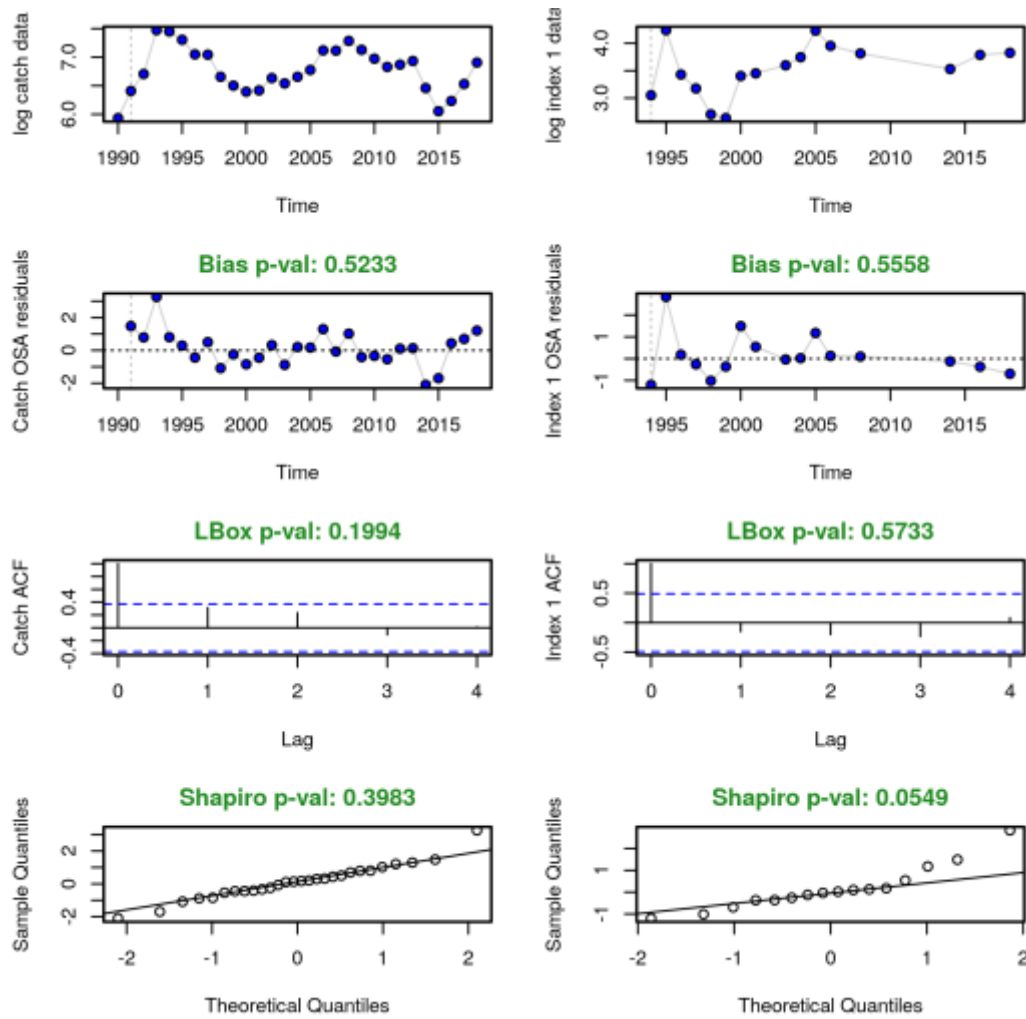
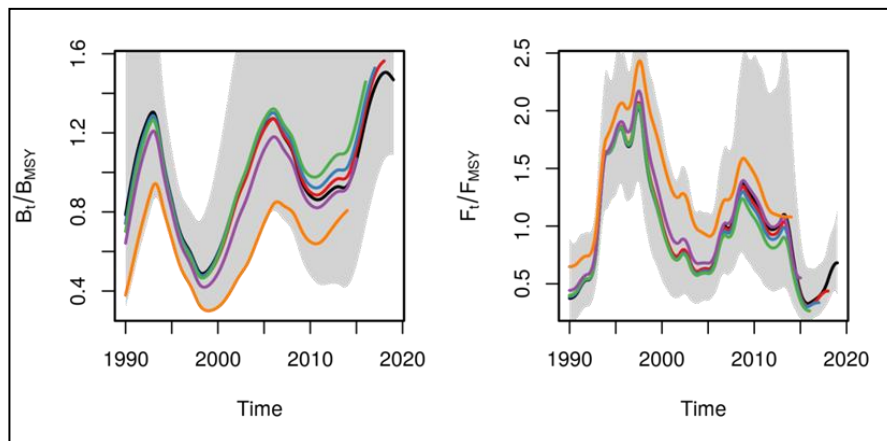


Figure 3.3.3.3. Diagnostic test for the fit of the residuals of the catch and abundance index series: log of input data series (first row), residuals plot (second row), autocorrelation of residuals (third row) and normality of residuals (fourth row) with a red header if the test is significant and a greenheader if it is not

D. Retrospective analysis, comparison between model runs, sensitivity analysis

The retrospective analysis for the last five years showed relatively consistent pattern of the fits, especially given the large gap created in the index series when the fifth year is excluded (Figure 3.3.3.4).



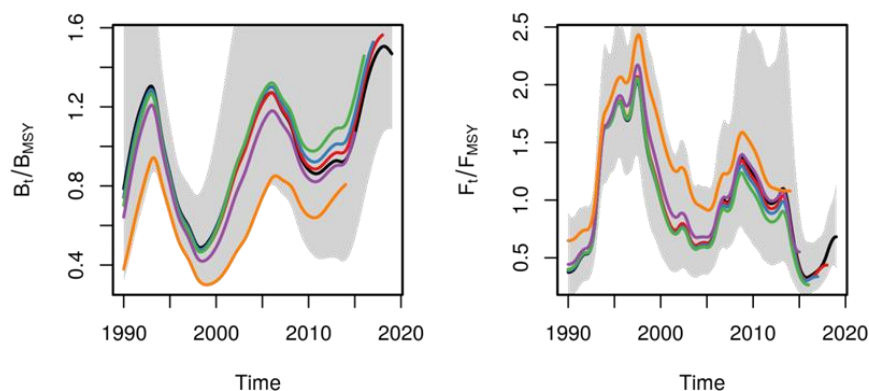


Figure 3.3.3.4. Retrospective plots of relative biomass and relative fishing mortality for European hake, produced by repeating the stock assessment after excluding one to five final year observations of the landings and abundance index time series (the shaded regions are the 95 percent CI for the fits to the complete dataset)

3.3.3.2. Method 2: Pseudo-cohort

Pseudo-cohort virtual population analysis (VPA) uses one year catch-at-age data and a vector of natural mortality by age to estimate fishing mortality by age.

A. Model assumptions

The model assumes that the given catch-at-age distribution is representative of the catch from a given cohort (equilibrium hypothesis). The “observed” total mortality (Z) for each age class is attributed to either fishing (fishing mortality, F) or natural causes (natural mortality, M). Working backwards from the plus age group, the total mortality for each age class is estimated and the fishing mortality is found as $F = Z - M$. The main assumption of VPA is that the snapshot of catch-at-age distribution represents the time evolution of a cohort, which would require the population to be at equilibrium and ignores any variability of recruitment on the population size of each age class. Additionally, the assessment requires a value of terminal E (exploitation rate of the last age class) as input; hence the assessment can be sensitive to this assumption.

B. Input data and parameters

Table 3.3.3.3. Input data and parameters to VPA for European hake in GSA 20 with catch-at-age, mean weight at age and mortality vector in 2016 and 2018 (source: DCF), parameters of von Bertalanffy growth relationship, parameters of weight-at-age relationship and terminal exploitation rate

	Catch-at-age		Mortality(M)	
Age class	2016	2018		VB growth
0	1 054 187	370 632	1.85	Linf = 122cm
1	2 163 511	2 067 370	0.80	$k = 0.11y^{-1}$, $t_0 = -0.65y$
2	1 280 896	1 658 548	0.48	L-W relationship
3	104 174	175 962	0.37	$a = 0.0045$
4	2 6685	18 715	0.30	$b = 3.13$
5+	23 290	11 170	0.27	Terminal E = 0.6

C. Results

The fishing mortality vector by age resulting from the VPA assessment shows that the age class mostly exploited by fishing is age class 2 (Figure 3.3.3.5). The yield per recruit curve (Figure 3.3.3.6) showed that in both years the current fishing mortality (F_c) is higher than $F_{0.1}$; hence the European hake stock in GSA 20 is being overfished.

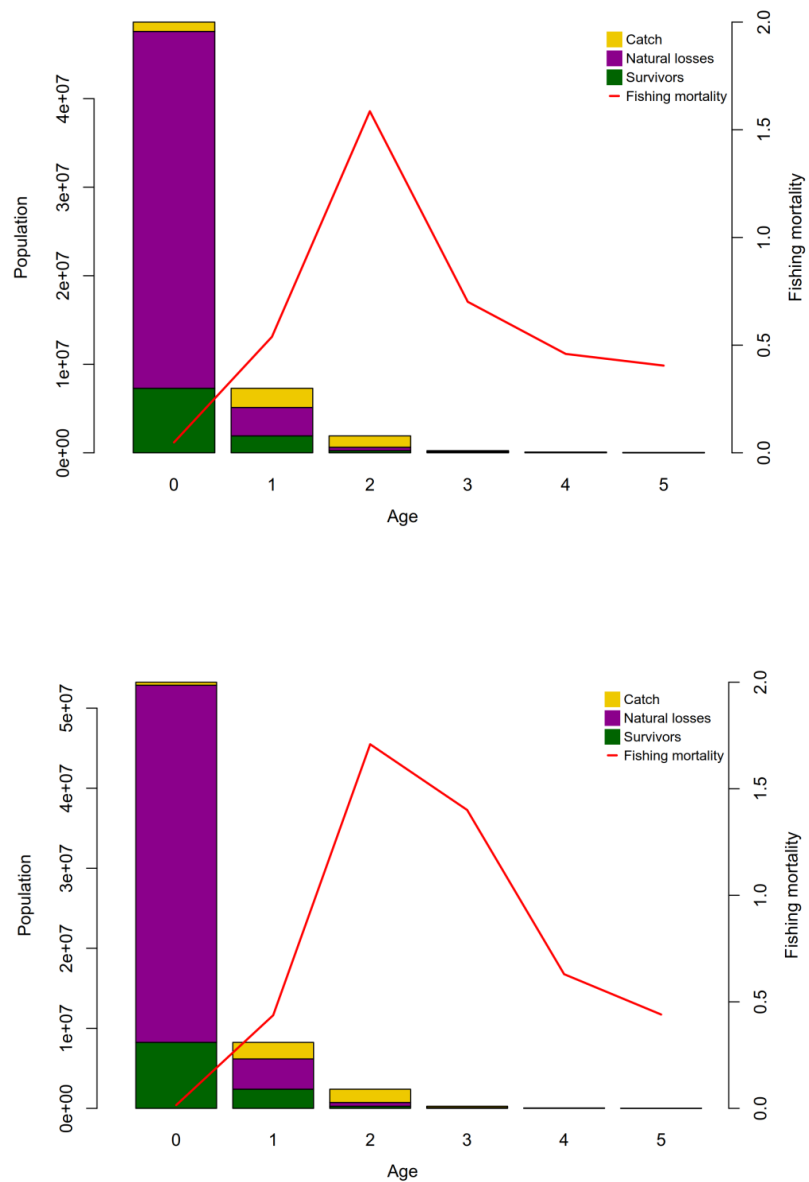


Figure 3.3.3.5. Result of VPA analysis for European hake in 2016 (upper graph) and 2018 (lower graph)

Bars show population numbers by age, partitioned into survivors, deaths due to fishing (catch) and deaths due to natural causes (natural losses). The red line shows the fishing mortality by age class estimated by the model.

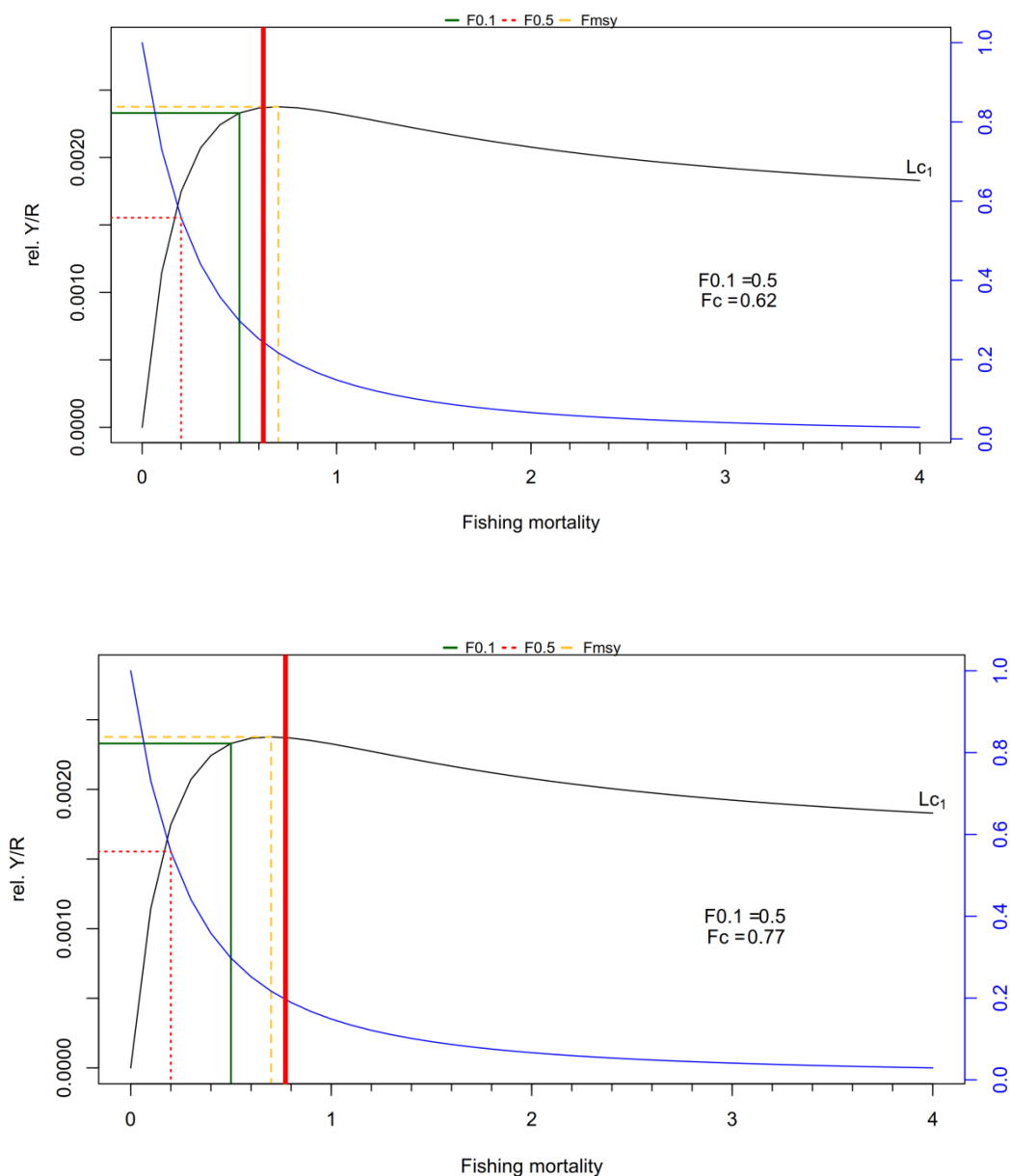


Figure 3.3.3.6. Yield per recruit relationship (black) and relative biomass (blue) for European hake in 2016 (upper graph) and 2018 (lower graph), current F rates (red solid line) above $F_{0.1}$ (green line)

D. Reference points

Given the aforementioned model uncertainties and the contrasting results of the applied methods, no reference points were adopted.

3.4. Eastern Mediterranean

3.4.1. Assessment unit: GSA 22

3.4.1.1. Method 1: Surplus production model with SPiCT

Stock assessment was based on a surplus production model twchich was implemented with the SPiCT package (Pedersen and Berg, 2017) in R environment (R core team 2017). SPiCT does a state-space implementation of

the Pella-Tomlinson surplus production model in continuous time, which assumes that both the biomass (process equation) and survey index equation (observation equation) are subject to errors. Additionally, SPiCT assumes that the catch equation is subject to error.

A. Model assumptions

Surplus production models aim to predict the biomass and exploitation level of stocks in cases where catch-at-age data are not available. The data required to fit the model are a time series of catches and a time series of CPUE or abundance indices. The model assumes that the rate of change of the total biomass is a function of the net biomass added or removed from the population through the processes of recruitment, growth and natural mortality (surplus production) and the biomass removed through fishing (the catch). The surplus production is the result of a constant density-independent growth rate, r (which incorporates recruitment, growth and natural mortality) and a density-dependent term that reduces the rate of growth when the biomass approaches the carrying capacity, K . The catch removed from the population is assumed to be proportional to the current biomass, B , and the fishing mortality, F . A second equation links the survey abundance index time series with the biomass equation, assuming that the abundance index is proportional to the biomass through a constant coefficient q that represents the catchability.

B. Input data and parameters

The input data are the time series of landings (1970–2018) in GSA 22 obtained from the National Statistical Service of Greece and a time series of abundance indices from the MEDITS trawl survey (1994–2018) (Table 3.4.1.1). The abundance index time series has a number of missing values, i.e. years when the sampling did not take place. Initially, the fits were performed using default SPiCT parameterization. Then, to improve the assessments, a number of different model fits were investigated, exploring all possible combinations of using: i) the complete series of landings from 1970–2018 with a prior for the initial B/K_{1970} (lognormally distributed with mean $\log(B/K_{1970}) = \log(0.9)$, and standard deviation of 0.5), or a shorter series of landings from 1990–2018; ii) a prior for the shape parameter n (lognormally distributed with mean $\log(n) = \log(2)$, and standard deviation of 0.4); and iii) a prior for the growth rate r (lognormally distributed with mean $\log(r) = \log(0.53)$, and standard deviation of 0.4). The prior mean estimate of growth rate r was taken from FishBase.

Table 3.4.1.1. Landings and abundance index by year for European hake in GSA 22

Year	Landings (tonnes)	Abundance index
1970	1 121.8	NA
1971	951.3	NA
1972	1 160.1	NA
1973	1 711.7	NA
1974	1 665.8	NA
1975	1 480.4	NA
1976	1 696.7	NA
1977	1 751.9	NA
1978	1 875.5	NA
1979	1 615.2	NA
1980	1 646.1	NA
1981	1 577.8	NA
1982	1 763.2	NA
1983	2 012.2	NA
1984	1 881.1	NA
1985	2 594.7	NA
1986	3 386.8	NA
1987	2 667.7	NA
1988	3 216.4	NA
1989	3 534.8	NA
1990	3 148.5	NA
1991	2 386.8	NA

Year	Landings (tonnes)	Abundance index
1992	3 080.9	NA
1993	2 763.2	NA
1994	4 336.0	32.53
1995	3 286.3	29.13
1996	3 040.1	34.11
1997	2 691.1	48.41
1998	2 203.4	44.64
1999	2 333.6	51.73
2000	2 268.3	48.46
2001	2 006.2	35.78
2002	2 101.1	NA
2003	2 373.4	46.58
2004	2 855.0	46.59
2005	2 873.7	46.65
2006	3 385.5	54.54
2007	3 761.4	NA
2008	3 849.2	52
2009	3 789.7	NA
2010	3 382.1	NA
2011	3 093.0	NA
2012	3 008.0	NA
2013	3 579.5	NA
2014	2 427.9	31.15
2015	2 741.9	NA
2016	3 085.5	38.57
2017	3 166.7	NA
2018	3 059.4	53.69

C. Results

From the models tested, the model with prior in n and r passed all seven criteria of the SPiCT checklist. No model converged when based on the long series of landings from 1970–2018. Hence focusing on the model based on the shorter landings series with prior in n - r hereafter, the model exhibited relatively lower than the other models variability in the fits of relative biomass and relative fishing mortality (top row of Figure 3.4.1.1). The fit of the production curve appeared satisfactory, although not covering a wide range of B/K , and the Kobe plot showed that the stock was never overfished in the period considered (bottom row of Figure 3.4.1.1). In specific, the SPiCT assessment estimated that the biomass in 2018 was around 1.5 of B_{msy} , and that fishing mortality was around 0.6 of F_{msy} (Table 3.4.1.2).

The model exhibited satisfactory behavior in the diagnostics. The posterior distributions for the parameters estimated using priors were narrower than their prior distributions, indicating that the empirical data were informative for these estimates (Figure 3.4.1.2). The diagnostic tests for the one-step-ahead residuals of both the catch and index fits did not show any residual mean different from zero, no empirical autocorrelation in the residuals, and no normality departure in the distribution of the residuals (Figure 3.4.1.3).

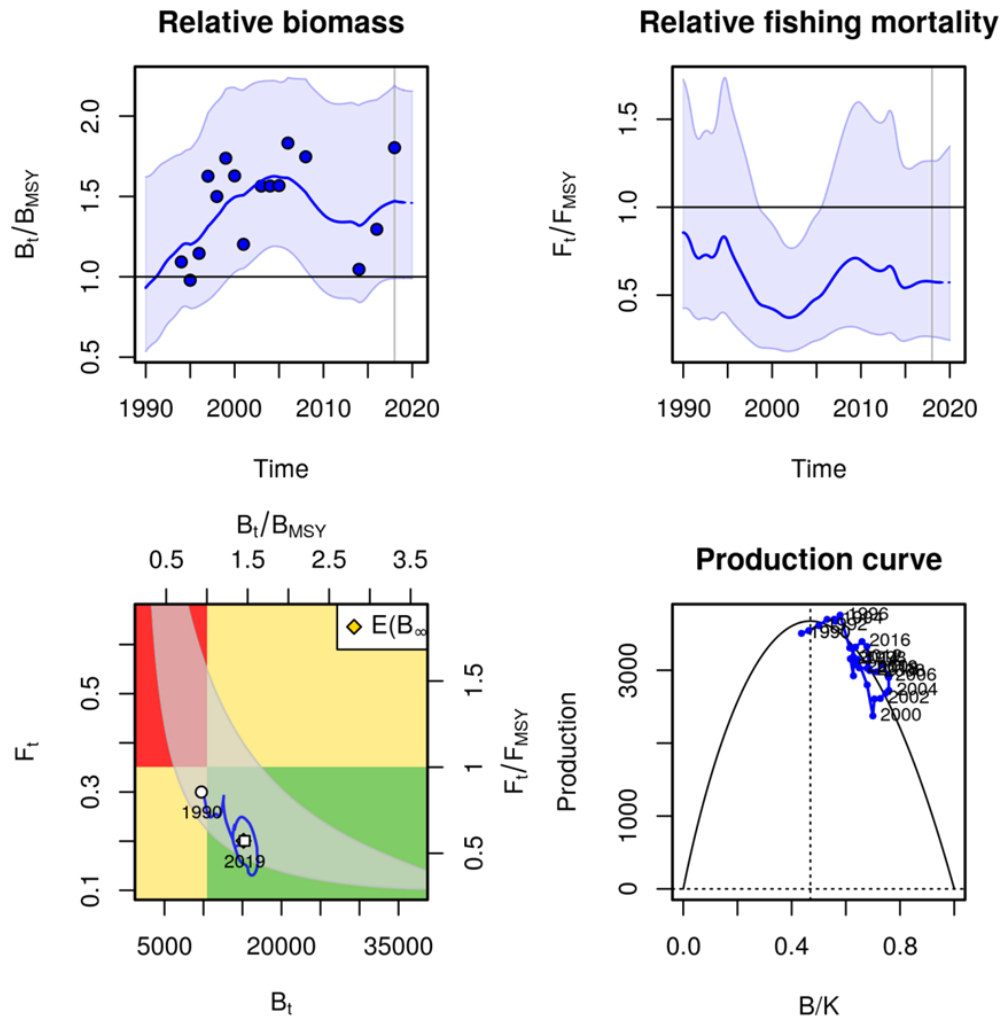


Figure 3.4.1.1. Stock assessment fits for European hake in GSA 22.

Top row shows the median (blue solid line) of relative biomass and relative fishing mortality with 95 percent CI (blue shaded region), while the bottom row features the Kobe plot of fishing mortality versus biomass (left), and the fitted production curve (right).

Table 3.4.1.2. Mean estimates of parameters, reference points, and their 95 percent CI

Variable	Estimate	Low	High
n	1.705	0.823	3.531
r	0.598	0.291	1.230
K	22320	8569	58134
Bmsy	10442	3432	31770
Fmsy	0.35	0.13	0.94
MSY	3660	2424	5527
BBmsy(2018)	1.471	0.988	2.189
FFmsy(2018)	0.577	0.263	1.264

Variable	Estimate	Low	High
n	1.705	0.823	3.531
r	0.598	0.291	1.230
K	22320	8569	58134
Bmsy	10442	3432	31770
Fmsy	0.35	0.13	0.94
MSY	3660	2424	5527
BBmsy(2018)	1.471	0.988	2.189
FFmsy(2018)	0.577	0.263	1.264

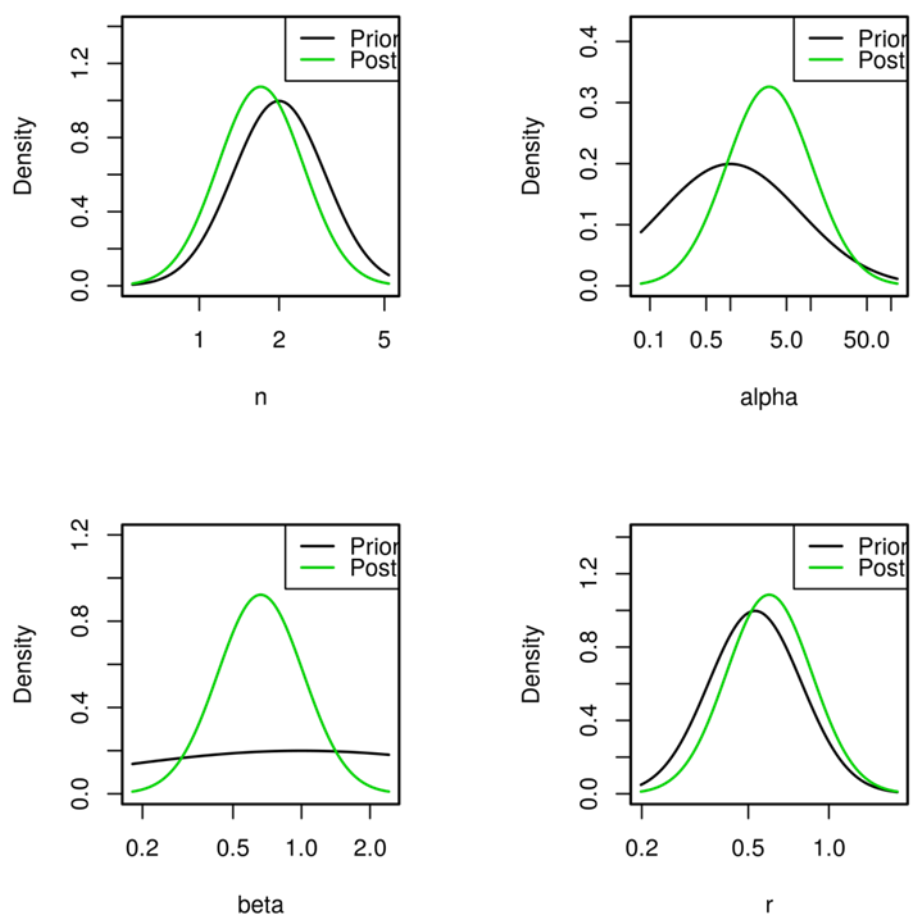


Figure 3.4.1.2. Prior–posterior distributions of all parameters that were estimated using priors

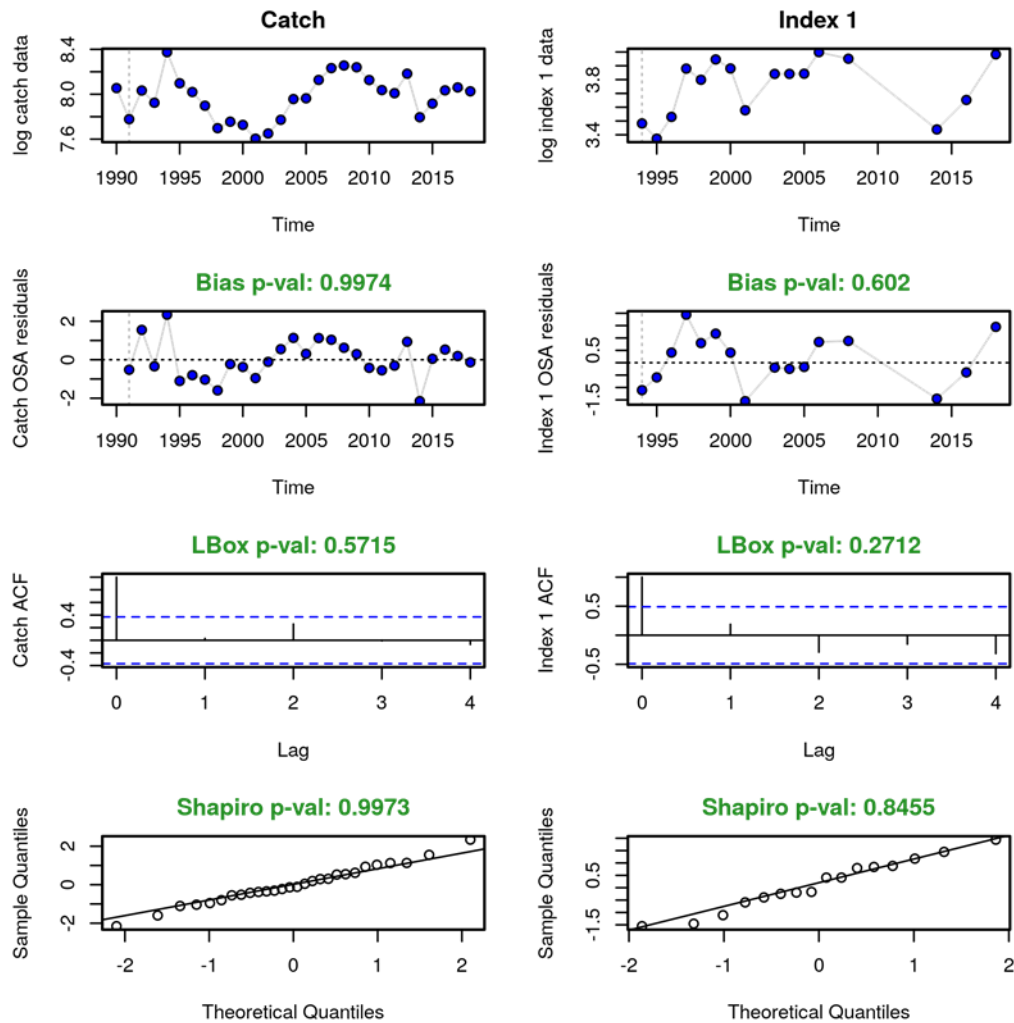


Figure 3.4.1.3. Diagnostic test for the fit of the residuals of the catch and abundance index series

Log of input data series (first row), residuals plot (second row), autocorrelation of residuals (third row) and normality of residuals (fourth row). If the header is green the test is not significant, otherwise the header is red.

D. Retrospective analysis, comparison between model runs and sensitivity analysis

The retrospective analysis for the last five years showed relatively consistent pattern of the fits, especially given the large gap created in the index series when the fifth year is excluded (Figure 3.4.1.4).

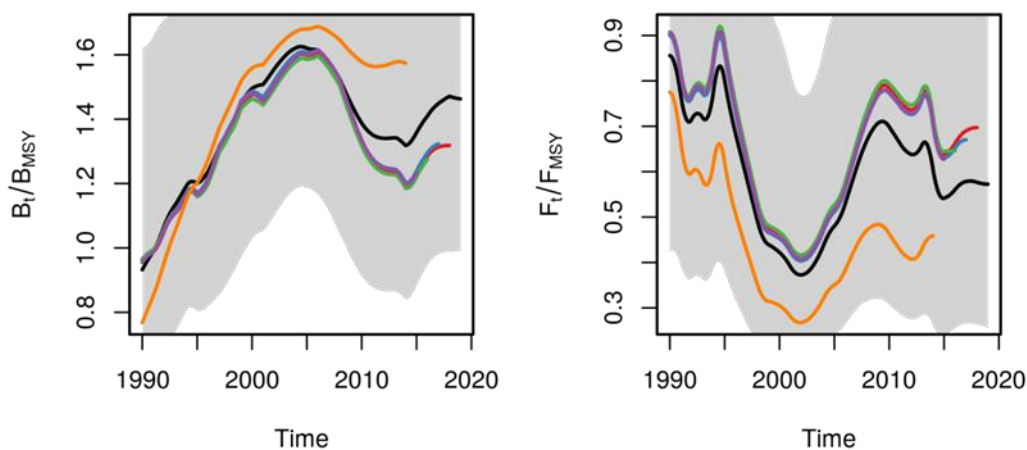


Figure 3.4.1.4. Retrospective plots of relative biomass and relative fishing mortality for European hake, produced by repeating the stock assessment after excluding one to five final year observations of the landings and abundance index time series (the shaded regions are the 95 percent CI for the fits to the complete dataset).

3.4.1.2. Method 2: Pseudo-cohort

Pseudo-cohort VPA uses one year catch-at-age data and a vector of natural mortality by age to estimate fishing mortality by age.

A. Model assumptions

The model assumes that the given catch-at-age distribution is representative of the catch from a given cohort (equilibrium hypothesis). The “observed” total mortality (Z) for each age class is attributed to either fishing (fishing mortality, F) or natural causes (natural mortality, M). Working backwards from the plus age group, the total mortality for each age class is estimated and the fishing mortality is found as $F = Z - M$. The main assumption of VPA is that the snapshot of catch-at-age distribution represents the time evolution of a cohort, which would require the population to be at equilibrium and ignores any variability of recruitment on the population size of each age class. Additionally, the assessment requires a value of terminal E (exploitation rate of the last age class) as input; hence the assessment can be sensitive to this assumption.

B. Input data and parameters

Table 3.4.1.3. Input data and parameters to VPA for European hake in GSA 22 with catch-at-age, mean weight at age and mortality vector in 2016 and 2018 (source: DCF), parameters of von Bertallanfy growth relationship, parameters of weight-at-age relationship, and terminal exploitation rate

	Catch-at-age		Mortality (M)	Parameters
Age class	2016	2018		VB growth
0	2 062 779	888 574	1.85	Linf = 106cm
1	4 515 612	3 687 650	0.80	k = 0.14y ⁻¹ , t0 = -0.54y
2	1 317 006	2484401	0.48	L-W relationship
3	576 690	1 112 144	0.37	a = 0.005
4	158 974	358 017	0.30	b = 3.11
5+	94 160	169 120	0.27	Terminal E = 0.6

C. Results

The fishing mortality vector by age resulting from the VPA assessment shows that the age classes mostly exploited by fishing are 2-4 (Figure 3.4.1.5). The yield per recruit curve (Figure 3.4.1.6) showed that in both years the current fishing mortality (F_c) is higher than $F_{0.1}$; hence the European hake stock in GSA 22 is being overfished.

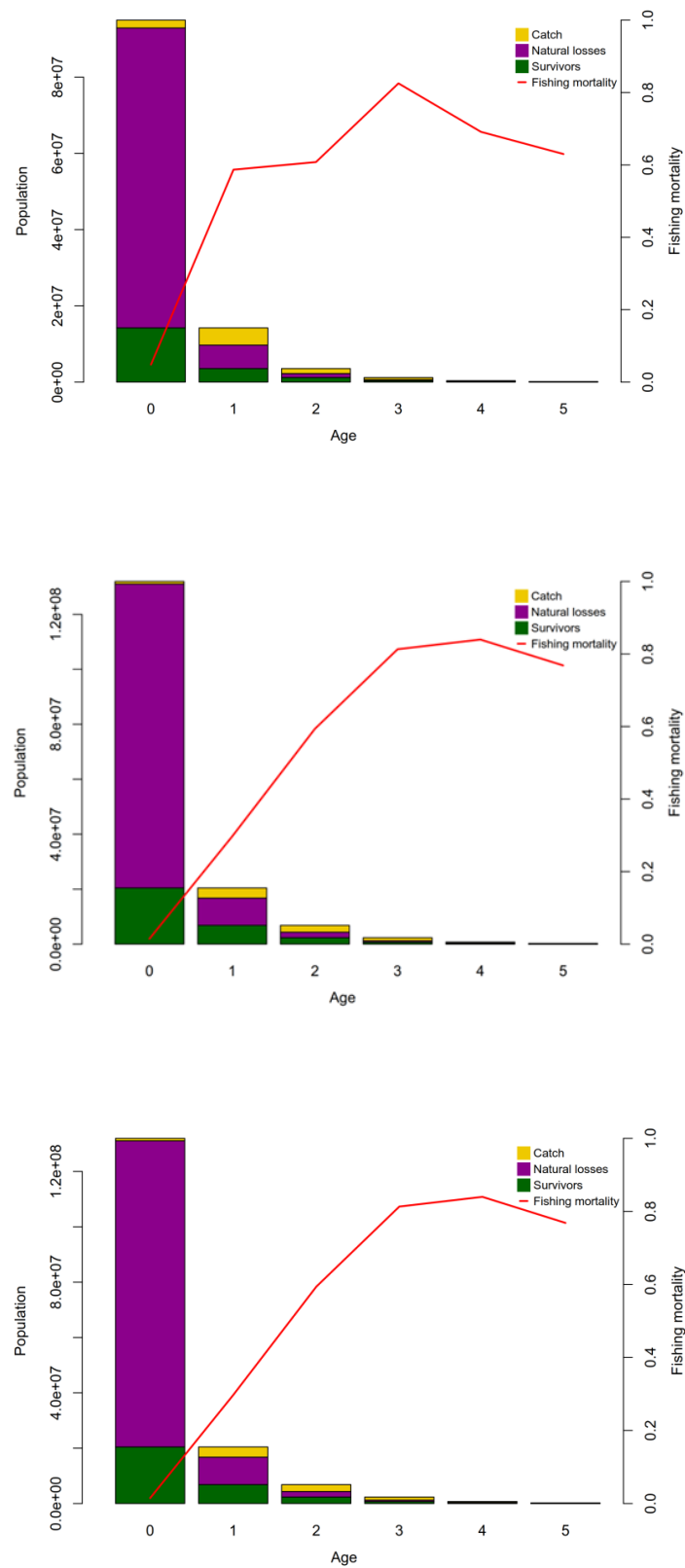


Figure 3.4.1.5. Results of VPA analysis for European hake in 2016 (upper graph) and 2018 (lower graph)

Bars show population numbers by age, partitioned into survivors, deaths due to fishing (catch) and deaths due to natural causes (natural losses). The red line shows the fishing mortality by age class estimated by the model.

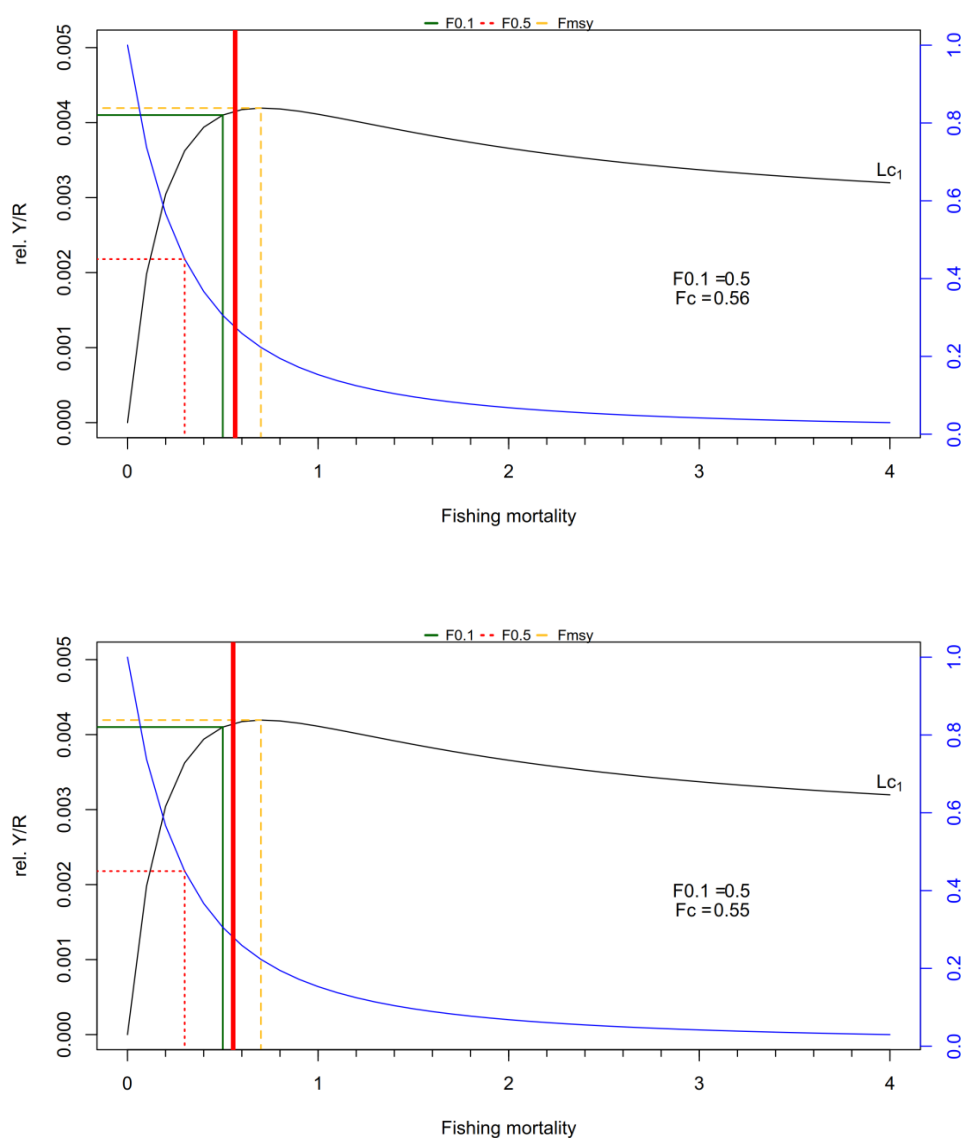


Figure 3.4.1.6. Yield per recruit relationship (black) and relative biomass (blue) for European hake in 2016 (upper graph) and 2018 (lower graph), current F rates (red solid line) above $F_{0.1}$ (green line)

D. Reference points

Given the contrasting results of the applied methods, no references points were adopted.

3.4.2. Assessment unit: GSA 23

3.4.2.1. Method 1: Surplus production model with SPiCT

Stock assessment was based on a surplus production model which was implemented with the SPiCT package (Pedersen and Berg, 2017) in R environment (R core team 2017). SPiCT does a state-space implementation of the Pella-Tomlinson surplus production model in continuous time, which assumes that both the biomass (process equation) and survey index equation (observation equation) are subject to errors. Additionally, SPiCT assumes that the catch equation is subject to error.

A. Model assumptions

Surplus production models aim to predict the biomass and exploitation level of stocks in cases where catch-at-age data are not available. The data required to fit the model are a time series of catches and a time series of CPUE or abundance indices. The model assumes that the rate of change of the total biomass is a function of the net biomass added or removed from the population through the processes of recruitment, growth and natural mortality (surplus production) and the biomass removed through fishing (the catch). The surplus production is the result of a constant density-independent growth rate, r (which incorporates recruitment, growth and natural mortality) and a density-dependent term that reduces the rate of growth when the biomass approaches the carrying capacity, K . The catch removed from the population is assumed to be proportional to the current biomass, B , and the fishing mortality, F . A second equation links the survey abundance index time series with the biomass equation, assuming that the abundance index is proportional to the biomass through a constant coefficient q that represents the catchability.

B. Input data and parameters

The input data are the time series of landings (1970–2018) in GSA 23 obtained from the National Statistical Service of Greece and a time series of abundance indices from the MEDITS trawl survey (1994–2018) (Table 3.4.2.1). The abundance index time series has a number of missing values, i.e. years when the sampling did not take place. Initially the fits were performed using default SPiCT parameterization. Then, to improve the assessments, a number of different model fits were investigated, exploring all possible combinations of using: i) the complete series of landings from 1970–2018 with a prior for the initial B/K_{1970} (lognormally distributed with mean $\log(B/K_{1970}) = \log(0.9)$, and standard deviation of 0.5), or a shorter series of landings from 1990–2018; ii) a prior for the shape parameter n (lognormally distributed with mean $\log(n) = \log(2)$, and standard deviation of 0.4); and iii) a prior for the growth rate r (lognormally distributed with mean $\log(r) = \log(0.53)$, and standard deviation of 0.4). The prior mean estimate of growth rate r was taken from FishBase.

Table 3.4.2.1. Landings and abundance index by year for European hake in GSA 23

Year	Landings (tonnes)	Abundance index
1970	76.2	NA
1971	64.7	NA
1972	78.9	NA
1973	116.3	NA
1974	113.2	NA
1975	100.6	NA
1976	115.3	NA
1977	119.1	NA
1978	127.5	NA
1979	109.8	NA
1980	111.9	NA
1981	107.2	NA
1982	119.8	NA
1983	136.8	NA
1984	127.9	NA
1985	176.3	NA
1986	230.2	NA
1987	181.3	NA
1988	218.6	NA
1989	240.2	NA
1990	190.3	NA
1991	222.4	NA
1992	243.4	NA
1993	519.4	NA
1994	334.4	33.7
1995	313.8	34.72

Year	Landings (tonnes)	Abundance index
1996	336.7	49.73
1997	380.5	19.22
1998	276.7	19.19
1999	126.9	10.13
2000	91.9	15.19
2001	134.4	6.64
2002	68.7	NA
2003	95.2	86.51
2004	115.5	53.51
2005	120.7	15.83
2006	174.1	61.52
2007	201.4	NA
2008	206.7	93.43
2009	193.5	NA
2010	152.0	NA
2011	95.9	NA
2012	80.7	NA
2013	88.6	NA
2014	69.1	3.37
2015	87.2	NA
2016	100.9	9.58
2017	109.7	NA
2018	68.2	9.52

C. Results

From the models tested, the model with prior in n and r passed all seven criteria of the SPiCT checklist. No model converged when based on the long series of landings from 1970–2018. Hence focusing on the model based on the shorter landings series with prior in n - r hereafter, the model exhibited relatively lower than the other models variability in the fits of relative biomass and relative fishing mortality (top row of Figure 3.4.2.1). The fit of the production curve appeared satisfactory, although not covering a wide range of B/K , and the Kobe plot showed that the stock has been probably overfished since 1990s (bottom row of Figure 3.4.2.1). In specific, the SPiCT assessment estimated that the biomass in 2018 was around 0.1 of B_{msy} , and that fishing mortality was around 2.7 of F_{msy} (Table 3.4.2.2).

The model exhibited satisfactory behavior in the diagnostics. The posterior distributions for the parameters estimated using priors were narrower than their prior distributions, indicating that the empirical data were informative for these estimates (Figure 3.4.2.2). The diagnostic tests for the one-step-ahead residuals of both the catch and index fits did not show any residual mean different from zero, no empirical autocorrelation in the residuals, and no normality departure in the distribution of the residuals (Figure 3.4.2.3).

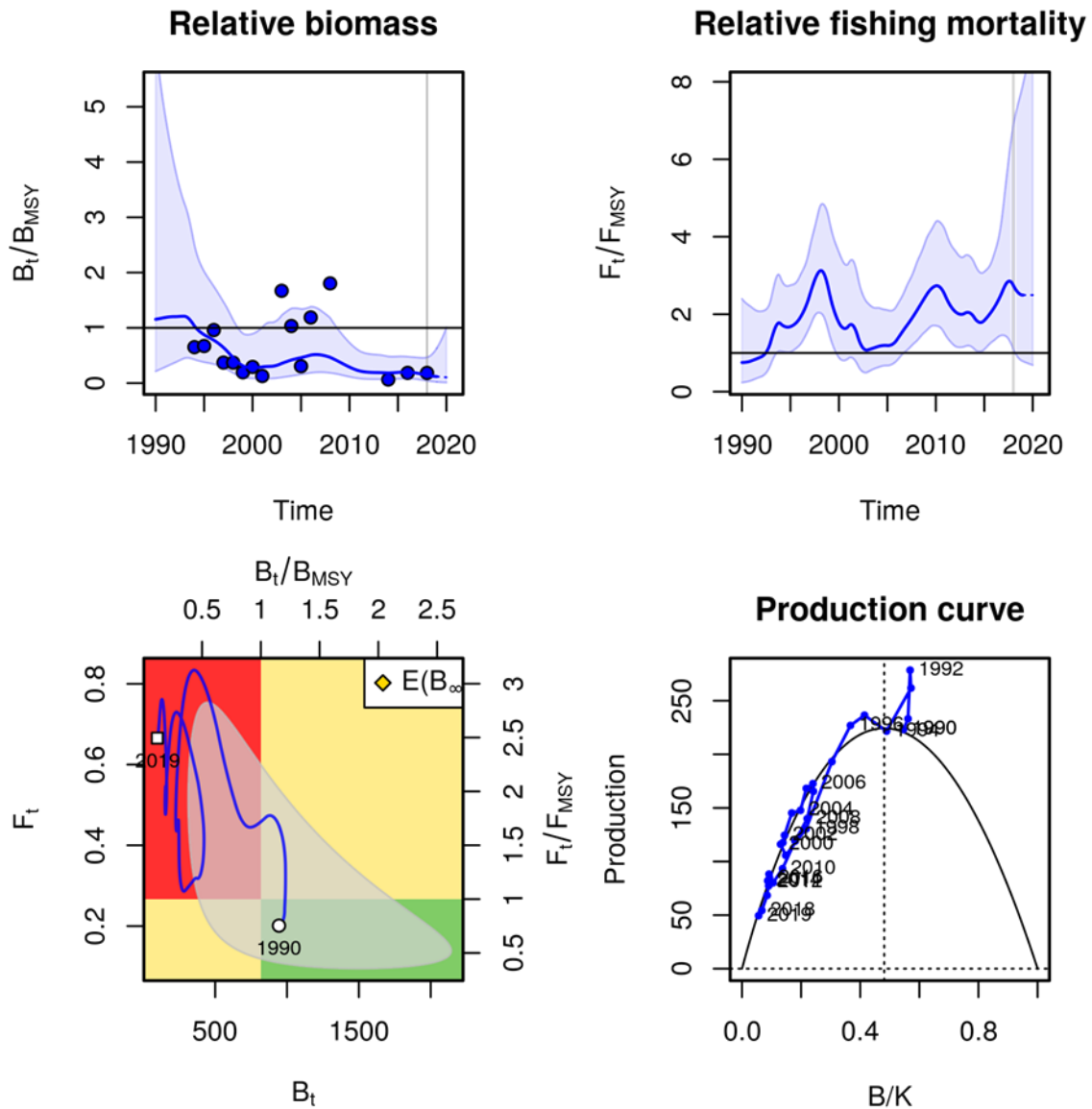


Figure 3.4.2.1. Stock assessment fits for European hake in GSA 23

The top row shows the median (blue solid line) of relative biomass and relative fishing mortality with 95 percent CI (blue shaded region), while the bottom row shows the Kobe plot of fishing mortality versus biomass (left), and the fitted production curve (right).

Table 3.4.2.2. Mean estimates of parameters, reference points, and their 95 percent CI

Variable	Estimate	Low	High
n	1.814	0.875	3.761
r	0.489	0.246	0.974
K	1729	876	3413
Bmsy	818	378	1769
Fmsy	0.27	0.12	0.61
MSY	218	109	437
BBmsy(2018)	0.142	0.043	0.466
FFmsy(2018)	2.742	1.090	6.894

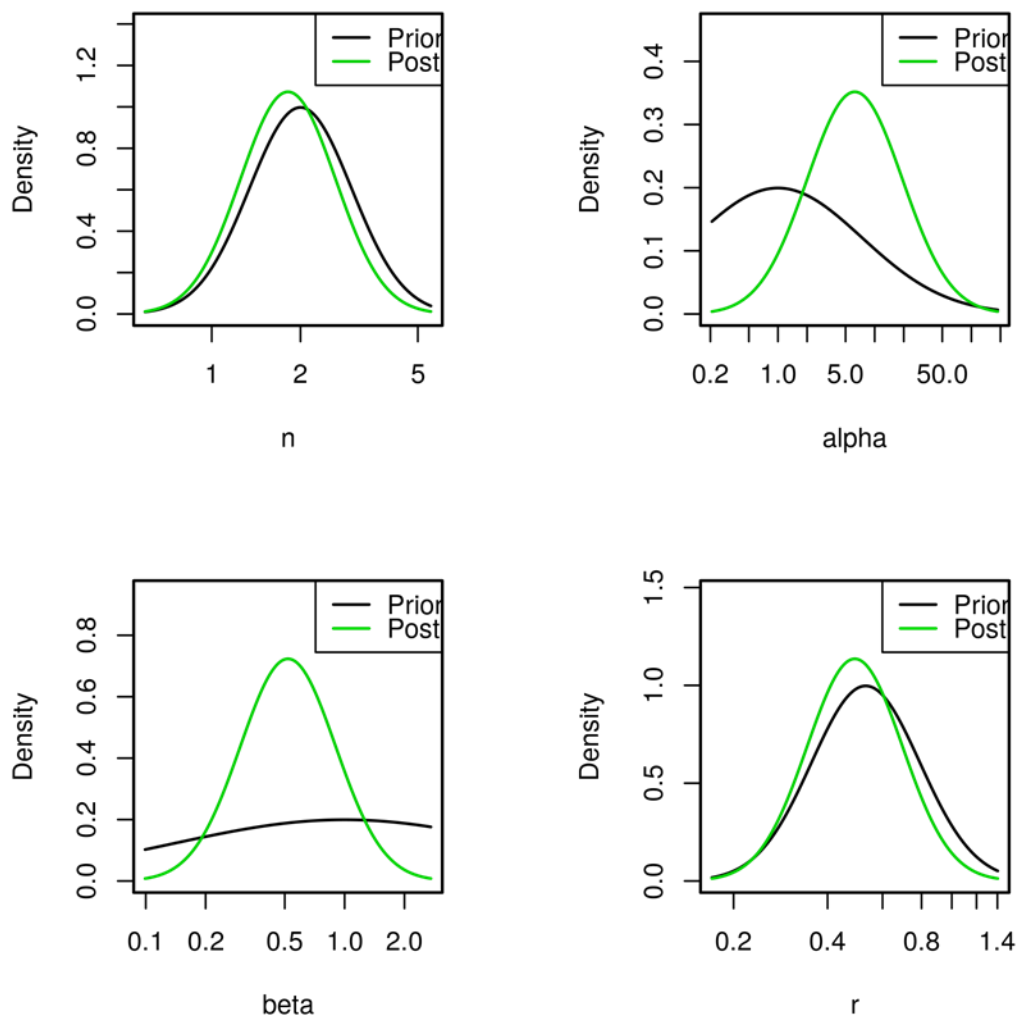


Figure 3.4.2.2. Prior-posterior distributions of all parameters that were estimated using priors

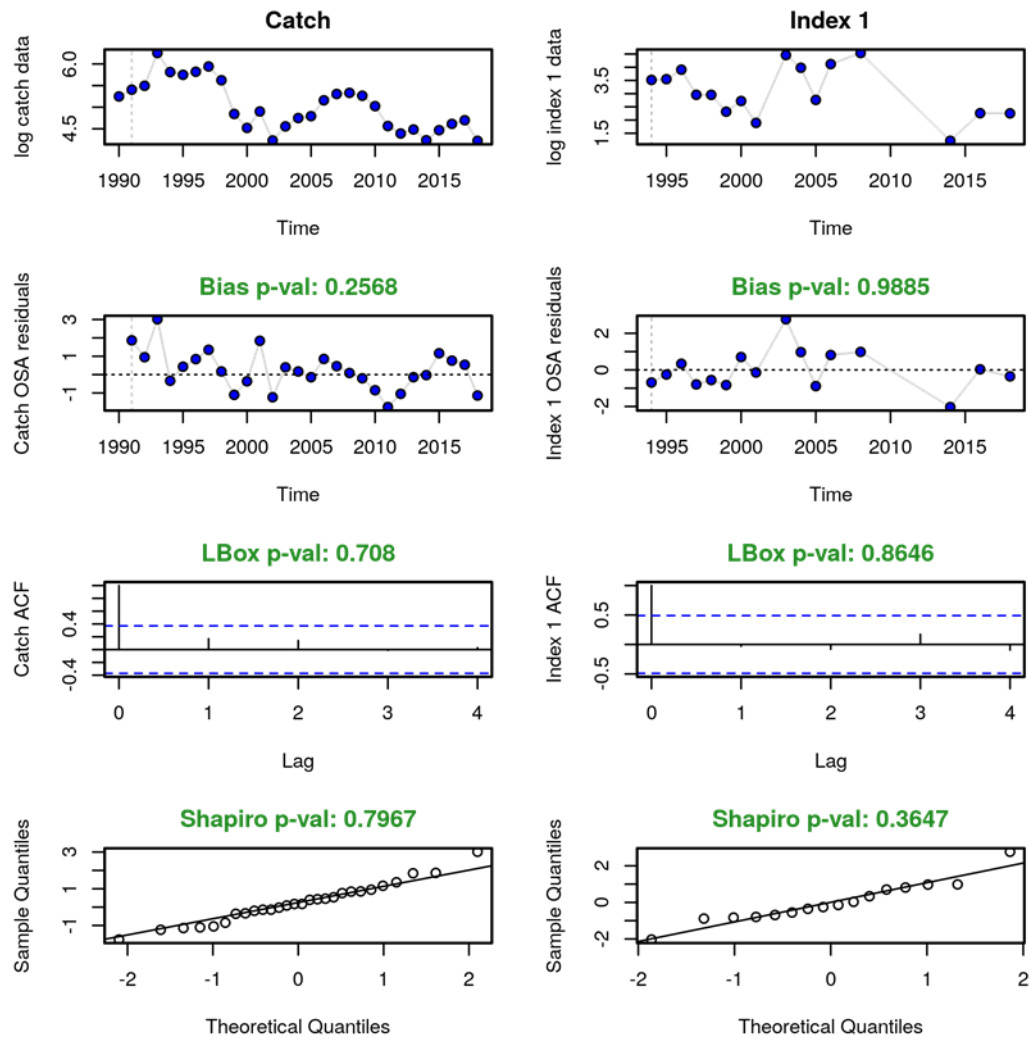


Figure 3.4.2.3. Diagnostic test for the fit of the residuals of the catch and abundance index series

Log of input data series (first row), residuals plot (second row), autocorrelation of residuals (third row) and normality of residuals (fourth row). If the header is green the test is not significant, otherwise the header is red.

D. Retrospective analysis, comparison between model runs and sensitivity analysis

The retrospective plots showed a certain degree of inconsistency as it can be seen in Figure 3.4.2.4.

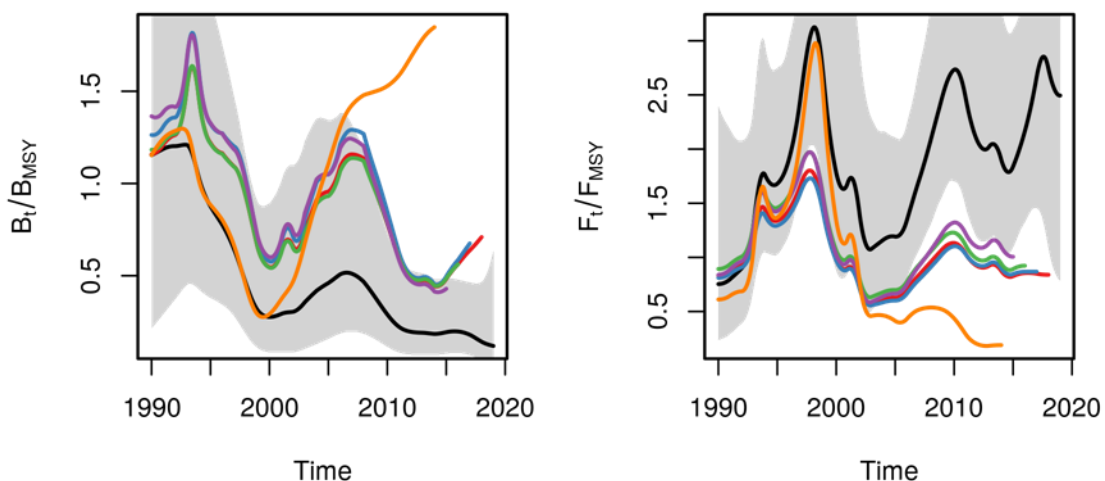


Figure 3.4.2.4. Retrospective plots of relative biomass and relative fishing mortality for European hake, produced by repeating the stock assessment after excluding one to five final year observations of the landings and abundance index time series (shaded regions are the 95 percent CI for the fits to the complete dataset)

3.4.2.2. Method 2: Pseudo-cohort

Pseudo-cohort VPA uses one year catch-at-age data and a vector of natural mortality by age to estimate fishing mortality by age.

A. Model assumptions

The model assumes that the given catch-at-age distribution is representative of the catch from a given cohort (equilibrium hypothesis). The “observed” total mortality (Z) for each age class is attributed to either fishing (fishing mortality, F) or natural causes (natural mortality, M). Working backwards from the plus age group, the total mortality for each age class is estimated and the fishing mortality is found as $F = Z - M$. The main assumption of VPA is that the snapshot of catch-at-age distribution represents the time evolution of a cohort, which would require the population to be at equilibrium and ignores any variability of recruitment on the population size of each age class. Additionally, the assessment requires a value of terminal E (exploitation rate of the last age class) as input; hence the assessment can be sensitive to this assumption.

B. Input data and parameters

Table 3.4.2.3. Input data and parameters of VPA for European hake in GSA 23: catch-at-age, mean weight at age and mortality vector in 2016 and 2018 (source: DCF), parameters of von Bertalanffy growth relationship, parameters of weight-at-age relationship, and terminal exploitation rate.

	Catch-at-age		Mortality (M)	
Age class	2016	2018		VB growth
0	2 062 779	888 574	1.85	$L_{inf} = 106\text{cm}$
1	4 515 612	3 687 650	0.80	$k = 0.14\text{y}^{-1}$, $t_0 = -0.54\text{y}$
2	1 317 006	2 484 401	0.48	L-W relationship
3	576 690	1 112 144	0.37	$a = 0.009$
4	158 974	358 017	0.30	$b = 2.94$
5+	94 160	169 120	0.27	Terminal E = 0.6

C. Results

The fishing mortality vector by age resulting from the VPA assessment shows that the age classes mostly exploited by fishing are 3-5 (Figure 3.4.2.5). The yield per recruit curve (Figure 3.4.2.6) showed that in both years the current fishing mortality (F_c) is slightly lower or close to $F_{0.1}$; hence the European hake stock in GSA 23 seems to be sustainably exploited.

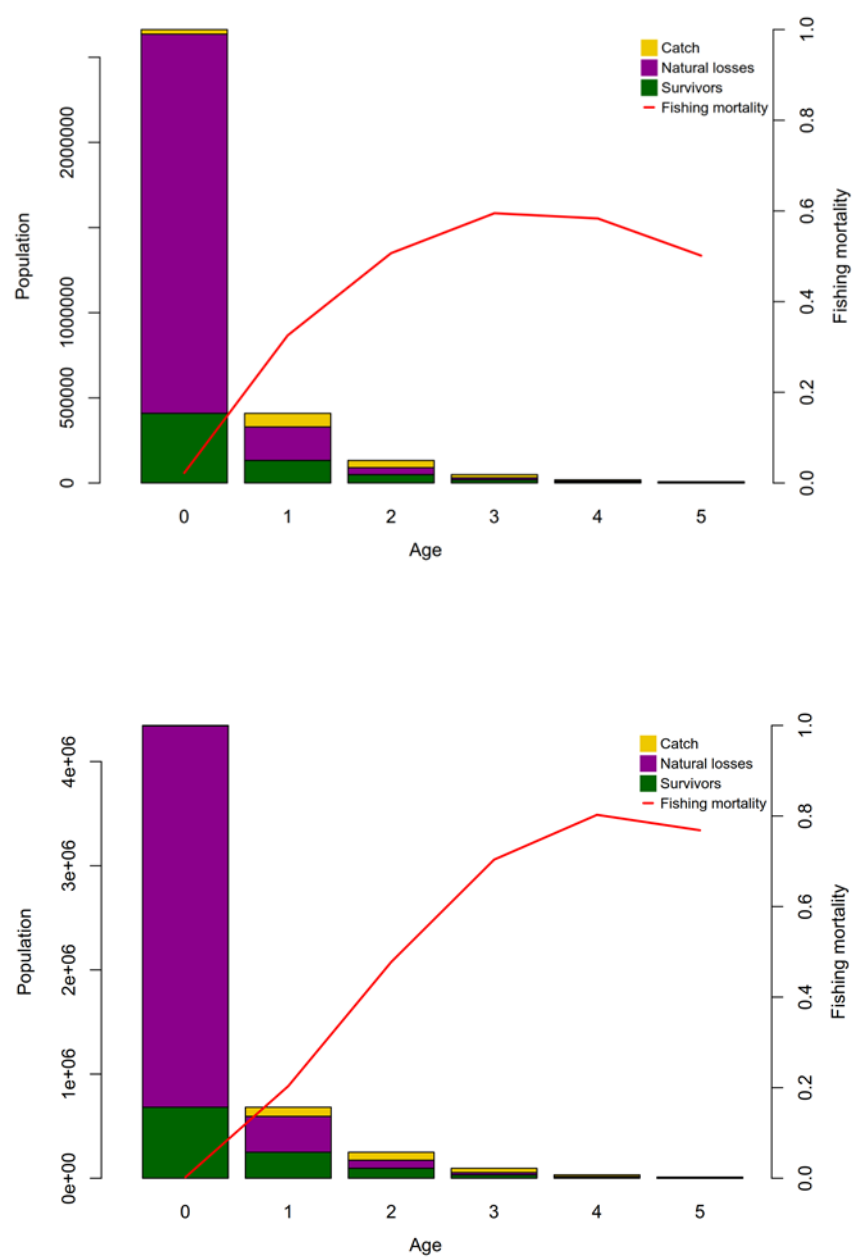


Figure 3.4.2.6. Results of VPA analysis for European hake in 2016 (upper graph) and 2018 (lower graph)

Bars show population numbers by age, partitioned into survivors, deaths due to fishing (catch) and deaths due to natural causes (natural losses). The red line shows the fishing mortality by age class estimated by the model.

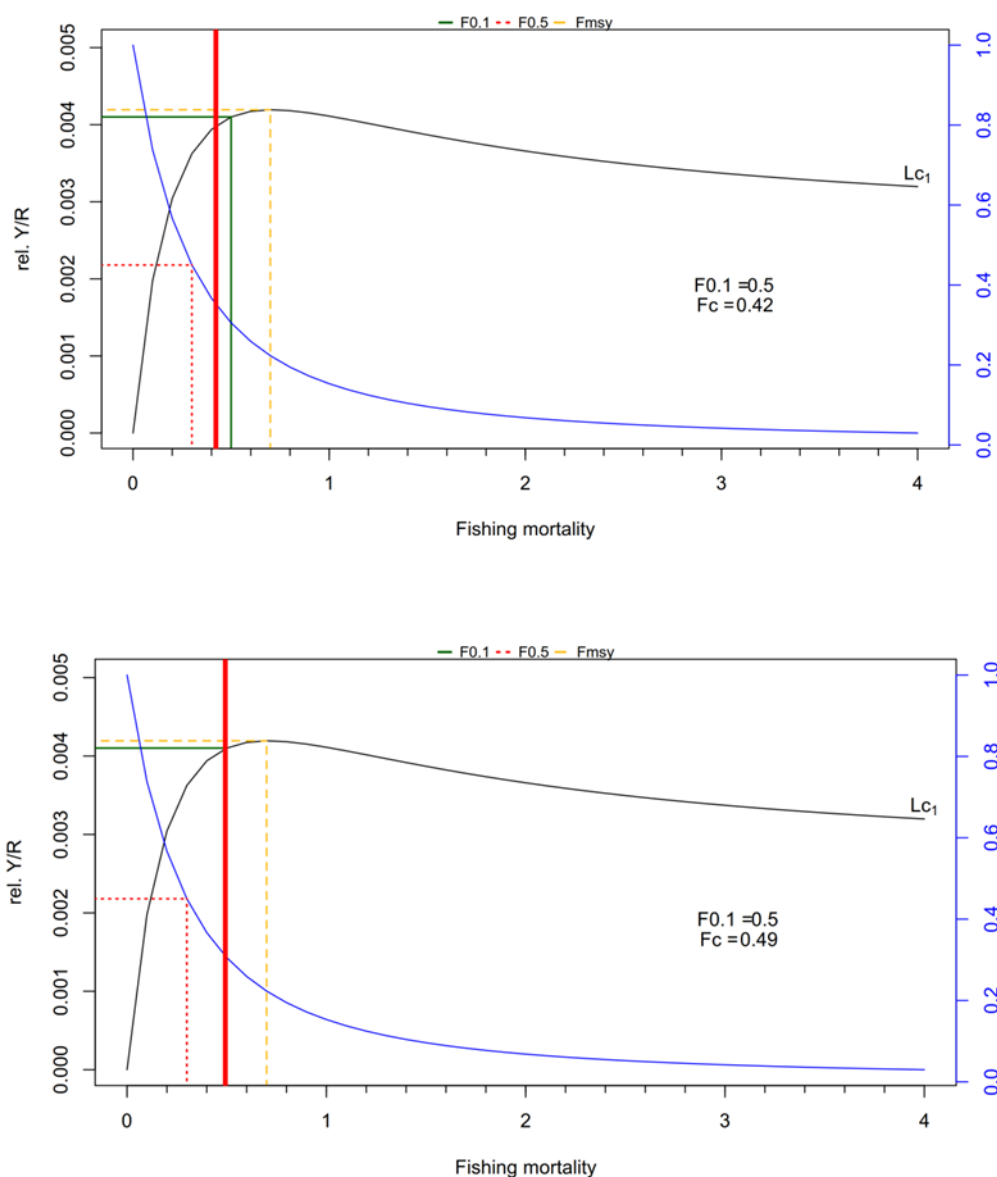


Figure 3.4.2.7. Yield per recruit relationship (black) and relative biomass (blue) for European hake in 2016 (upper graph) and 2018 (lower graph), current F rates (red solid line) above $F_{0.1}$ (green line)

D. Reference points

Given the inconsistency of the retrospective analysis of the SPiCT model and the contrasting results of the applied methods, no reference points were adopted.

3.4.3. Assessment unit: GSA 26

3.4.3.1. Pseudo-cohort virtual population analysis with VIT

European hake is a target demersal species of the Egyptian Mediterranean fishing fleets. It is mainly exploited by trawlers, but also by hook and lines, gillnets and trammel nets. The trawler fleet in the Egyptian Mediterranean (GSA 26) is composed of about 1 200 vessels. The vessel length varied between 18 and 24 m and its width varied from four to six metres. Most vessels are powered by a main engine of 100 to 500 hp, 110 vessels are from 500 to 800 hp and 13 vessels are powered by more than 800 hp engines. Some trawlers are equipped with echo-sounders and fish finder but the fishers prefer to depend on their skills rather than on the devices. The main landing sites for European hake in GSA 26 are: Alexandria, Rashid (Rosetta), El-Maadia

and Ezbet Elborg (2015–2017) but Alexandria is the most productive area for European hake followed by Rashid (Rosetta).



Figure 3.4.3.1. Main landing sites along the Egyptian Mediterranean sea

This stock was assessed using pseudo-cohort VPA. The assessment uses three years catch-at-age or length data and a vector of natural mortality by age or length to estimate fishing mortality by age or length. It assumes that the given catch-at- age or length distribution is representative of the catch from a given cohort (equilibrium hypothesis). The “observed” total mortality (Z) for each age or length class is attributed to either fishing (fishing mortality, F) or natural causes (natural mortality, M). Working backwards from the plus age group or length group, the total mortality for each age or length class is estimated and the fishing mortality is found as $F = Z - M$. The main assumption of VPA is that the snapshot of catch-at-age or length distribution represents the time evolution of a cohort, which would require the population to be at equilibrium and ignores any variability of recruitment on the population size of each age or length class. Additionally, the assessment requires a value of terminal E (exploitation rate of the last age or length class) as input; hence the assessment can be sensitive to this assumption

A. Input data and parameters

Input data and parameters of VPA for European hake in GSA 26 are catch-at-length, mean weight at length, mortality vector, von Bertalanffy growth parameters, length-weight relationship parameters and terminal fishing mortality, as summarized in the figures and tables below.

Table 3.4.3.1. Maximum size, size at first maturity and size at recruitment

Somatic magnitude measured (LT, LC, etc)	Total length (LT)	Units	cm
Sex	Combined	Reproduction season	
Maximum size observed	63	Recruitment season	
Size at first maturity	30.9	Spawning season	
Recruitment size to the fishery	15	Nursery area	

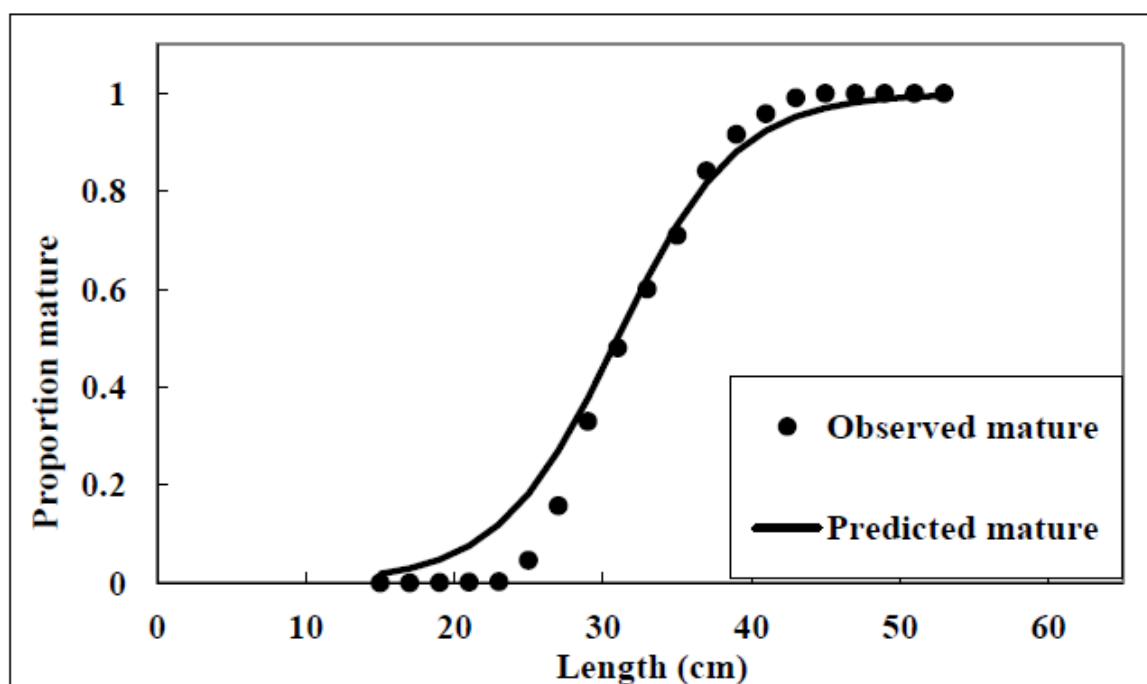


Figure 3.4.3.2. Maturation curve for combined data

Table 3.4.3.2. M vector and proportion of matures by size (combined)

Size group	Natural mortality **	Proportion of matures
15	2.59	0
17	1.56	0
19	1.19	0.05
21	0.95	0.11
23	0.77	0.19
25	0.64	0.28
27	0.55	0.39
29	0.49	0.47
31	0.40	0.56
33	0.35	0.66
35	0.31	0.75
37	0.29	0.86
39	0.28	0.98
42	0.27	1
45	0.26	1
47	0.25	1
49	0.25	1
51	0.24	1
53	0.23	1
55	0.23	1
57	0.22	1
59	0.22	1
61	0.21	1
63	0.21	1

**Natural mortality vector, PROBIOM. Abell,a A.; Caddy, J.F.; Serena, F. (1999)

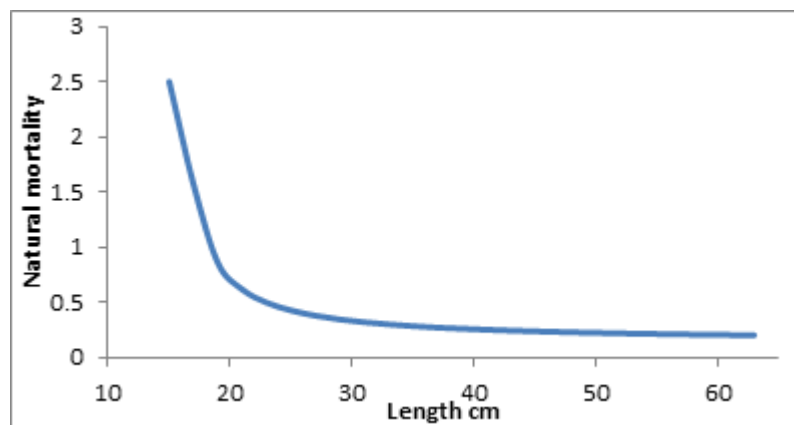


Figure 3.4.3.3. Natural mortality vectors for length groups

Table 3.4.3.3. Growth and length weight model parameters

Growth model			Units		Combined sexes		
	L_{∞}		Cm		68.5		
	K		Year ⁻¹		0.29		
	t_0		Year		-0.3		
	Data source		Otolith readings and back-calculations				
Length weight relationship	a b M (scalar)				0.0046 3.119 0.56 (Vector average)		
	sex ratio (% females/total)						

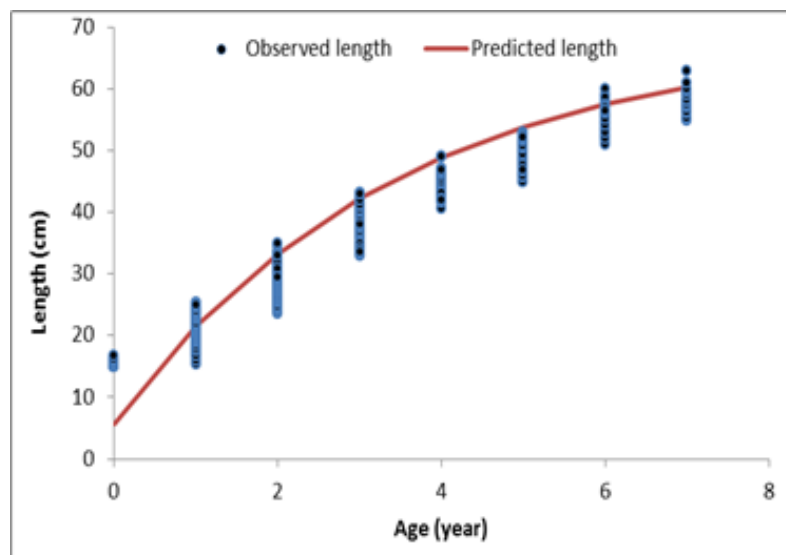


Figure 3.4.3.4. Length at age

3.4.3.2. Fisheries information

A. Description of the fleet

The vessel length varied between 18 and 24 m and its width varied from four to six metres. Most vessels are powered by a main engine of 100 to 500 hp, 110 vessels are equipped with a main engine of 500 to 800 hp and 13 vessels are powered by more than 800 hp engines. Some of trawlers are equipped with echo-sounders and fish finder but the fishers prefer to depend on their skills rather than on the devices. The main landing sites for European hake in GSA 26 are: Alexandria, Rashid (Rosetta), El-Maadia and Ezbet Elborg (2015–2017) but Alexandria is the most productive area for European hake followed by Rashid (Rosetta).

Table 3.4.3.4. Segment fleet characteristics in Egyptian Mediterranean GSA 26

Ports	Number of trawlers	HP
Alexandria	53	120-500
Rashid	82	120-500
El- Maadia	87	120-500
Ezbet Elborg	650	120-800

Table 3.4.3.5. Description of the operational units exploiting the stock

		Country	GSA	Fleet Segment	Fishing Gear Class	Group of Target Species	Species	
Operational Unit 1*		Egypt	26	E-Trawl 12-24 m	03- Trawls	33 – Demersal shelf species	HKE	

Table 3.4.3.6. Catch, bycatch, discards and effort by operational unit in the reference year

Operational Units	Fleet (n° of boats) Average 2015-2017*	Landings/ Catch (T average 2015-2017) species assessed	Other species caught (names and weight)	Discards (species assessed)	Discards (other species caught)	Effort average 2015-2017 (days)
03-Trawls-GSA26 (Alexandria)	53	128	Red mullet, seabreams, flatfishes, triglids, shrimp, and cephalopods			1 6960/year

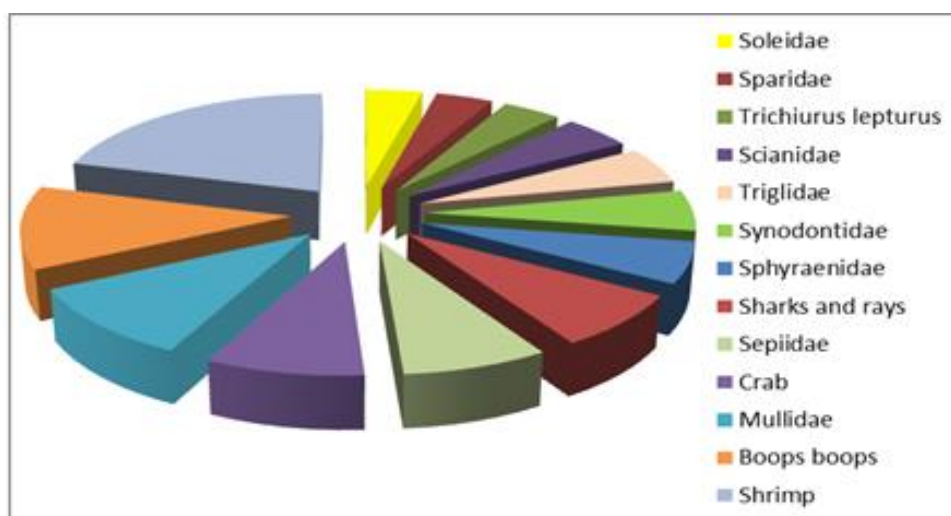


Figure 3.4.3.5. Different species caught by trawl fishery in GSA 26

B. Historical trends

Landings have shown important oscillations along the period of the data series. It is worth mentioning that the recording system in Egypt lacks the accuracy and the catch by species didn't cover all the important species caught by different types of fishing gear in GSA 26. Also, the catch were not recorded by different types of fishing gear separately in the Egyptian Mediterranean. Accordingly and based on the field observations and historical data, we tried to estimate the catch of European hake as well as to separate the catch by species for each fishing gear. In the last years from 2008 onwards, a decreasing trend in landings is observed for total and European hake catches.

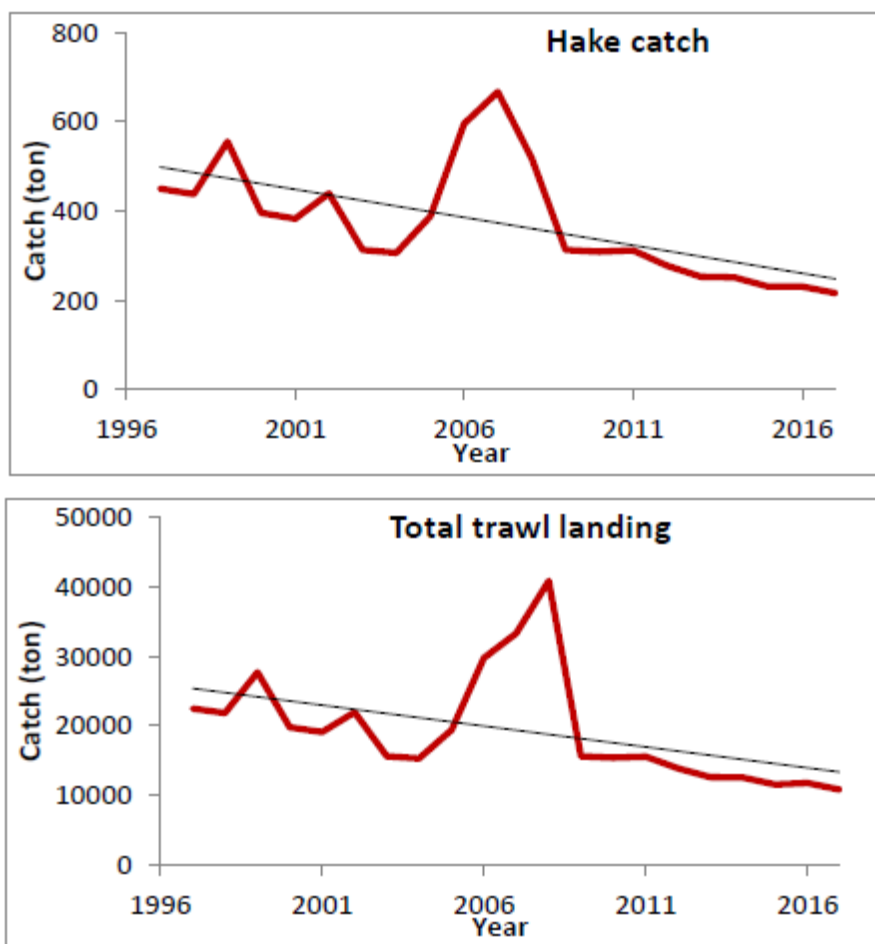


Table 3.4.3.7. Catches from trawl fisheries in GSA 26 (Alexandria fishing area) for 2015–2017

Year	2015	2016	2017
Catch (tonnes)			
Landings (tonnes)	140	128	115
Minimum size	17	15	15
Average size	31.88	29.51	28.11
Maximum size	65	63	57
Fleet: TB (Alexandria)	52	53	55

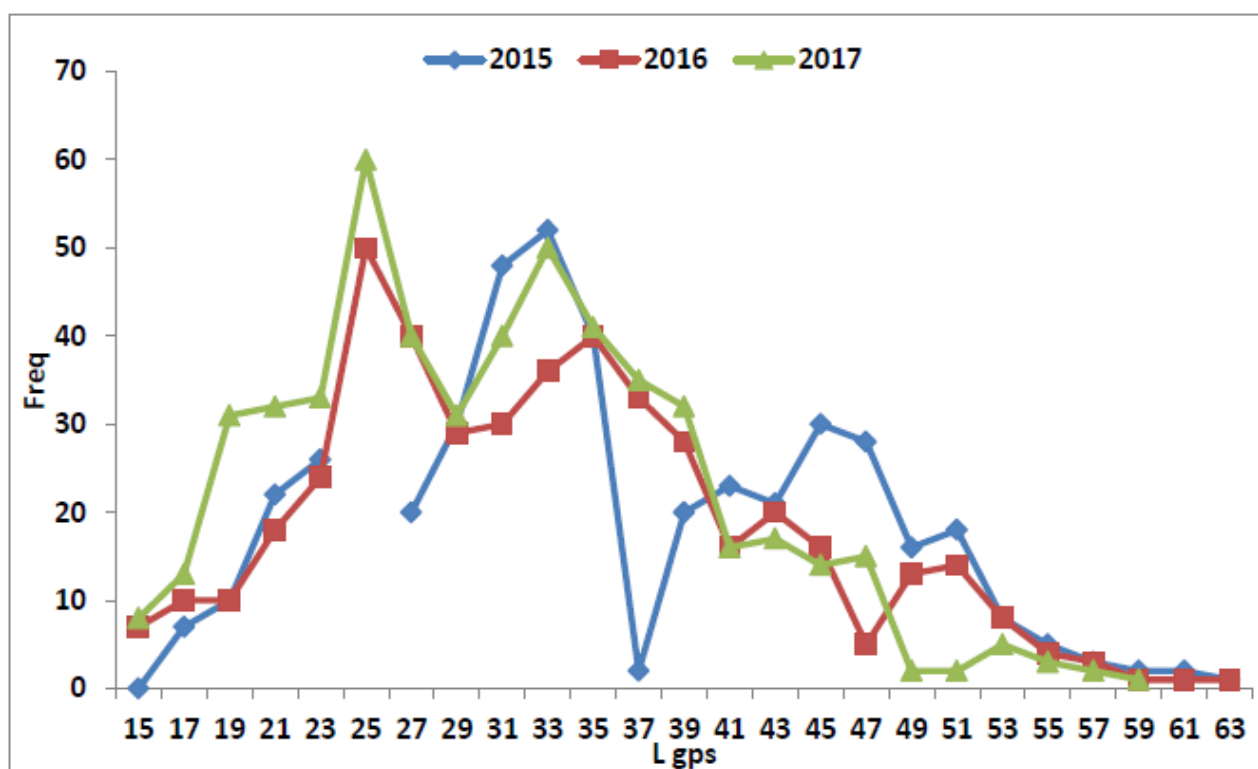


Table 3.4.3.8. Selectivity

L25*	
L50*	23.75 cm
L75*	
Selection factor	

C. Management regulations

- Closed season for 45 days (from 1 May to mid- June) since 2006: not fully observed.
- No new licenses are given since 1996: not fully observed.
- Prevention from any improvements on fishing vessels: not fully observed.
- Mesh size regulation: not fully observed.

D. Reference points

No formal reference points have been previously adopted for this stock. The default Fmsy and Bmsy approach was followed in this assessment.

E. Model results

The VPA assessment was done using three trials of terminal F and the fishing mortality vector by length resulting from the three trials showed that the length classes mostly exploited by fisheries are 33-51 cm (Figure 3.4.3.6).

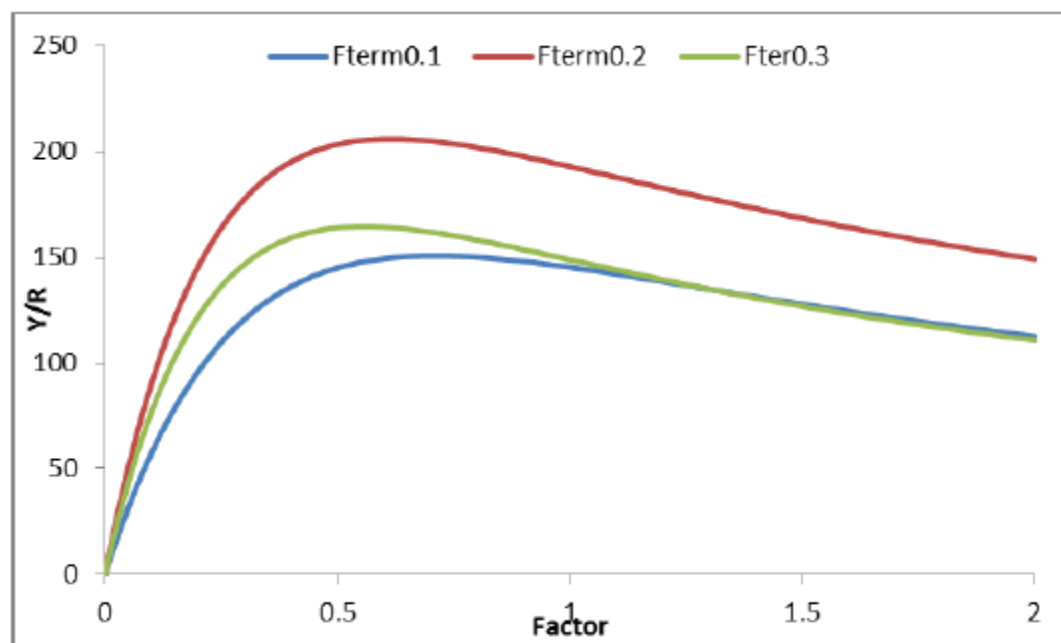
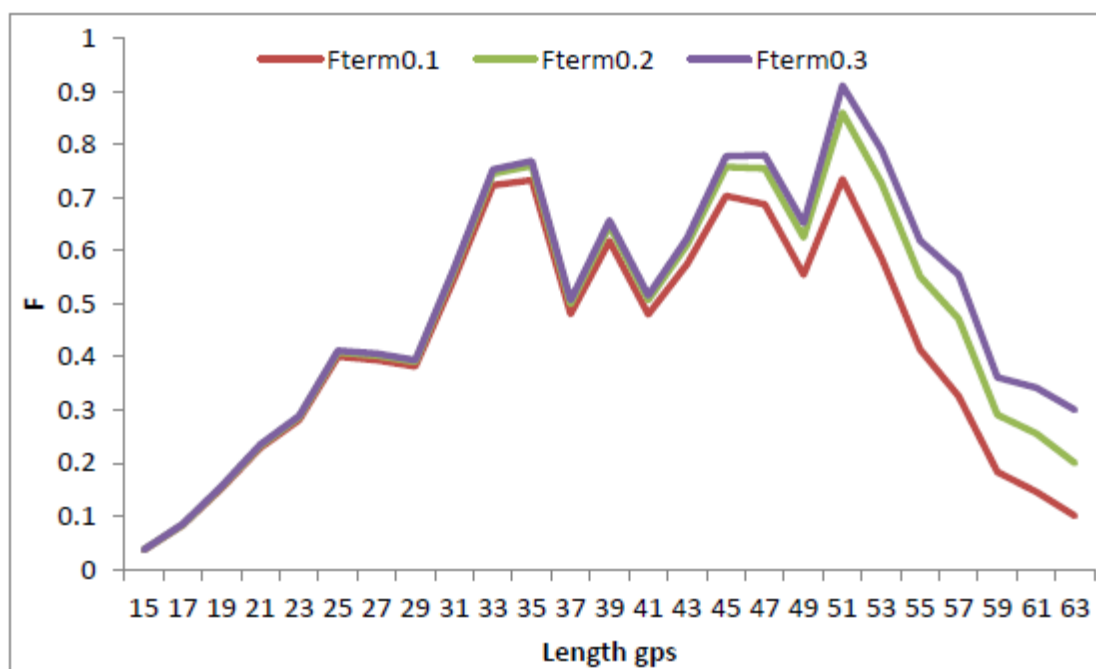


Figure 3.4.3.6. Yield per recruit analysis and estimation of fishing mortality reference points

F. Stock status

Item	Fterm0.1	Fterm0.2	Fterm0.3	Stock status
F_{max}	0.392	0.427	0.497	
$F_{0.1}$	0.23	0.28	0.22	
$F_c/F_{0.1}$	4.35	3.57	4.54	Overfished

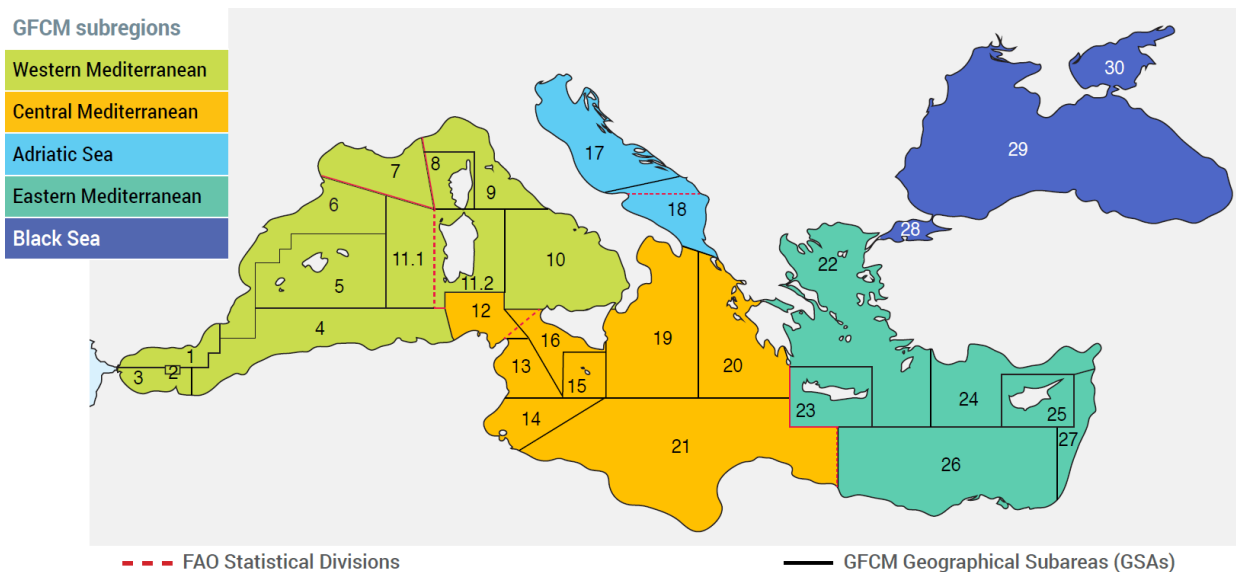
4. REPORT OF THE EXTERNAL REVIEWERS

This section has been prepared by three external reviewers (Valerio Bartolino, Steve Cadrin and Carmen Fernández) who were invited to participate in the European hake benchmark. It should be noted that this review is limited to documents and materials presented during the benchmark workshop (FAO headquarters, Rome, Italy, December 2019), and the discussions that took place during that workshop, at which point almost no text had been written about any sections of the benchmark report.

The GFCM organized a benchmark assessment of European hake in most of the Mediterranean Sea. The assessment of European hake in the Adriatic Sea, which was benchmarked in January 2019 (GFCM, 2019), was excluded from the present benchmark. Over the past two years, European hake in the Mediterranean has been assessed by the GFCM as nine stocks, some of which aggregate multiple GSAs (Table 4.1, Figure 4.1). Through correspondence and a conference call before the benchmark meeting, the GFCM identified two major uncertainties to be addressed by this benchmark process: i) different perceptions of spatial stock structure among different experts, particularly in the western Mediterranean, and the possibility for developing new stock assessments for alternative stock units; and ii) uncertainty about growth and difficulties in age determination.

Table 4.1. Mediterranean European hake stocks, GSAs and assessment methods applied by the GFCM over the last two years

GSA	Label	Methods initially proposed for consideration at benchmark	Previous agreed method	Documents provided in relation to previous assessments
1&3	Alboran Sea	XSA, CMSY, SPiCT	XSA	HKE_GSA_01-03_2017_ESP_MAR.pdf**
4	Algeria	XSA, a4a	LCA	HKE_GSA_04_2017_DZA.pdf**
5	Balearic Islands	XSA, a4a	a4a	HKE_GSA_05_2016_ESP.pdf*
6	Northern Spain	XSA, a4a	a4a	HKE_GSA_06_2017_ESP.pdf*
7	Gulf of Lion	XSA, a4a	XSA	HKE_GSA_07_2017_ESP_FR A.pdf**
1, 5, 6, 7	Western Med	a4a	N/A	STECF report 19-10 - MED stock assessments_part 1.pdf
8-11	Tyrrhenian Sea	a4a, SS3	a4a	STECF report 19-10 - MED stock assessments_part 1.pdf
12-16	Strait of Sicily	XSA, SS3	XSA	HKE_GSA_12-16_2017_ITA_MLT_TUN.pdf*
17-18	Adriatic Sea*	SS3	SS3	GFCM report WGSAD_hke17-18_2019_Report
19	West Ionian Sea	a4a	a4a	STECF report 17-15 - Med stock assessments 2017-p2.pdf
20	East Ionian Sea	SPiCT	N/A	STECF report 17-15 - Med stock assessments 2017-p2.pdf
22	Aegean Sea	SPiCT	SPiCT	HKE_GSA_22_2016_GRC.pdf**
23	Crete	SPiCT	N/A	STECF report 17-15 - Med stock assessments 2017-p2.pdf
26	South Levant Sea	LCA	N/A	Never assessed
* benchmarked in January 2019				** GFCM Stock assessment form



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - South of Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Figure 4.1. Geographical subareas (GSAs), FAO General Fisheries Commission for the Mediterranean

4.1. GSA groupings

Each GFCM stock assessment form includes Section 2 for background on “Stock identification and biological information”, but the content provided in those documents for European hake ranged widely among assessments, from simply stating the GSAs included in the assessment (e.g., GSAs 1-3, GSA 4, GSA 6, GSAs 9-11, GSAs 17-18) to providing justification for the GSA grouping (e.g., GSA 5, GSAs 12-16):

- GSA 1-3 Alboran Sea – no information provided in HKE_GSA_01-03_2017_ESP_MAR.pdf.
- GSA 4 Algeria – no information provided in HKE_GSA_04_2017_DZA.pdf.
- GSA 5 Balearic Islands – The deep channel between the Balearic Islands and the Iberian Peninsula forms a natural barrier to movement of adult European hake, the benthic community and ecosystem around the Balearic Islands is different from those from GSA 6, there are distinct fishing fleets in GSA 5 and the exploitation history is different (with less fishing pressure and larger fish in GSA 5) (Quetglas *et al.*, 2012; HKE_GSA_05_2016_ESP.pdf).
- GSA 6 Northern Spain – no information available in HKE_GSA_06_2017_ESP.pdf.
- GSA 7 Gulf of Lion – recent information suggests that European hake in the Gulf of Lion might be connected to other areas (GSAs 5 and 6) in HKE_GSA_07_2017_ESP_FRA.pdf.
- GSAs 1-7 Northwestern Mediterranean – no information provided in STECF report 19-10 - MED stock assessments_part 1.pdf (where a stock assessment was included for GSAs 1-5-6-7 combined).
- GSAs 9-11 Tyrrhenian Sea – no information provided in STECF report 19-10 - MED stock assessments_part 1.pdf.
- GSAs 12-16 Strait of Sicily – An early study (Levi *et al.*, 1994) found similar growth patterns from European hake samples from the northern Strait of Sicily (GSAs 15 and 16) and from the Gulf of Gabès (GSA 14), but a more recent study (Levi *et al.*, 2004) found significant differences in

morphometry and growth within the area (GSAs 12-16) although no genetic differences. Trends in CPUE are similar for GSAs 12, 13 and 14. Milano *et al.* (2014) found genetic differences between the western, central and eastern Mediterranean, but the spatial groupings were different from the GSA definitions of western, central and eastern areas in this benchmark (e.g. the results suggest that European hake in GSAs 12 and 15 are genetically similar to those in the western Mediterranean GSAs 1, 3, 7, 9, 10, and 11). Similarly, the multidisciplinary results from the STOCKMED project (Fiorentino *et al.*, 2014) suggest a single stock of European hake from the Ligurian-North Tyrrhenian Sea (GSA 9) to the western Ionian Sea (GSA 19) (HKE_GSA_12-16_2017_ITA_MLT_TUN.pdf).

- GSAs 17-18 Adriatic Sea – no information provided in GFCM report WGSAD_hke17-18_2019_Report.
- GSA 22 Aegean Sea – The Aegean Sea is considered to be a distinct ecosystem, separated from the Cretan Sea (GSA 23) by a deep basin. Fishery exploitation patterns differ between the two GSAs (with much less intense trawling in GSA 23) (HKE_GSA_22_2016_GRC.pdf).

Some information on stock identity was presented at the workshop, but it provided an insufficient basis for benchmark decisions on GSA groupings. As a supplement to this information, the external reviewers have developed an initial additional review of information on stock identity (Annex 5.1), which can hopefully constitute an additional resource for future discussion of the issue. In summary, there is a distinct boundary between European hake populations in the Atlantic Ocean and the Mediterranean Sea, but population structure within the Mediterranean is less certain. The STOCKMED project provides extensive information on spatial patterns of Mediterranean European hake and identified the following stock units: GSAs 1-5-6-7, GSAs 9-10-11-15-16-19, GSAs 17-18-20, GSAs 22-23 and GSAs 24-25. However, the project lacked information for several GSAs, particularly those in non-European waters, and the project report noted that the results should be regarded as “work in progress” and could be updated based on improvements of the level of information. There is other work in progress that is also expected to fill some information gaps (TRANSBORAN, Hidalgo *et al.* 2018; MED_UNITS, CopeMed II 2019). Information from neutral genetic characters indicates broad-scale populations in the western Mediterranean (GSAs 1-16), central Mediterranean (GSAs 17-19) and eastern Mediterranean (GSAs 22-25) that are reproductively isolated on evolutionary timescales, with considerable advection of eggs and larvae among areas providing connectivity of early life stages among GSAs in those broad-scale regions. Finer-scale differences in selected characters (allozymes, growth rates, size at maturity) and natural tags (e.g. parasites) suggest limited movement, local selection of post-larval life stages, and some demographic independence on ecological timescales.

The information available suggests that the ideal assessment units would be GSAs grouped by Mediterranean basins (as defined by oceanographic current and gyre systems, e.g. Pinardi and Masetti, 2000), and local heterogeneity could be accounted for with fleet structure and spatially stratified sample estimates (e.g. stratified surveys, fishery CPUE standardizations, length and age composition sampling and expansion). If there was a wish to develop truly spatially-structured estimation models, then this would require acquiring more information on movement of juveniles and adults among areas. Considering that self-recruitment within GSAs appears to be greater than transport among areas (Hidalgo *et al.*, 2019b), areas with different recruitment patterns could be modeled as unit stocks for the purposes of estimating recruitment and survival of recruits for comparison with “per-recruit” reference points; however, stock-recruitment relationships could be confounded for small areas because of intermittent mixing of eggs and larvae. Therefore, spawner-per-recruit reference points would be appropriate for conserving spawning potential in all areas for self-recruitment and recruitment subsidies.

The major discussion on appropriate stock assessment units at the benchmark meeting revolved around the western Mediterranean, particularly regarding GSAs 1 to 7. According to the reviewers’ understanding, conducting a joint GSA 1-5-6-7 European hake assessment is supported by genetic similarity (Cimmurata *et al.*, 2005; Milano *et al.*, 2014), multi-disciplinary cluster analysis and similar parasite prevalence in these GSAs (STOCKMED, Fiorentino *et al.*, 2014). On the other hand, conducting separate assessments of European hake in each of these GSAs is supported by asynchronous survey trends among GSAs (STOCKMED, Fiorentino *et al.*, 2014; Hidalgo *et al.*, 2018), the apparent barrier to larval mixing between GSA 1 and GSA 6 at the Almeria-Oran front (TRANSBORAN, CopeMed II 2019) and the apparent ecosystem barrier between the Balearic Islands (GSA 5) and the Iberian Shelf (GSA 6; Quetglas *et al.*, 2012). An assessment of European hake for GSAs 1 and 3 combined is supported by genetic similarity (Milano *et al.*, 2014), intermittent mixing

of eggs and larvae between GSA 1 and GSA 3 (TRANSBORAN, CopeMed II 2019) and similar growth (STOCKMED, Fiorentino *et al.*, 2014).

Several uncertainties about stock identity should be reconsidered at the end of several ongoing projects, in particular: i) the grouping of GSAs 1 and 3 (and, possibly GSA 4) should be reconsidered after the final results and conclusions of TRANSBORAN become available; ii) the grouping of GSAs 1, 5, 6 and 7 should be reconsidered after the MED_UNITS results and conclusions become available; and iii) GSA groupings in the central and eastern Mediterranean should be reconsidered after the MED_UNITS results and conclusions become available.

At this stage the group agreed on the following actions:

- To defer any final decisions on stock assessment units until the TRANSBORAN and MED_UNITS projects conclude and their results become available, with a new European hake benchmark likely needed in about three years from now.
- To include GSA 8 within the GSAs 9-11 European hake assessment. This decision was supported by the lack of known barriers to dispersion between Corsica and the rest of the Tyrrhenian Sea, similar growth of European hake in GSA 8 and GSAs 9-11, as well as significant correlation of survey biomass trends in GSA 8 and GSA 9 (STOCKMED, Fiorentino *et al.*, 2014). It should, however, also be noted that there are almost no European hake fishery catches in GSA 8, only some on the East of Corsica and none in the West. The MEDITS survey only goes in the East, but experts at the benchmark noted that significant European hake presence is not expected in the West because of the narrow continental shelf and very deep waters. Including GSA 8 in the assessment of GSAs 9-11 does not change the assessment significantly, but managers should be aware of the situation in GSA 8 so that they can take appropriate decisions.

The reviewers support these decisions.

The group discussed stock assessment units using criteria based on identification of stock units and criteria based on quality of stock assessments. It considered that:

- main criteria to be used to identify stock units include:
 - genetics;
 - heterogeneity in populations, including life history, parasite, and others;
 - dispersal patterns (e.g., transport of eggs and larvae);
 - demographic independence (e.g., different recruitment patterns and stock development);
- criteria for evaluating the stock assessments include:
 - consistency of input data (e.g. cohort tracking in input data to age-based assessments, inputs providing sufficient “contrast” in surplus production models, etc.);
 - model diagnostics (residuals, retrospective, etc.); and
 - plausibility of exploitation patterns obtained (based on expert knowledge of the fishery, etc).

On stock units, the group agreed that genetics should be used as a primary criterion, with heterogeneity and different patterns on fleet structure also to be considered, although not necessarily guiding the conclusion (particularly the fleet structure, which is more appropriately represented by different fleets within the assessment model or by appropriate calculation of partial F_s post-assessment; see below). Given the lack of a final decision on stock assessment units at the benchmark meeting, the stock assessment criteria indicated above were used to provide a temporal “best solution” for advice provision, pending the more conclusive indications on stock identification expected from the ongoing projects (TRANSBORAN and MED_UNITS).

For the western Mediterranean, applying the stock assessment criteria to the stock assessments presented with a4a or XSA, led to selecting an a4a assessment for GSAs 1-5-6-7 combined as the main basis of advice for these GSAs during the interim period. In order to examine differences in fishing patterns, partial F_s by fishing fleet and/or individual GSA can be calculated post-assessment using the input catch-at-age matrix partitioned at the required fleet and/or GSA level. The group agreed to use the a4a assessment presented for GSA 5 and the XSA assessment presented for GSAs 1 and 3 combined to provide complementary advice for GSA 1 and as the basis of advice for GSA 3. Assessments were also presented for the individual GSA 6 and GSA 7, but

not accepted for complementary advice because of low consistency of input data and unrealistic estimates of selectivity (GSA 6) and poor residual patterns (GSA 7). The reviewers support the decisions taken by the benchmark meeting about the basis of interim advice until final decisions on stock assessment units are made.

There are also some uncertainties in stock identity for European hake in the central and eastern Mediterranean, but they appeared to generate less discussion at the benchmark and any new decisions on stock structure were postponed, pending the outcomes of the MED_UNITS project. The reviewers support the decision to maintain the current assessment units for those basins at this time (i.e., GSAs 12-16, GSAs 17-18, GSA 19, GSA 20, GSA 22, GSA 23 and GSA 26; see Table 4.1) and to review them, as appropriate, when more information becomes available in the future.

4.2. Biological parameters

A session during the benchmark meeting was spent on general discussion on biological parameters, in particular, growth (alternative approaches considered were age-length key, length frequency slicing or fitted growth model), length-weight relationship, spawning time (i.e. proportion of annual mortality that occurs before spawning), fraction mature, stock weights, and natural mortality. Agreement was reached on some practical procedures: how to perform the slicing, spawning occurs all year but modeled as 1 January spawning, and natural mortality as average of ensemble of empirical methods. More detail is provided below.

4.2.1. Growth

Ageing of European hake has been difficult and controversial. Piñeiro (2000) noted difficulties locating the first annual ring (first annulus), classifying rings as growth rings with annual periodicity or false rings due to phenomena other than growth, or interpreting the nature of the edge. Moreover, the spawning period of European hake extends throughout the year, with prolonged and multiple spawning events (Belcari *et al.*, 2006; Recasens *et al.*, 2008; Carbonara *et al.*, 2019), which complicates age determination. A recent study using bomb radiocarbon dating (Vitale *et al.*, 2016) has validated the hypothesis of a slow growing pattern for European hake in the Mediterranean (i.e. a fish of 85-90 cm in total length would have approximately 25 years). A handbook with guidelines to standardize age reading for the most important commercial fish species in the Mediterranean, including European hake, has been recently published (Carbonara and Follesa, 2019), which should help to reduce bias associated with the activities of age determination and to improve precision and reproducibility among readers and laboratories. The external reviewers are not aware of recent calibration studies which would be required to evaluate some of the uncertainties in age determination for European hake across the wide geographical span covered by this benchmark.

Von-Bertalanffy growth models with a range of parameters for different GSAs (and often by sex) were presented at the benchmark; the growth parameters were derived from literature or directly estimated from catch or survey data. Geographic differences in growth cannot be ignored, but it is difficult to draw conclusions from the material presented, as it included data collected in different seasons and years and through different types of gear. Additional complications arise from the marked differences in the growth of the two sexes, which makes it relevant to identify sex-specific growth trajectories. A systematic analysis estimating growth with the same methodology and possibly using a standardized source (i.e. the MEDITS survey) was not available at the benchmark. The importance of such an analysis was discussed at the meeting and it is advised to further investigate the growth of European hake at the Mediterranean geographical scale.

Although growth is likely to vary through time to some degree, no analysis was provided of the extent of such potential variability, which remains unknown. Consequently, it was decided to use constant (over time) growth parameters for all the assessments, and it was agreed that these parameters would be kept fixed until the next benchmark unless major changes are suggested by the data. The reviewers support this decision.

4.2.2. Natural mortality

It was decided to assume natural mortality (M) to be age-dependent and to derive the mortality vector applying the same procedure for all the age-based analytical assessments considered at the benchmark. Given the large uncertainty around the actual values of natural mortality, it was decided to derive this vector as an ensemble estimate (here a simple average) of different methods, similarly to what was done at the recent benchmark of

European hake in the Adriatic Sea. The different methods selected are mostly based on life history invariants, linking mortality rates with different aspects of growth (i.e., von Bertalanffy growth parameters, longevity, mean weight and length at first maturity), and are those described in Gulland (1987), Chen and Watanabe (1989), Lorenzen (1996), the revised version of Abella *et al.* (1997) by Martiradonna (2012), Gislason *et al.* (2008) and Brodziak *et al.* (2011). The reviewers support the group decision to derive natural mortalities using this common rationale. It is important to note that, with this approach, uncertainties in ageing and estimation of growth also affect the value derived for M .

4.2.3.Maturity

Spawning activity of European hake is reported from most of the GSAs. As far as the reviewers are aware, maturity was in all cases estimated based on macroscopic visual inspection. Spawning activity is protracted throughout the year with multiple peaks (i.e. in winter, in late summer and early autumn), which represents a possible difficulty for the estimation of proportion of mature. A validation of the macroscopic maturity scale based on histology was recently presented by Carbonara *et al.* (2019) for samples from the central Mediterranean and southern Adriatic. They found no significant trend in the estimation of L_{50} from the analysis of samples from 2007 to 2015. No information of potential temporal trends in maturity at length or age were presented at the meeting from any area and the group decided to use fixed (over time) maturity ogives for calculation of SSB in all the assessments. In light of the material presented and discussed at the meeting, the reviewers support this decision.

Benchmark conclusions on biological parameters

Most of the discussion related to growth and cohort slicing, with slicing being particularly relevant for age-based analytical assessments that require using age-structured data inputs (such as XSA or the statistical catch-at-age model applied with a4a).

- It was noted that performing slicing (to transform length-structured data inputs to age-structured data inputs) on a quarterly basis instead of an annual basis seemed generally more appropriate. This conclusion was supported by the fact that age-length data aggregated at the year level were seen to display substantial overlap between the length ranges observed for consecutive ages. The overlap is expected to be less pronounced when length data are sliced by quarter rather than by whole year.
- Given the differences in growth of females and males, it was also noted that the slicing should be preferably performed by sex.
- The procedure for obtaining combined-sex weight-at-age input data for a4a (or XSA) stock assessment models, taking into account slicing performed by sex, was explained to be as follows: i) for each sex separately, slice the numbers-at-length (fishery catch or, if relevant, stock abundance index) and the corresponding biomass-at-length and calculate the weight-at-age as the ratio of the resulting biomass-at-age and numbers-at-age; and ii) for each age separately, calculate the combined-sex weight-at-age as a weighted average of the sex-specific weight-at-age values, with the weights (in the weighted average) being the sex proportions in the numbers-at-age. This two step procedure was considered appropriate.
- To obtain a combined-sex natural mortality-at-age vector starting from sex-specific vectors, it was considered that the sex proportions in the catch-at-age, for each age separately, could be used to provide the weight of each sex on the combined-sex value. Note that this corresponds to the same weighted average procedure described in the second step of the previous bullet point.
- It was agreed to calculate M -at-age based on an average of methods, as it has been explained in the paragraph on “Natural mortality” above, similarly to what had been done for European hake in the Adriatic Sea.
- In relation to maturity and spawning, it was agreed to set spawning time to be 1 January and to assume that maturity at age 0 is equal to 0. It was also agreed to use a combined-sex maturity ogive when the assessment is for both sexes combined (such as in the a4a or XSA models).
- Finally, it was agreed not to change growth models, weight, maturity or natural mortality assumptions until the next benchmark, unless substantive new information indicated that this was necessary.

The reviewers accept the benchmark conclusions on biological parameters.

4.3. Stock assessments

General comments – Hake stock assessments considered at the benchmark vary in their uncertainties and how they inform management.

- The benchmark assessments of HKE-GSAs 8-11, HKE-GSAs 12-16 and HKE-GSA 19, based on integrated (SS3; GSAs 12-16) and statistical catch-at-age (a4a; GSAs 8-11 and GSA 19) models, meet the needs for describing stock status and providing management advice. There was no time at the benchmark to examine reference points in any detail and there is remaining uncertainty, particularly in biomass reference points, not addressed in the benchmark.
- The assessments of HKE-GSAs 1&3, HKE-GSAs 1-5-6-7 and HKE-GSA 5 involve dynamic age-based models (XSA for GSAs 1&3, and a4a for GSAs 1-5-6-7 and GSA 5). There are uncertainties regarding the appropriate stock assessment units and these assessments are not considered to represent benchmark assessments. The comment made in the previous paragraph about reference points also applies here.
- The assessments of HKE-GSA 4 and HKE-GSA 26 apply equilibrium age- or length-based models (VIT pseudo-cohort analysis) that provide some qualitative exploitation status, but the results of this method are always substantially uncertain and the outcomes were, therefore, classed as “precautionary advice”.
- European hake in the remaining areas could not be quantitatively assessed. Little data are available for HKE-GSA 20, HKE-GSA 22 and HKE-GSA 23. A surplus production model (SPiCT) and pseudo-VPA analysis were applied in each of these GSAs, with the two methods resulting in different conclusions about exploitation status in each case; therefore, the status is uncertain and the outcomes were classed as “precautionary advice”.
- The stock assessments presented for HKE-GSA 6 and HKE-GSA 7, using a4a or XSA, were not accepted for complementary advice because of low consistency of the input data and unrealistic selectivity estimates (GSA 6) and poor residual patterns (GSA 7).

Several of the assessments (and particularly those in GSAs 4, 20, 22, 23 and 26) need to be advanced through data investments and subsequent model development to meet the needs of the management framework. As management needs increase in order to reduce overexploitation, more precise and informative approaches should be developed. The reviewers offer some general recommendations for such advances:

- Collect and recover (where possible) accurate fishery statistics.
- Extend the time series of assessment models (reconcile fishery statistics).
- Conduct regular and representative length and age sampling of the fishing activity.
- Further progress on age validation.
- Estimate present and reconstruct past discards rates.
- Develop time series of stock abundance indices, either through research surveys or, in their absence, through appropriate standardization of commercial CPUE. A common concern that should be investigated for each European hake stock is uncertainty in the MEDITS index for the first few years when the survey protocols were being developed.
- Further development of dynamic (i.e. not steady state) stock assessment models, preferably models that can incorporate information on both catch and abundance indices and length or age composition of the catch and indices (such as e.g. a4a or SS3).

Two main types of age-structured stock assessment models were used in the meeting for the quantitative assessments: i) models such as XSA or the statistical catch-at-age model applied with a4a, where input data are aggregated to the level of stock assessment unit prior to being entered in the stock assessment model; and ii) “integrated” assessment models, such as SS3, where the data are typically entered in a less aggregated and less preprocessed fashion in the stock assessment model. A third type of stock assessment models can also be considered, which may be seen as an intermediate between the two types indicated above; they essentially correspond to standard statistical catch-at-age models but with an internal model structure that allows explicit representation of multiple fishing fleets. The reviewers consider that all options are possible for the Mediterranean European hake assessments and any of them has the potential to be developed and applied

effectively. For example, “fleet-aggregated” assessments, such as the statistical catch-at-age model applied with a4a are, in general relatively easy to use and able to provide robust results, provided that the input data are fairly complete and have been aggregated (i.e. fleet or area aggregation, sex aggregation; generally involving some gap filling for strata with missing data) to the level of stock assessment unit in a manner considered appropriate. To apply these models, length frequencies from the catch and abundance indices are converted to age frequencies (via age-length keys or through the so-called “slicing” procedure using a growth model) prior to running the stock assessment. They are also fast to run and there is software readily available (e.g. FLR-based XSA or a4a) as well as generally easy to link with software for reference points calculation, short-term forecasts and management strategy evaluation (e.g. software available in FLR). If results are needed at a less aggregated level than the stock assessment unit, partial Fs by fleet and/or GSA can be calculated a posteriori from the results of the assessment using the input catch-at-age matrix partitioned at the required level of disaggregation. Note that this way of achieving disaggregation requires assuming that the partition of the input catch-at-age matrix can be considered to be reasonably certain, whereas this procedure would be questionable when this can not be assumed.

“Integrated assessments”, such as models developed in SS3, generally offer greater flexibility in the population model structure and types of data that can be fitted. They also generally limit or avoid data imputation (such as filling gaps, slicing length frequencies to age frequencies, etc) prior to entering them in the stock assessment, hence reducing the risk of making potentially inappropriate assumptions at the pre-assessment stage. In line with this, these assessment models typically can:

- fit directly to length and age-at-length samples when they are available (note that the SS3 model is structurally still age-based and a growth model is internally applied by the stock assessment model to convert between ages and lengths);
- estimate discards with selectivity and retention functions fit to observed landings and discards, when discards estimates are available for some time periods;
- extend the range of years covered by the assessment, e.g. by fitting only to catch tonnage in earlier years for which composition data are not available;
- directly provide results for individual fishing fleets;
- explicitly consider two sexes (with different biological parameters) within the stock assessment model, when appropriate for the biology of the species (such as in the case of European hake); and
- have time steps shorter than a year (e.g. quarterly steps), which can result in a more precise conversion between ages and lengths (particularly relevant for fast-growing species).

The downside of the great flexibility that integrated stock assessment models can offer is that they are generally complex to set up and difficult to tune, in the sense of it being difficult to find an appropriate level of aggregation (spatial, temporal, fleets, sex, etc) to be used for model configuration and data inputs, appropriate model settings, etc. These models obviously need to make many assumptions within the stock assessment model itself (in some ways, making assumptions when preparing the input data is replaced by assumptions in the assessment model about population and data structure, relative importance of different datasets, etc) and their results can display unexpected sensitivities to certain inputs or model settings that can be very difficult to understand and resolve. Integrated models often have built-in calculation of reference points and, possibly, short-term forecast, but their complexity tends to make them more difficult to use in management strategy evaluation contexts than using a4a may be.

The reviewers note that, despite uncertainties in stock assessment units, data and results, all assessments indicated current fishing mortalities clearly above reference points (with the possible exception of GSAs 20, 22 and 23, for which results were considered uncertain). In many cases, there is no obvious sign of a decreasing trend in fishing mortality and very small sizes of fish are generally being caught in the fisheries. These conclusions appear to be largely independent of choices about stock assessment method, and seem, therefore, robust and an important message to convey to managers.

4.4. Comments on the GFCM European hake benchmark process

The reviewers found the benchmark process interesting, enjoyed their participation, and express their gratitude to the GFCM for having invited them to take part in the process. As reviewers, we offer some comments on the European hake benchmark process, from our perspective, hoping that some of them may be found useful by the GFCM in their organization of future benchmark processes.

- The process was successful for developing three benchmark assessments (HKE-GSAs 8-11, HKE-GSAs 12-16 and HKE-GSA19), new exploratory assessments (HKE-GSA 26), and identifying issues to be resolved in other areas.
- The benchmark included European hake in the entire Mediterranean Sea (excluding only GSAs 17 and 18). As a consequence of this broad coverage, many different issues ended up “competing” for attention at the benchmark. The very broad extent of the benchmark was useful to develop a common perspective throughout the Mediterranean, but in the future it could be fruitful to focus more specifically on certain areas or issues, so that fuller attention can be devoted to them.
- Data preparations (via meetings or in a less structured fashion) were carried out prior to the benchmark. It is recommended that, in the future, outcomes should be documented and made available as material for review in advance of the benchmark meeting.
- Any technical documentation, including working documents with assessments planned to be presented at the benchmark meeting, that could be received by reviewers in advance of the meeting (e.g. about two weeks in advance) would be very helpful.
- Integrated peer review (in which reviewers contribute to data and model decisions) could be more effective than terminal peer review (in which reviewers judge final acceptability of methods).
- More exploration and documentation of alternatives to help determine benchmark methods would be very useful.
- When a pre-existing assessment model has been used to provide advice in the past, this should be used as a starting point for a new benchmark. This is usually easier when the same modeling framework is maintained, and in this case incremental update of the old model should be presented to evaluate the impact of updated data, assumptions and processes. However, also in the case when a completely new modeling framework is introduced at a benchmark, the old model should be used as initial reference for evaluation. This approach will become clearer as the working group matures and more benchmarked assessments are available.
- Detailed comments on each assessment are provided below. The information available allowed for more in-depth review of stocks with more information. For example, many assessment documents for eastern and western GSAs do not report discard estimates, and those assessment analyses implicitly assume no discards. Recommendations to improve discard estimates are provided for other GSAs.

GSAs 1-5-6-7 (northwestern Mediterranean)

Data

- Landings data are available for 1940s–2018.
- Landings peaked in 2009 (7 362 tonnes) and gradually declined since then (3 462 tonnes in 2018).
- MEDITS survey data are available for 1994–2018.
- Size composition data for the fishery and survey are available for 2007–2018.
- Age at size is estimated from an estimated growth function (used to slice length-structured input data into age-structured input data for use in the stock assessment model).
- Correlations of catch-at-age for GSAs 1-5-6-7 indicates strong cohort tracking in the fishery and moderate cohort tracking in the survey.

Model

- The a4a statistical catch-at-age assessment developed by STECF (2018) was updated and revised.
- The assessment is for 2007–2018, ages 0-5+; F is summarised via the average F ($\bar{F}$) for ages 1-3.
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.

- The assessment model estimates fishing mortality by age and year (assuming flexible smooth functions over years and ages), survey catchability by age (assuming the catchability to be proportional to a logistic function of age, constant over the years), and annual recruitment.
- Model residuals show some minor cohort and year effect patterns. However, on the whole, no major diagnostic problems are suggested by the residuals.
- There was no retrospective pattern.
- Results indicate a generally declining SSB, high and gradually increasing fishing mortality (2018: $F=1.93$), and relatively constant low recruitment (R) since 2013.
- Model estimates of uncertainty indicate that the estimated changes in SSB, F and R over time are significant.

Reference points: $F_{0.1}=0.346$, $F_{current}/F_{0.1}=5.58$, in overexploitation

Conclusion: in the interim, until a benchmark decision on GSA groupings is reached, the a4a assessment of GSAs 1-5-6-7 should be the basis of advice, supplemented with information from separate GSA assessments whenever those assessments are considered to be of sufficient quality.

Recommendations

- The assessment starts in 2007, but survey data are available back to 1994, and fishery data are available back to the 1940s. Therefore, extending the time series in the assessment should be explored as a candidate for the benchmark method.
- In addition to calculating appropriate partial Fs (post-assessment), catch and survey biomass series could be tabulated by GSA to provide information on fishery and stock patterns in each area.

GSAs 1+3 Alboran Sea

Data

- Landings and size composition data are available for 2007–2018.
- Landings peaked in 2011 at around 800 tonnes.
- Fishery CPUE data are available for 2007–2018. CPUE decreased for Spain during 2011–2015 and then increased in the last few years, whereas CPUE was relatively stable for Morocco.
- Survey index and size composition data are available for 2007–2018 from MEDITS and 2010–2018 from CIMD.
- Age at size is estimated from an estimated growth function (used to slice length-structured input data into age-structured input data for use in the stock assessment model).
- Correlations of catch-at-age for GSAs 1-3 indicate moderate cohort tracking in the fishery and weak cohort tracking in the surveys (MEDITS and CIMD).

Model

- The approach is based on XSA, years 2007–2018, ages 0-5+, tuned with both surveys; F is summarised via the average F (F_{bar}) for ages 0-3.
- Several XSA configurations were explored, including the base run with cubic taper-weighting.
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.
- Model residuals for the assessment of GSAs 1-3 have some minor cohort and year effect patterns.
- There was no retrospective pattern.
- Results indicate a general decline in SSB during 2010–2016, with some increase since then; 2018 SSB=360 t, and $F_{current}$ (2016–2018 F)=1.2.
- Recent recruitment was around average, after experiencing below-average recruitment during 2012–2016.

Reference points: $F_{0.1}=0.17$, $F_{current}/F_{0.1}=7.02$, in overexploitation

Conclusion: in the interim, until a benchmark decision on GSA groupings is reached, the a4a assessment of GSAs 1-5-6-7 should be the basis of advice for GSA 1, and the GSAs 1-3 joint assessment is supplemental information to inform management in GSAs 1 and 3.

Recommendations

- A statistical catch at age model (e.g. as provided in a4a) should be explored to allow for observation error in the catch at age.
- The XSA analysis starts in 2007 because of data gaps in earlier years. An integrated model may allow for a longer stock assessment time series by fitting to the available data without the need to fill data gaps; it is also noted that the statistical catch-at-age model in a4a allows data gaps (i.e. missing years) in the catch-at-age matrix.

GSA4 Algeria

Data

- Landings data are available for 1970–2018.
- Landings decreased from 2 300 tonnes in 2005 and have been around 800-1 000 tonnes since 2012.
- CPUE data are available for 2005–2014. During this period, CPUE declined until 2010 and then increased.
- Some survey size composition data are available for 2012–2017
- Size composition data are available for 2012–2017 from surveys and 2015–2017 from the fishery.
- Age at size is estimated from an estimated growth function (used to slice length-structured data into age-structured data for use in the stock assessment).

Model

- The approach is based on equilibrium cohort analysis (VIT).
- The assessment is for 2015–2018 (separate and pooled-year analyses were conducted), ages 0-5+, with age 5+ $F=0.5$ assumed from comparison to F at younger ages. F is summarised via the average F (F_{bar}) for ages 1-3.
- The model estimates fishing mortality by age, assuming the input data (age frequencies) correspond to a population in equilibrium, and natural mortality at age as obtained from an average of methods in line with the benchmark decision.
- Results indicate $F_{current}$ (2015-2018 F)=0.97.

Reference points: $F_{0.1}=0.21$, $F_{current}/F_{0.1}=4.5$, in overexploitation

Conclusion: the data-limited assessment indicated an overexploited stock, but supports precautionary advice.

Recommendations

- A dynamic age-based assessment (e.g., XSA, or the statistical catch-at-age model in a4a) should be explored with the use of the available survey data and, possibly, standardized CPUE.
- The assessment time series should be extended, if possible, exploring historical data back to 1970.

GSA5 Balearic Islands

Data

- Catch (landings and discards) and size composition data are available for 1980–2018.
- The catch peaked at 260 tonnes in 1992 and have been around 50-150 tonnes since then.
- MEDITS survey index and size composition data are available for 2001–2018.
- Age at size is estimated from an estimated growth function (used to slice length-structured input data into age-structured input data for use in the stock assessment model).
- Correlations of catch-at-age for GSA 5 indicate weak cohort tracking in the fishery and in the survey.

Model

- Both XSA and the statistical catch-at-age model in a4a were run for 1980–2018, ages 0-5+. F is summarised via the average F (Fbar) for ages 0-3.
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.
- Several a4a configurations were explored that allow for fishing mortality to vary by age and year and the survey catchability to vary by age (constant over time).
- Model residuals for the assessment of GSA 5 have some minor patterns.
- The updated assessments produced a considerable change in the perception of selectivity from the previous assessment
- There was no retrospective pattern.
- XSA and a4a estimate similar time series of recruitment, SSB and F that generally reflect the patterns in the catch time series:
 - XSA results indicate F_{current} (2016-2018 F) = 1.27; and
 - a4a results indicate F_{current} (2018 F) = 1.40.

Reference points

- XSA results indicate $F_{0.1}=0.12$, $F_{\text{current}}/F_{0.1}=10.34$, in overexploitation.
- a4a results indicate $F_{0.1}=0.31$, $F_{\text{current}}/F_{0.1}=4.5$, in overexploitation.

Conclusion: in the interim until a benchmark decision on GSA groupings is reached, the a4a assessment of GSAs 1-5-6-7 should be the basis of advice for GSA 5, and the GSA 5 assessment could be used to provide complementary information to inform management in GSA 5.

Recommendations: the weak consistency in the age-structured catch and survey data should be further investigated. It is not entirely clear to the reviewers how aspects such as slicing were applied for the GSA 5 assessment; consideration of points emerging from the general benchmark discussion on this (e.g. slicing by sex and by quarter) should be investigated for future assessments.

GSA6

Data

- Landings data are available for 1995–2018.
- Landings peaked at 5 400 tonnes in 1996 and generally declined to approximately 1 700 tonnes during 2015–2017.
- Survey data are available for 1995–2018, indicating a general increase in abundance until 2006 and a general decrease since then.
- Size composition data for the fishery and survey are available for 1995–2018.
- Age at size is estimated from an estimated growth function (used to slice length-structured input data into age-structured input data for use in the stock assessment model).
- Correlations of catch-at-age for GSA 6 indicate moderate cohort tracking in the fishery and weak cohort tracking in the survey. Shortening the survey time series to start in 2002 results in slightly stronger cohort tracking.

Model

- The approach is based on XSA (2002–2018, ages 0-5+) and a4a (1995–2018, ages 0-5+).
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.
- Several XSA configurations were explored for modeling survey catchability and shrinkage.
- The a4a models attempted allow F to vary by age and year, and assumed survey catchability at age constant over the years. In general, the estimated pattern of F at age (peaking at the oldest age) is not consistent with perceptions from any other Mediterranean European hake fisheries. Alternative

configurations were also explored, which produced more realistic selectivity estimates but some poor residual patterns, particularly trends for age-0.

- In general, both XSA and a4a models indicate decreasing recruitment and SSB through the assessment time series.
- XSA results indicate current $F=1.2$.
- A4a results (from one of the runs) indicate 2018 $F=1.14$.

Reference points

- XSA results indicate $F_{0.1}=0.11$, $F_{\text{current}}/F_{0.1}=11.2$, in overexploitation.
- A4a results (from one of the runs) indicate $F_{0.1}=0.17$, $F_{\text{current}}/F_{0.1}=6.5$, in overexploitation.

Conclusions

- The assessment of European hake in GSA 6 was not accepted because of weak cohort tracking and unrealistic estimates of selectivity.
- In the interim until a benchmark decision on GSA groupings is reached, the a4a assessment of GSAs 1-5-6-7 should be the basis of advice for GSA 6.

Recommendations

- The weak consistency in the age-structured data, specially the survey, should be further investigated. It is not entirely clear to the reviewers how aspects such as slicing were applied for the GSA 6 assessment; consideration of points emerging from the general benchmark discussion on this (e.g. slicing by sex and by quarter) should be investigated for future assessments.
- The source of the unrealistic selectivity estimates should be explored, including length compositions, growth estimates, catch at age and modeling options for both the fishery and the survey catchability at age.

GSA7

Data

- Landings data are available for 1998–2018.
- Landings were above 2 000 tonnes during 1998–2013 and then decreased to approximately 1 000 tonnes in 2018.
- Survey data are available for 1998–2018, indicating peak abundance in 2008 and a general decline since then.
- Size composition data for the fishery and survey are available for 1998–2018.
- Age at size is estimated from an estimated growth function (used to slice length-structured input data into age-structured input data for use in the stock assessment model).
- Correlations of catch-at-age for GSA 7 indicate strong cohort tracking in the fishery and moderate cohort tracking in the survey.

Model

- The approach is based on XSA and a4a; years 1998–2018, ages 0-5+.
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.
- The a4a model estimates fishing mortality by age and year, survey catchability by age (constant over the years) and annual recruitment. Several alternative configurations were explored.
- Both the XSA and a4a models have a major residual pattern in which all residuals for ages 1-2 in 2012–2018 are positive. These patterns persist for several alternative model configurations and could only be resolved by allowing survey catchability to change over the years (for which there was no justification that could be provided).

- Results indicate a general decrease in recruitment and SSB and a general increase in F throughout the assessment time series, with 2018 $F=2.75$ (XSA result, with F as F_{bar} of ages 0-2).

Reference points: $F_{0.1}=0.15$ (ages 0-2), 2018 $F/F_{0.1}=18.9$, in overexploitation

Conclusion

- The assessment of European hake in GSA 7 was not accepted because no agreeable model formulation was able to fit the data properly (poor residual patterns). In addition, the assessment indicates a very strong overexploitation status, which may be unrealistic.
- In the interim, until a benchmark decision on GSA groupings is reached, the a4a assessment of GSAs 1-5-6-7 should be the basis of advice for GSA 7.

Recommendations

- The source of the major residual pattern should be explored, including fishery and survey data, growth estimates, catch at age and modeling options for both the fishery and the survey catchability at age.
- Extending the time series in the assessment could be explored.

GSAs 8-11 (Tyrrhenian Sea)

Data

- Historical landings show a progressive steady decline from the 1970s to the early 2000s. Knowledge of the development of the fisheries does support this trend. A marked increase in catches is reported at the beginning of the EU DCF in the early 2000s, which raises concern about the reliability of the catch statistics (in absolute values) before that period. For this reason, the assessment is limited to data from 2005 to 2018.
- High discards characterize the catches of the bottom trawlers. Discards are calculated from on-board sampling data raised to total landing. Estimation is problematic for two reasons: i) only a very small portion of fishing operations are observed; and ii) potential bias of the proportion and characteristics of discards from the observed trips due to changes in fishermen behavior. In addition, gaps in the discards time series are filled using the average of the time series (no trend in the ratio discards/landings is observed). High uncertainty and concerns remain regarding the reconstruction of European hake discards in the area.
- Internal consistency of the catch and survey data is moderate for the first ages (which contain most of the catch, both in fishery and in survey) and generally deteriorates quickly above age 2.
- The MEDITS survey indices time series, which starts in 1994, shows an abrupt increase after the first four to five years, and some concerns exist about the quality of those initial years when the vessels carrying out the survey were familiarizing themselves with the sampling gear.

Model

- During the benchmark meeting, it was agreed to include GSA 8 (Corsica) in the assessment of European hake in the Tyrrhenian and Ligurian Sea (there was no previous assessment of European hake in GSA 8).
- The assessment is based on the a4a statistical catch-at-age model. It covers the years 2005–2018, ages 0-7+; F is summarised via the average F (F_{bar}) for ages 1-3.
- The assumed natural mortality at age vector was obtained from an average of methods, in line with the benchmark decision.
- The a4a model selected at the benchmark adopts a separable model for the fishing mortality, applying a smooth formulation over the years, and assumes survey catchability-at-age constant over the years. For both fishery and survey, separate age-specific parameters were used, with a plateau assumed for ages ≥ 4 . The resulting estimates of F-at-age and survey catchability are both dome-shaped with a peak on age 1.
- The preferred model was selected among four rather similar formulations based on an improved BIC.

- The residuals are considered generally acceptable, although there are some trends over time (e.g. a preponderance of negative survey residuals for several young ages in recent years).
- The retrospective pattern in F and SSB is minor.
- Cryptic biomass (i.e. the portion of the resource that is not fully vulnerable to fishing and here defined as the plus-group) is <10 percent but it tends to increase in the recent period as a result of decreasing F.
- Main assumptions used in the short-term forecasts seem reasonable (i.e. maturity and weight-at-age as average from the last three years). Recruitment is projected using the geometric mean from the last eight years (2011–2018), which correspond to a recent period of generally low recruitment. F for the intermediate year (2019) is assumed to be the same as in the terminal year (2018), which seems more appropriate than an average on the recent years given the estimated negative trend in F.

Reference points: $F_{0.1} = 0.165$, $F_{\text{current}} = 0.670$, $F_{\text{current}}/F_{0.1} = 4.04$, overexploitation

Conclusions: the general impression is that of a noisy assessment for European hake in GSAs 8-11. Moderate-low consistency in both the catch and survey data, poor information on the old age classes, noisy compositional data and short time series all contribute to this perception. Despite these difficulties, the assessment was considered to be of sufficient quality to be considered as a benchmark assessment for European hake in these GSAs and should be the basis of the advice.

Recommendations

- Work is needed to improve the quality of landings, survey indices and compositional data from both commercial fisheries and survey.
- Growth assumptions are highly influential to convert length-structure to age-structured data inputs for the assessment. Quarterly slicing would likely be an improvement over annual slicing, as discussed in the general section on biological parameters.
- A better perception of the recent temporal dynamics of the stock could be achieved if a longer time perspective was available. The assessment starts in 2005, but survey data from MEDITS are available back to 1994. It is recommended to explore the possibility of extending the time series in the assessment. In this context, information from the GRUND survey, which was carried out in this region since the mid-1980s, should also be considered.
- This assessment unit extends across a wide geographical range, from the southern Tyrrhenian to the Ligurian Sea, including also the waters around Sardinia and Corsica. In addition to biogeographical differences, these areas are characterized also by differences in the fisheries and their exploitation levels. Some work is recommended to provide a clear representation of the contribution of the different areas to the combined aggregated input for the assessment (i.e. catch-at-age matrix, survey indices of abundance). In addition to calculating appropriate partial F_s (post-assessment), catch and survey biomass series could be tabulated by GSA to provide information on fishery and stock patterns in each area.

GSAs 12-16 (Strait of Sicily)

Data

- Italian commercial catches prior to the beginning of the EU DCF in the early 2000s were retrieved from ISTAT. Catches for the period 1980s–1990s were originally reconstructed by ISTAT based on unreasonable assumptions (i.e. a simple x3 scaling factor). Catches for this period were corrected for the stock assessment by applying an adjustment factor based on previous works by Andreoli *et al.* (1995) and recently reviewed by two MEDSUDMED working group.
- Fishing fleets were pooled into three units (essentially corresponding to OTB in Italy, OTB in Tunisia, and nets) for the purpose of the stock assessment, which seems reasonable given the size and characteristics of the fisheries. The assessment includes annual catches of the OTB fleets since the mid-1940s and the nets fleet since around 1990. Length composition data were available for each of these fleets starting around the years 2006–2010 (actual starting year depending on the fleet).

- Discards were estimated for recent years. Before the 2000s there was no incentive for discarding due to the lack of a specific legislation and because of a receptive market for juvenile European hake.
- A biomass index was derived from the MEDITS survey. To be able to cover a longer time period (i.e. starting from 1994), the MEDITS survey data were restricted to GSA 16, therefore excluding MEDITS survey information from GSA 15. Some concerns were raised about containment and representativeness of a survey covering only part of the stock distribution. In this respect:
 - a plot comparing the indices and length distributions from only GSA 16 and from both GSAs 15 and 16 was not presented, but was recommended for documentation to be added to the benchmark report; and
 - sensitivity runs using MEDITS from 2002 (instead of 1994) to evaluate changes in the survey coverage suggest some sensitivity of historical estimates but nearly no difference from mid 1990s.
- The sampling level of the MEDITS survey has been variable through time. It was reported at the benchmark that some test had been performed with the index calculated based on the only hauls which have been sampled consistently throughout time and that the result was similar. The same test was not performed to evaluate the impact of variable sampling effort on the length distributions from the survey.
- In 2014 and 2017, the MEDITS survey was carried out several months later than usual and the survey length composition data from those years were not used in the stock assessment model. It was reported that the effect of this exclusion on the assessment results was negligible.
- Age-at-length sampling data were available from the catch of the Italian OTB fleet since the early 2000s. These were the only age-at-length data used in the stock assessment model.
- The length composition data for the two OTB fleets was provided for each of the two sexes separately and, in addition, the dataset also indicated the (year-specific) sex ratio (i.e. proportion female) observed in each length class. The MEDITS survey length composition data also distinguished sexes for lengths ≥ 10 cm. The length composition data of the nets fleet was for both sexes combined.
- The age-at-length sampling data was provided for each of the two sexes separately and, in addition, also included the (year-specific) sex ratio (i.e. proportion female) observed in each length class.

Model

- A single-area two-sexes SS3 stock assessment model, with three fishing fleets, was developed for the benchmark. The model started in the mid-1940s, although the survey information included in the model starts only in 1994 and the length composition data from the commercial fisheries starts in the mid-2000s. Several model configurations in SS3 were examined in advance of the benchmark as well as during the benchmark workshop.
- The biological parameters were all assumed by sex and all treated as known in the assessment, with the only exception of the sex-specific t_0 parameters in the von-Bertalanffy growth models, which were estimated in the stock assessment model. As it is usual in SS3, a CV (whose value was also assumed known) was included around the growth models.
- Recruitment was assumed to follow a Beverton-Holt relationship with steepness fixed at 0.88 based on likelihood profiles and estimates for other European hake stocks in the Pacific and off South Africa. Log-normal yearly recruitment deviations, with an assumed CV=0.5, were included starting from the year 1984.
- For each fishery and the survey, the selectivity-at-length was assumed to have a “double-normal” shape over the length range. For the Italian OTB and the nets fisheries, the selectivity was allowed to have year-to-year changes in the recent period (since the mid-2000s).
- The composition data were weighted using the approach of McAllister and Ianelli (1997). Although the so-called Francis method is more commonly applied in SS3 these days, it was reported that investigations on alternative data weighting approaches conducted before the benchmark led to the conclusion that the McAllister and Ianelli’s method had better performance for the European hake assessment in GSAs 12-16.
- Numerous model diagnostics were presented and this was found to be very useful. The high level of agreement obtained with an age-structured production model (ASPM), which used the stock-recruitment relationship with no deviation, no compositional data and the same selection pattern for

the fisheries estimated in the “main” SS3 run, suggests that fisheries exploitation may explain most of the recent history of this stock.

- Assessment model diagnostics were generally considered acceptable. The main misfit encountered pertained to the sex ratio at length of the length composition data, for which model predictions differed substantially from the observed values (in particular, underestimating the observed proportion of females at intermediate and relatively large lengths). There were also some (relatively minor) misfits to the age-at-length data; this may not be surprising given that both the parameters k and L_{∞} of the von Bertalanffy growth models, and the CVs around the growth functions, were fixed in the assessment model.
- To address the misfit observed in the sex ratio at length of the length composition data, and following a suggestion in the SS3 manual, it was decided to ignore the data available in this regard in the age-at-length dataset and to keep only this information from the length composition dataset. It is unclear to the reviewers if there are overlaps in the data on sex ratio at length between the two datasets. The final model configuration selected at the benchmark includes this modification. However, it should be noted that the fits to the sex ratio at length remained poor.
- Estimation of the von Bertalanffy growth parameters for males and females was tried in some test runs with little success.
- Dome-selectivity is estimated for all the fleets including the survey. This might be problematic due to the potential risk of so-called cryptic biomass.
- An error was found in the length distribution of the MEDITS, which caused the parameter of the selection curve to hit its lower bound. Correction of the input data during the meeting appeared to solve the issue.

Reference points

- Even though this stock assessment starts in the 1940s, it is important to keep in mind that the information before the mid-1990s is very limited (only total catch in tonnes). As a consequence, estimates of stock size further back in time rely strongly on modelling assumptions, in particular the form of the stock-recruitment relationship and the assumed value for steepness. Different steepness values or functional forms of the stock-recruitment relationship (e.g., Ricker versus Beverton-Holt) would likely give considerable different historical biomass estimates and it should be kept in mind that, based on European hake’s cannibalistic behaviour, a Ricker functional form cannot be ruled out. The assessment is considered to be more reliable as of the mid-1990s which is, in any case, the most relevant period for the estimation of the current level of stock size and exploitation.
- $F_{msy}=0.29$. F_{msy} is very close to F_{01} ($=0.3$). The assessment estimates $F(2018)/F_{msy}=1.66$, so current status is in overexploitation.

Conclusions

- The material presented suggests that the model is able to reconstruct the catches and fits reasonably well to survey indices and compositional data from both commercial fisheries and survey. Issues with the fits to sex ratio (proportion female) at length remain.
- There is uncertainty in estimates of historical biomass, which is partly related to limited knowledge on the productivity of the stock at high levels of SSB. However, assessment of the current status of the stock and exploitation level appear robust to such uncertainties and main assumptions.
- The assessment was considered to be of sufficient quality to be treated as a benchmark assessment for European hake in GSAs 12-16 and should be the basis of the advice

Recommendations

- Issues remain with the fits to the sex ratio at length, which should be further investigated in future assessments.
- Additional work on individual growth by sex would be relevant. Estimation of growth parameters internal to the model should be further explored in the future using information from age-at-length data or other auxiliary information.

- An assessment model with quarterly (instead of yearly) internal time step could be investigated if length composition fishery data are available. This would be in line with the conclusion in the general discussion on biological parameters about considering slicing on a quarterly basis.
- The decision to exclude information on the sex ratio (proportion female) observed in each length class from the age-at-length sampling dataset could be reexamined in the future, taking into account the sampling procedures applied. Potential conflicts between age-at-length data and other compositional data should be further investigated in this integrated model (see Lee *et al.*, 2019 for a more in depth consideration on possible bias and conflicts related to the inclusion of age-at-length data).
- The inclusion of indices, length distributions and, if available, age-at-length data from the GRUND survey should be explored. This would offer two main advantages, namely, it would cover another season of the year and extend back in time to the 1980s.
- Tunisia has recently started a survey aligned with MEDITS; this survey should be continued and integrated in the stock assessment with time.
- Model-based standardisation of survey indices (for instance, see the model proposed by Berg *et al.*, 2014) should be investigated, with the aim to improve indices calculated on the current data and, in the long run, to include data from all the areas where the survey is carried out.
- It would be useful to conduct further work to provide insight into the productivity of the stock back in time when it was at high SSB levels and characterized by a wider length distribution than at present.
- The presence of unaccounted fishing effort and catches originating from vessels not included among the fisheries presented but which are known to catch European hake in this area was noted at the benchmark. Although it may be difficult to address or resolve this issue, examination of possible impacts on stock assessment results seems relevant.

GSA 19 (western Ionian Sea)

Data

- MEDITS survey indices were available since 1994. The MEDITS indices showed generally higher levels and wider range of variation since 2004. Screening the data did not reveal any change in the survey methodology that could be related to possible changes in catchability or representativeness of the survey. The survey indices were adopted in their current form for the time being, but further scrutinizing of the data is recommended.
- Internal consistency (cohort tracking from year to year) of the catches-at-age in the commercially fishery and survey was generally low. The impact of age slicing (using DCF growth parameters) versus “consolidated ALK” (slicing using growth parameters estimated from otolith readings; FAO handbook on fish age determination, 2019) for the calculation of commercial catch-at-age and age-based survey indices was evaluated. There were some visible differences, especially on the relative importance of age 0 and age 1, and the internal consistency of both catches and survey were marginally improved (although it remained still very low) with the age slicing method using DCF growth parameters, which was the preferred option for the benchmark model.

Model

- The assessment is based on the a4a statistical catch-at-age model. It covers the years 2004–2018, ages 0-7+; F is summarised via the average F (Fbar) for ages 0-4.
- Among the many alternative assessment model formulations examined, two were selected as competing candidates for the benchmark assessment. Both formulations shared the same F-submodel (a separable smooth model over ages and years, with additional inter-year variability on age 0) and recruitment submodel (geometric mean with CV=0.2). The two formulations differed on the survey catchability part, with catchability assumed constant over all the ages (v18) or variable using a separate parameter for each age (v15). The fits of the two models appeared to be very similar. However, selection of an age-specific catchability of the survey appears justified based on:
 - small improvement in the GCV value, which is used as model selection criteria;
 - prior knowledge of the selectivity of the MEDITS for European hake based on other areas; and
 - small but significant difference ($p < 0.05$) in the age-specific coefficients.

- The CV of the recruitment is quite small (0.2), especially if compared with values from other stocks (often around 0.4-0.5). However, fitting of the age 0 group is of similar quality when compared to the other ages, so it was considered appropriate for the stock.
- The cryptic biomass was estimated to be particularly low for this stock (<5 percent in the terminal year) as it should be expected by the high proportion of longlines and gillnets.
- The model from previous STECF assessment (STECF EWG 17-15), was not discussed in detail during the benchmark so the model introduced at the benchmark was not presented as an incremental improvement on the existing assessment model but rather a stand-alone work. This made the comparison between the old and new model difficult and, from a review perspective, it was not possible to evaluate the contribution of updating each individual assumption and data component.

Reference points

- $F_{0.1}=0.132$ and $F_{current}/F_{0.1}=2.4$, in overexploitation
- Partial F_s were derived by fleet which is particularly useful in this area where passive gear contribute to approximately 40 percent of the total catches of European hake.

Conclusions: the assessment was considered to be of sufficient quality to be treated as a benchmark assessment for European hake in GSA 19 and should be the basis of the advice.

Recommendations

- The assessment starts in 2004, but survey data are available back to 1994 (and fishery data may start even earlier). Therefore, extending the time series in the assessment should be explored as a candidate in future benchmarks.
- Further in depth scrutiny of the MEDITS data is necessary in preparation for the next benchmark, to explain the reasons behind the abrupt change observed in the indices in 2004.
- The weak consistency in the age-structured data should be further investigated. Consideration of points emerging from the general benchmark discussion on this (e.g. slicing by quarter) should be investigated in the future.
- Longlines and gillnets/trammel nets represent a good portion of the European hake landings (approx. 40 percent) in this GSA, which is different to the predominant situation in other areas. Their temporal development is not homogeneous among these fisheries and the calculation made of partial F_s over time is very useful in this regard. An alternative for advice and management could be the future development of a multi-fleet model.
- It is recommended that at the next benchmark comparison between new and old models is enhanced with benefit for the model improvement. This is valid for most of the areas and it is likely to become easier when models will get better established.

GSA 20, 22 and 23 (eastern Ionian Sea, Aegean Sea, Cretan Sea)

Stock assessments were attempted for each of these GSAs separately, but as issues were encountered and the conclusions are similar for all three GSAs, they are all addressed here (even though the assessments were separate for each GSA).

Data

- Annual landings for 1990–2018 (from HELSTAT and FAO).
- Biomass index from MEDITS surveys in years 1994–2001, 2003–2006, 2008, 2014, 2016, 2018. Note that the index is missing in many recent years, starting in 2007.
- Length frequency distributions start in 2003, but are missing in the same recent years in which the survey index is missing.

Model

- A surplus production model (SPiCT) and pseudo-VPA (equilibrium cohort analysis) were attempted for each GSA.
- It was agreed that SPiCT runs should use the biomass index from MEDITS with the existing gaps, instead of attempting to fill the gaps by applying some kind of smoother prior to including the index in the model. Model runs were revised to fit to the annual indices rather than smoothed values.
- For each GSA, several SPiCT runs were conducted, investigating various configurations of the input data (e.g. exploring the use of the landings series since 1990 or a longer time series starting in 1970) and model settings (such as priors on the intrinsic growth parameter and the parameter controlling the shape of the production function). There were often difficulties encountered in terms of lack of convergence or very large uncertainty in model outputs, which is not surprising given the gaps in the MEDITS index.
- It should also be noted that applying SPiCT with the MEDITS survey index could be problematic, because this survey index does not represent the exploitable biomass.
- For each GSA, the pseudo-VPA was conducted twice, based on the length frequency data of 2016 and 2018, respectively.
- The results from SPiCT and the pseudo-VPA analyses concerning the exploitation status relative to fishing mortality reference points are opposite to each other and this situation occurs in all three GSAs.

Reference points: given the inconsistencies found between the results of the two methods applied, the exploitation status is considered uncertain and there are no reference points.

Conclusions: given the inconsistency found between SPiCT and pseudo-VPA results in all three GSAs, status is considered uncertain and the exploitation level relative to reference points unknown. This occurs for GSA 20, GSA 22 and GSA 23.

Recommendations

- In the future, an assessment incorporating all available information (catch, survey index, length frequencies), such as a statistical catch-at-age model in a4a, should be developed.
- STECF representatives noted that, in an earlier STECF meeting, substantial differences had been noticed between catch data from DCF and other sources (FAO and Greek statistical services). It is unclear to the reviewers if this issue has been clarified at present. Given the importance that having good catch data has for conducting reliable stock assessments, the reviewers consider that whichever may be considered the best source(s) of data should be used for the stock assessment.

GSA 26 (south Levant)

Data

- Annual recorded landings from trawl fishery during 1997–2017, and non-standardised LPUE (recorded landings per boat) from the same fishery.
- The available landings do not represent the total European hake catch in GSA 26. There are catches in other fisheries whose magnitude is currently unknown but expected to be significant.
- Length frequencies were available for the trawl fishery for 2015, 2016 and 2017. No length frequencies were available for other fisheries.
- In the biological sampling of the trawl fishery (in 2015–2017), the following information was collected for individual fish: total length, weight, sex, maturity stage, and otoliths.
- Fishery-independent information: a trawl survey was conducted in only one year (2008).

Model

- VPA with VIT (equilibrium cohort analysis), using the length composition data from the trawl fishery combined for 2015, 2016 and 2017.
- The observed length frequencies were similar for the three years, but the individual years had some gaps in the observed frequencies and more noise, so VIT was run only for the combined 2015–2017 length frequencies.
- The biological inputs used to run VIT (growth parameters, length-weight parameters, natural mortality-at-length and maturity-at-length) were estimated from the biological samples of the trawl fishery in 2015–2017. All estimations were performed only for combined sex. Growth parameters estimates rely on the ages read from the otoliths. Natural mortality-at-age was estimated by the method of Abella *et al.* (1997) and subsequently converted to natural mortality-at-length using the growth parameters.
- VIT was run with three different values of terminal F (F at 63 cm): 0.1, 0.2 and 0.3.

Reference points

- Following the VPA analysis, a “per-recruit” analysis was run with VIT, for the three values of terminal F, resulting in: $F/F_{0.1} = [3.57- 4.54]$ and $B/B_{0.1} = [0.25 - 0.29]$, where the range corresponds to the 3 values of terminal F.

Conclusions

- This was the first time that European hake in GSA 26 was assessed by the GFCM and the work represents a very important first step towards the development of future assessments based on more complete information, which is highly encouraged.
- The method applied is considered to be appropriate, given the scarcity of data. The method applies an equilibrium model (VIT pseudo-cohort analysis) and provides some qualitative exploitation status, but the results of this method are obviously substantially uncertain and the outcome was, therefore, appropriately classed as “precautionary advice”.

Recommendations to progress towards a more complete assessment in the future

- Complete the fishery catch data as much as possible. Try to recover information on past catch of the different fisheries, as well as on composition data (length frequencies). Continue and improve the collection of these data in future years.
- Develop an index of European hake abundance. Initially, if it not possible to develop a fishery-independent index from a survey, then aim to gather relevant information in order to achieve an appropriate standardisation of the commercial CPUE.
- Further examine length composition data from different fishing areas, fishing gear, fleet segments, etc.
- Continue the biological sampling and the analysis of the information gathered, examining also sex differences.
- The otolith-reading procedure used in the analysis was validated within Egypt, but unfortunately it was not possible for experts to join the FAO ageing validation group. It is therefore recommended that results from the reading in Egypt be compared with outputs from the recent FAO workshop on this matter; if differences are detected, then consider what actions or developments may be needed.

Agenda

- 1. Opening session**
- 2. Review of previous advice and identified issues**
- 3. Review of available fisheries dependent and fisheries independent information**
- 4. Analysis of potential assessment models, including detected issues with previous assessment models, and identification of candidate models and assumptions**
- 5. Practical session; assessment runs and compilation of tentative results**
- 6. General discussion on assessment outcomes**
- 7. Simulations and reference points**
- 8. Conclusions and preparation of draft advice**

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Table of advice on the status of European hake (*Merluccius merluccius*) in the GSAs addressed in this benchmark

N	GSA	Method	Fc	Bc	F Reference point	B Reference point	Stock status (quantitative)	Stock status (qualitative)	Scientific advice	Benchmark Conclusions
Western Mediterranean										
1	01_05 _06_ 07	a4a	1.93	--	0.35	--	$F/F_{0.1} = 5.58$	In overexploitation and with relatively low biomass	Reduce fishing mortality Partial F and STF available	Basis for advice Stock identification remains uncertain. Advice with this aggregation should be provided in the next 2- 3 years until results of stock identification projects are available
2	01&03	XSA	1.2	--	0.17	--	$F/F_{0.1} = 7.02$	In overexploitation and with intermediate biomass	Reduce fishing mortality STF available	Complementary advice Stock identification remains uncertain. Update of previous years advice with new biological parameters
3	05	a4a	1.40	--	0.31	--	$F/F_{0.1} = 4.5$	In overexploitation and with relatively low biomass	Reduce fishing mortality STF available	Complementary advice Stock identification remains uncertain. Update of previous advice with new biological parameters and model formulation
4	06	XSA / a4a	--	--	--	--	--	--	--	No additional advice Problems with input data: low consistency in the catches and in the survey

N	GSA	Method	Fc	Bc	F Reference point	B Reference point	Stock status (quantitative)	Stock status (qualitative)	Scientific advice	Benchmark Conclusions
Western Mediterranean										
5	07	XSA / a4a	--	--	--	--	--	--	--	No additional advice No agreeable model formulation is able to fit the data properly
6	04	VIT	0.97 I _C = 0.14	130 5 I _C = 345	0.21 I _C = 0.05	7205 I _C = 1972	F/F _{0.1} = 4.5 B/B _{0.1} = 0.18	In overexploitation and overexploited	Reduce fishing mortality	Precautionary advice Stock identification remains uncertain. Range of F/F _{target} and B/B _{target} based on 4 separate years and all combined

N	GSA	Method	Fc	Bc	F Reference point	B Reference point	Stock status (quantitative)	Stock status (qualitative)	Scientific advice	Benchmark Conclusions
Western Mediterranean										
7	08, 09, 10, 11	a4a	0.67		0.16	--	F/F _{0.1} = 4.06	In overexploitation and with relatively low biomass	Reduce fishing mortality Partial F and STF available	Benchmark agreed GSA 8 included for the first time – low contribution to catch and overall fishing mortality – Consistent with previous advice
Central Mediterranean										
8	12- 16	SS3	0.48	4397	F _{MSY} = 0.29	SSB _{MSY} = 7021	F/F _{MSY} = 1.66 SSB/SSB _{MSY} = 0.63	In overexploitation and overexploited	Reduce fishing mortality Partial F and STF available	Benchmark agreed Longer time series used, model changed from XSA to SS3. Overall perception on stock status in recent years similar to previous advice, new advice

N	GSA	Method	Fc	Bc	F Reference point	B Reference point	Stock status (quantitative)	Stock status (qualitative)	Scientific advice	Benchmark Conclusions
Western Mediterranean										
										provides lower overexploitation index. Some concerns on the B/Bmsy levels were raised and this should be further investigated
9	19	a4a	0.31		$F_{0.1} = 0.13$		$F/F_{0.1} = 2.4$	In overexploitation and with relatively high biomass	Reduce fishing mortality Partial F and STP available	Benchmark agreed New assessment
10	20	SPiCT, Pseudo VPA	--	--	--	--	--	Uncertain	Do not increase fishing mortality	Precautionary advice Models used did not provide a consistent perspective,

N	GSA	Method	Fc	Bc	F Reference point	B Reference point	Stock status (quantitative)	Stock status (qualitative)	Scientific advice	Benchmark Conclusions
Eastern Mediterranean										
1 1	22	SPiCT, Pseudo VPA						Uncertain	Do not increase fishing mortality	Precautionary advice Models used did not provide a consistent perspective
1 2	23	SPiCT, Pseudo VPA						Uncertain	Do not increase fishing mortality	Precautionary advice Models used did not provide a consistent perspective The size composition of the catch show a relatively larger portion or large individuals in comparision with other areas
1 3	26	VIT					F/F0.1 = [3.57- 4.54] B/B01= [0.25 - 0.29]	In overexploitation and overexploited	Reduce Fishing mortality	Precautionary advice Range of F/Ftarget First time this stock is assessed

Footnote 1: This is the basis of advice for the state of European hake in GSAs 1, 5, 6, and 7. Complementary information for GSAs 5 and GSAs 1 and 3 is provided as well (see section 3.1).

Footnote 2: This assessment is the only basis for advice for GSA 3, while it provides complementary information on GSA 1 (see section 3.1).

Information on stock identity

Mediterranean European hake fisheries are managed as several separate spatial units, but the boundaries of previous stock assessment units were not based on biological population structure (CopeMedII 2017). Alternative spatial units were considered in some recent stock assessments (e.g., aggregation of GSAs 1 and 3, GFCM 2016; aggregation of GSAs 1, 5, 6 and 7, STECF 2018, although GFCM agreed assessments were for the separate GSAs, see Table 4.1). The aggregation of GSAs for stock assessment units should ideally be based on an understanding of spatial population structure. European hake has been extensively studied, and some historical and recent research has investigated spatial patterns, but information on stock identity is not definitive. A preliminary synthesis is provided by the reviewers to identify the best scientific information available for spatial assessment units of European hake in the Mediterranean. The following pages provide a summary of the reviewers' understanding of the issues.

Distributional Patterns - The European hake is widely distributed along the northeastern Atlantic coast from Morocco to Norway and throughout the Mediterranean Sea and the Black Sea (Svetovidov, 1986). European hake have demersal habitats, mostly from 70 to 370 m depth (Murua, 2010), and spawning is throughout the year, mostly at depths of 150–350 m (Recasens *et al.*, 1998). Spawning has been observed in all sampled GSAs throughout the year (Carbonara *et al.*, 2019). In the Mediterranean Sea, European hake appear to be most abundant from northern Spain to the Aegean Sea (Figure A4.1). Annual survey indices of abundance were significantly correlated among western areas (GSAs 7-9, 6-11 and 10-16), and survey biomass indices were correlated in the Alboran Sea (GSAs 1-2) and central Mediterranean areas (GSAs 10-15-16-18-19-20; Figure A4.2; Fiorentino *et al.*, 2014). It should be noted that the results of Fiorentino *et al.* (2014) displayed in Figures A4.1 and A4.2 do not cover the southern part of the Mediterranean (non-European waters).

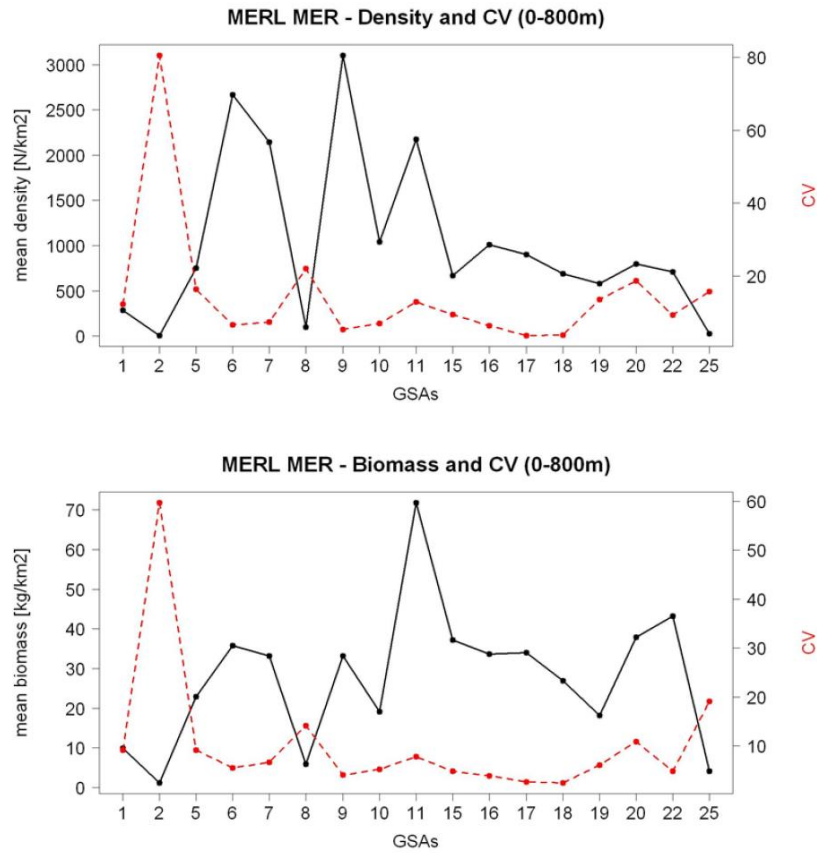


Figure A4.1. Spatial patterns in abundance (N/km², top panel,) and biomass (kg/km², bottom panel) 2002–2011 (from Fiorentino *et al.* 2014)

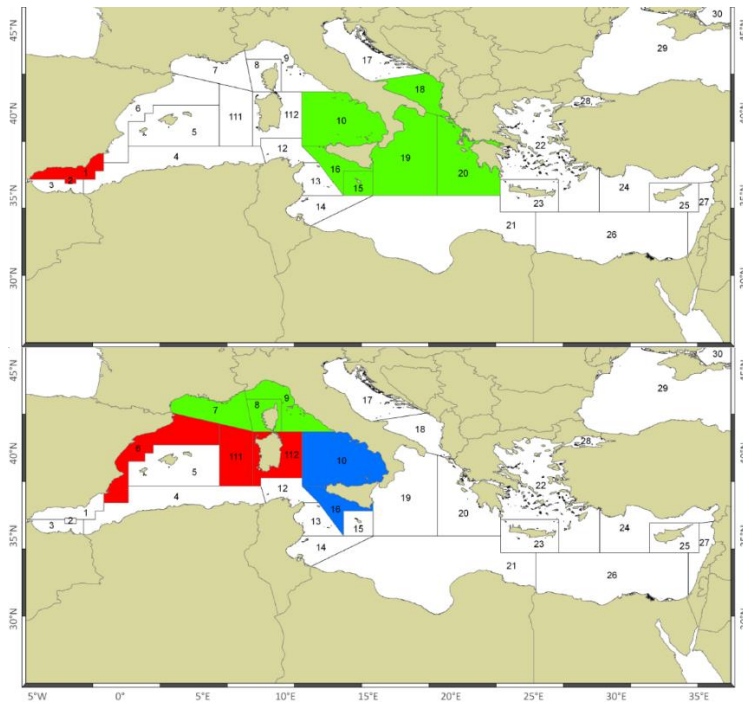


Figure A4.2. Clusters of correlated trends in abundance (top) and biomass (bottom, from Fiorentino *et al.*, 2014)

Hidalgo *et al.* (2019a) analyzed recruitment time series from several areas of the northern Mediterranean to explore synchrony among areas (Figure A4.3). Each area appears to have relatively independent recruitment patterns, with the exception of GSA 6 (northern Spain) and GSA 7 (Gulf of Lion), where recruitment had an increasing trend in the late 1990s and a decreasing trend in the last decade.

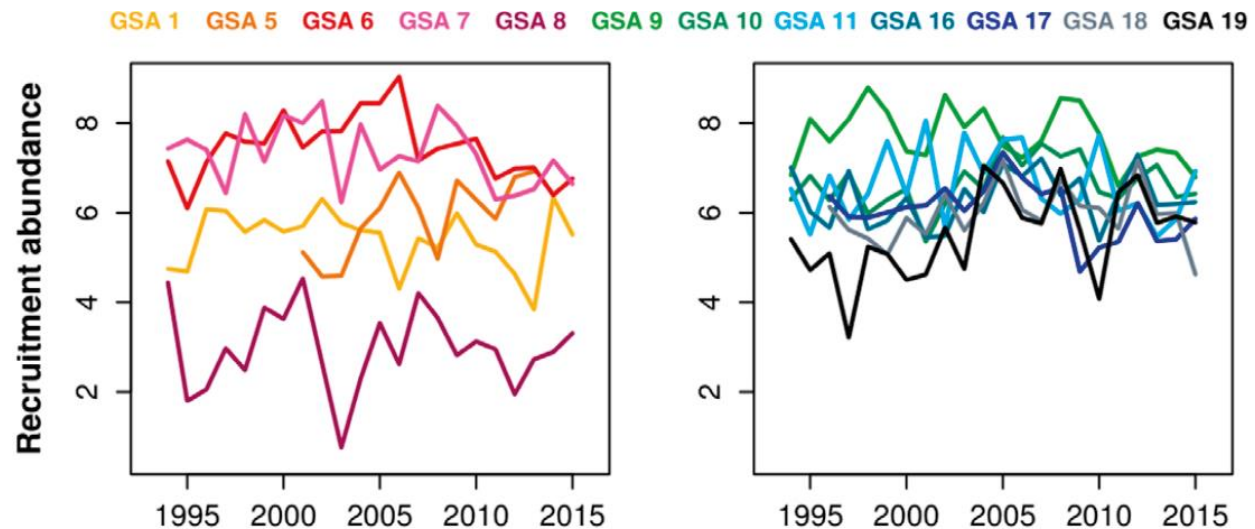


Figure A4.3. Abundance indices (log scale) for recruits for each GSA (from Hidalgo *et al.*, 2019a)

Dispersal – European hake spawn on the continental slope (Recasens *et al.*, 1998), where the main currents advect eggs and larvae among GSAs, but there are some fronts that form barriers to transport of European hake and other meroplankton (Pascual *et al.*, 2017). Oceanographic modeling of European hake dispersal in GSAs 5, 6 and 7 suggested that self-recruitment (the portion of recruits spawned within the GSA) is greater than transport among areas, and transport among GSAs varies widely among years based on environmental conditions (Hidalgo *et al.*, 2019b). The TRANSBORAN project concluded that the Almeria-Oran front forms a barrier to larval transport between GSAs 1 and 6 (Hidalgo *et al.*, 2018, CopeMed II 2019). Preliminary results from the SAFENET project suggest connectivity of European hake larvae among GSAs 9 and 10 (Radici *et al.*, unpublished).

There is no regional tagging information available to infer movement of juveniles and adults among GSAs. Tagging studies designed to estimate growth report recaptures within the same area of release. For example, Mellon-Duval *et al.* (2010) tagged European hake in the Gulf of Lion (GSA 7) and reported recoveries over two years in the same area. Analysis of survey data suggests limited movement of juveniles and adults (Demestre and Sanchez 1998). Bathymetric features may form barriers to movements of juvenile and adult European hake. For example, the deep channel between the Balearic Islands and the Iberian Peninsula forms a natural barrier to movement of adult European hake (Quetglas *et al.*, 2012). However, de Pontual *et al.* (2012) observed diel vertical migration of European hake that may involve off-bottom transport across deep channels.

Genetics – Several studies using a range of genetic characters including allozymes, microsatellites and single nucleotide polymorphisms (SNPs) provide strong evidence of separate Atlantic and Mediterranean populations (Roldán *et al.*, 1998; Lundy *et al.*, 2002; Castillo *et al.*, 2005; Cimmaruta *et al.*, 2005; Milano *et al.*, 2014). Geographic patterns in allozyme frequencies indicate a steep change across the Almeria-Oran

front and a cline within the Mediterranean Sea that is correlated with salinity and possibly associated with local selection (Cimmaruta *et al.*, 2005; Figure A4.4). Lundy *et al.* (2002) found no significant differences in microsatellite frequencies among sample locations in the Mediterranean. Milano *et al.* (2014) found differences in SNPs between the western (GSAs 1, 3, 7, 9, 10, 11, 12, 15, 16), central (GSAs 17, 18, 19) and eastern Mediterranean (GSAs 22, 23, 24, 25; Figure A4.4), suggesting reproductive isolation among those areas (note that the terminology for these regions is different than those used by GFCM). Levi *et al.* (2004) analyzed allozymes, morphometrics and growth from samples in the Strait of Sicily (GSAs 12-16) and found significant differences in morphometry and growth within the area but no genetic differences. Lo Brutto *et al.* (1998) found no geographic variation in allozymes from GSAs 9, 11, 12, 15, 16 and 18. The STOCKMED project concluded that Milano *et al.* (2014) is the strongest evidence of genetic population structure.

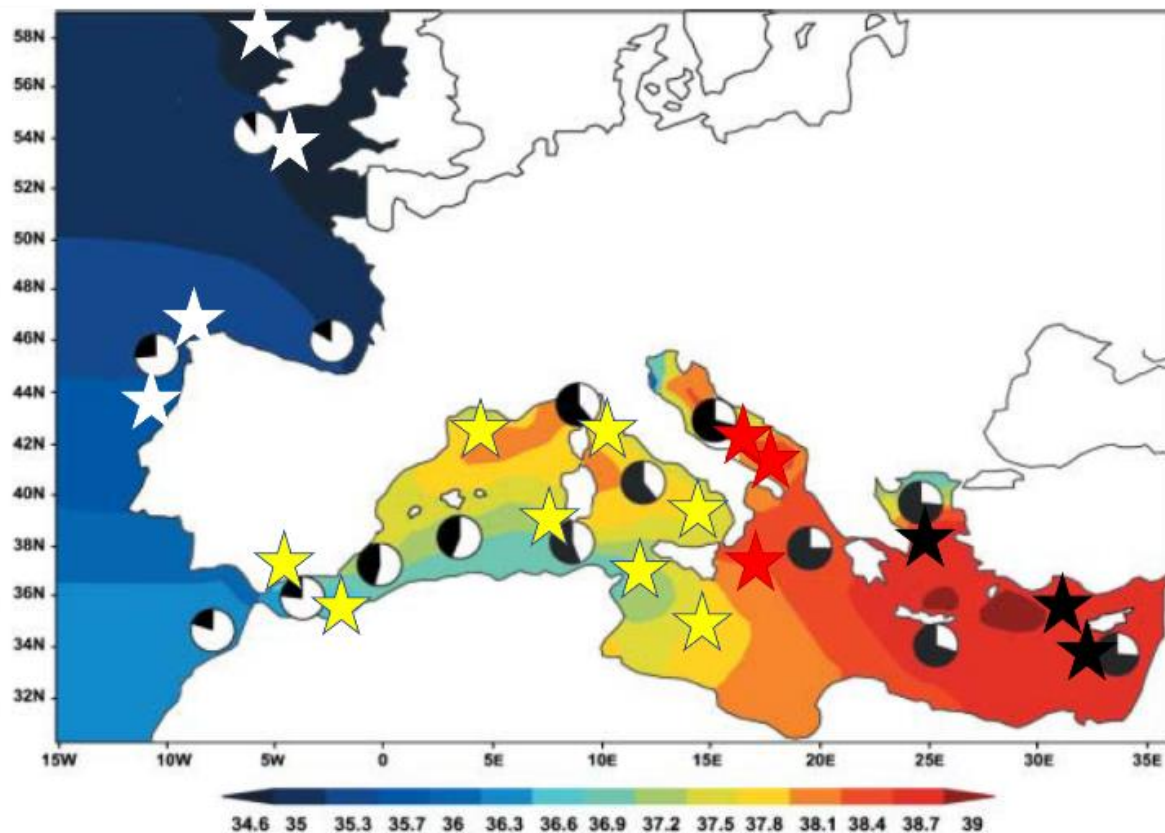


Figure A4.4. Surface salinity (‰) and allozyme frequencies (pie charts, from Cimmaruta *et al.*, 2005), and four SNP genotypic groups (stars, from Milano *et al.*, 2014)

Life history patterns – The STOCKMED project compared biological data from surveys throughout the northern Mediterranean (Fiorentino *et al.*, 2014), including growth parameters, size at maturity, mean weight, median length of spawners, sex ratios, and proportion of females in spawning stage. There was a geographic pattern of growth rates, with clusters in the southwest Mediterranean (GSAs 1-4), off Spain (GSAs 5-6), northern Mediterranean (GSAs 7-11, 17-18), and central-eastern Mediterranean (GSAs 12-16, 19-24) similar in parameters (Figure A4.5). Considering that the Adriatic Sea (GSAs 17-18) is not adjacent to other northern Mediterranean areas with similar growth (GSAs 7-11), these geographic patterns probably have large environmental influence (e.g. temperature). Levi *et al.* (1994) also found similar size at age for European hake in GSAs 12-16.

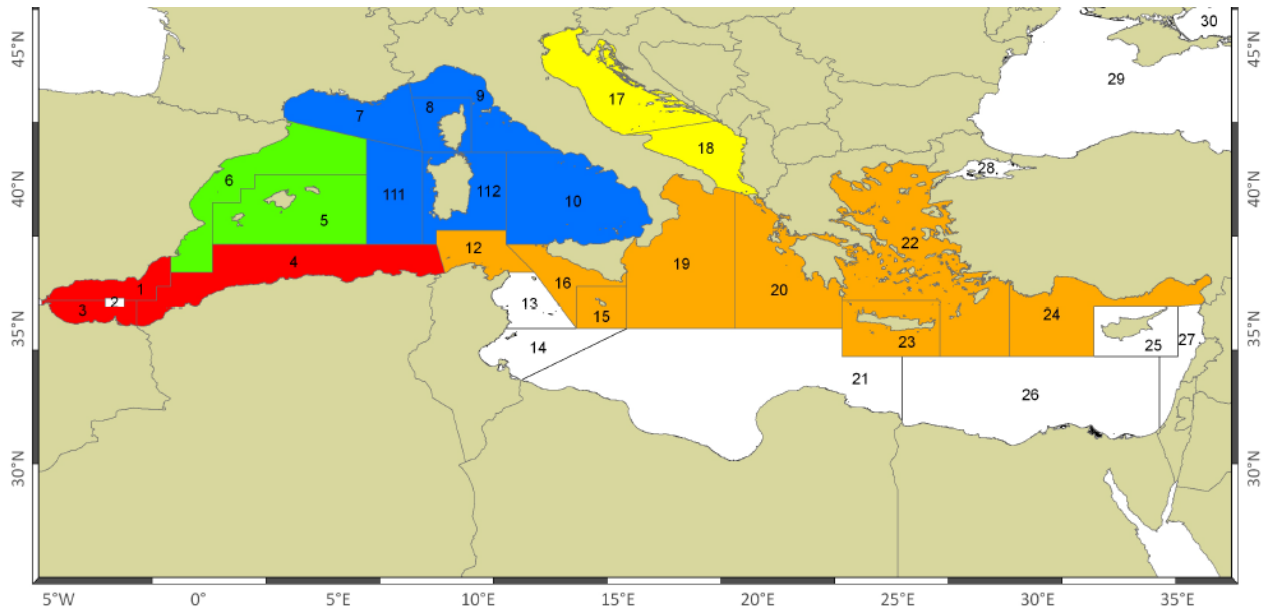


Figure A4.5. Geographic clusters with similar growth rates of European hake (from Fiorentino *et al.*, 2014).

There was a geographic pattern in size at maturity, with clusters in the northwest Mediterranean (GSAs 5, 6, 7, 9), in the southwest Mediterranean (GSAs 4, 12, 13, 14), the Tyrrhenian Sea (GSA 10), the Adriatic Sea (GSAs 17, 18), and the central-eastern Mediterranean (GSAs 16, 19-23, 26; Figure A4.6; Fiorentino *et al.*, 2014). Note that there is a contradiction in the STOCKMED report where the geographic clusters of the report (Figure A4.7) are not consistent with the text or WP4.

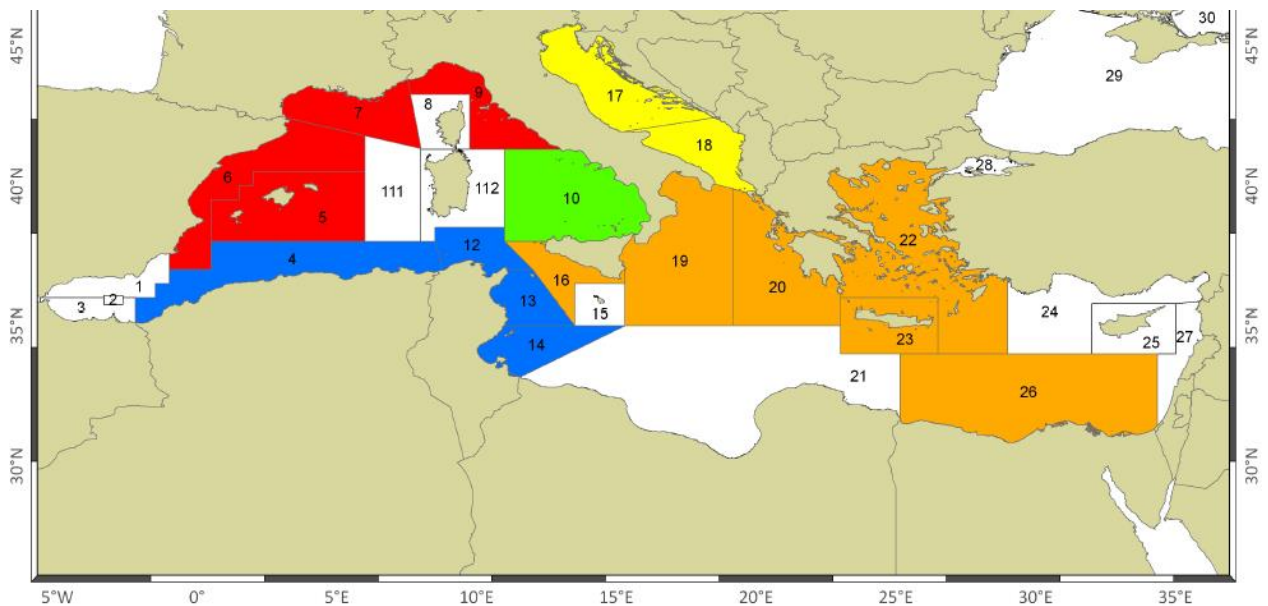


Figure A4.6. Geographic clusters with similar European hake size at maturity (from Fiorentino *et al.*, 2014)

Geographic patterns in mean weight, median length of spawners, percent of females in spawning stage, and sex ratio were variable and less distinct (Figure A4.7).

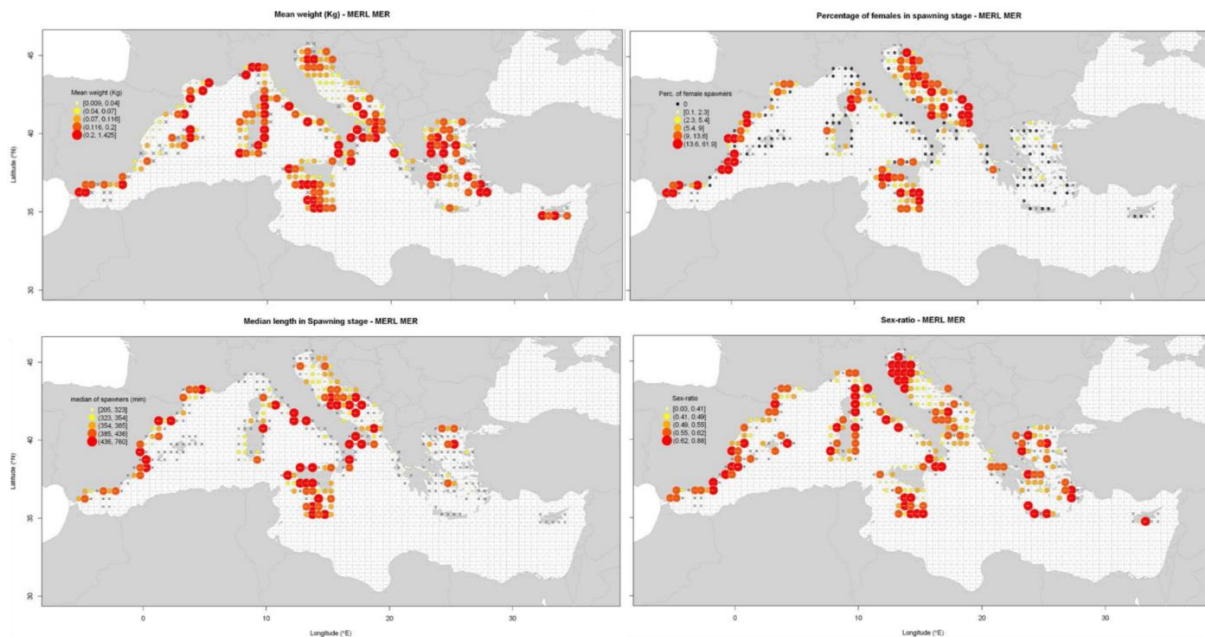


Figure A4.7. Spatial patterns in European hake mean weight (upper left), median length of spawners (lower left), proportion of females in spawning stage (upper right), and sex ratio (lower right, from Fiorentino *et al.*, 2014)

Natural tags – The little information on movement available from tagging studies suggests little movement of juveniles and adults among GSAs (Mellon-Duval *et al.*, 2010), so information from natural tags is valuable. The STOCKMED project provided a comprehensive review and analysis of geographic patterns in parasite infestation, which indicate groups with limited mixing. Geographic patterns of parasite prevalence formed three clusters, in the western Mediterranean (GSAs 1, 5, 6, 7, 9, 12), the Southern Tyrrhenian Sea (GSA 10), and the eastern Mediterranean (GSAs 17, 20-22, 25; Figure A4.8; Fiorentino *et al.*, 2014). Significant differences between European hake sampled in the Atlantic and the Mediterranean were found for otolith size and shape (Torres *et al.*, 2000) and otolith chemistry (Swan *et al.*, 2006), but there was no clear difference in chemistry between samples from Majorca (GSA 5) and the Catalan Slope (GSA 6). Morales-Nin *et al.* (2014) found that the otolith edge of European hake was similar among samples from Cabrera and Palma (GSA 5), Murcia and Tarragona (GSA 6) and Port de la Selva (GSA 7), which may suggest high mobility of juvenile European hake among areas or chemical homogeneity of water masses.

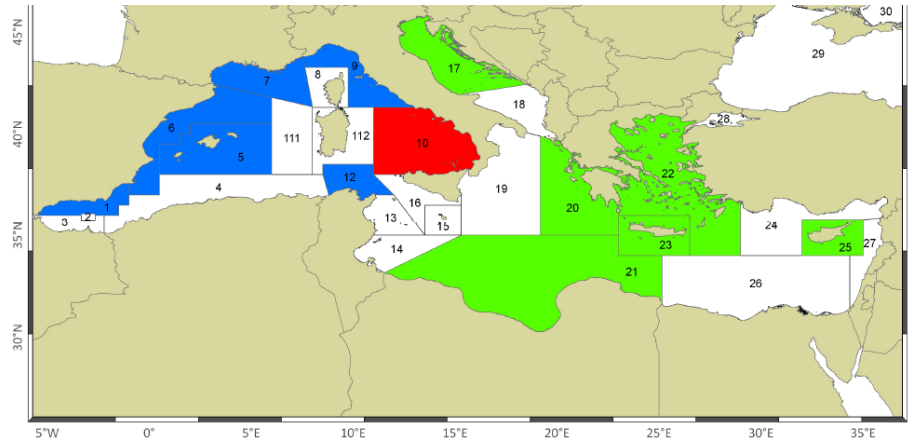


Figure A4.8. Geographic clusters with similar European hake parasite prevalence (from Fiorentino *et al.*, 2014)

Interdisciplinary evaluations - The STOCKMED project (“*Stock units: Identification of distinct biological units (stock units) for different fish and shellfish species and among different GFCM-GSA*”) applied a holistic approach to integrating the available information on stock identity for 19 species, including European hake, in the Mediterranean (Fiorentino *et al.*, 2014). Spatial information from different aspects of stock identification were explored, and six indicators were selected (median length of spawners, proportion of females in spawning stage, mean weight, sex ratio, variability of survey abundance, and survey biomass). The optimal cluster pattern suggested six groups by GFCM statistical grid (Figure A4.8). The GSA groupings recommended by STOCKMED are:

- northwest Mediterranean (GSAs 1, 5, 6, and 7), although note the overlap in GSA 7 (Figure A4.9);
- central Mediterranean (GSAs 9, 10, 11, 15, 16, and 19);
- Adriatic-eastern Ionian Seas (GSA 17, 18, and 20), note that the definition of stocks by GSA is somewhat different than those defined by statistical grid;
- Aegean Sea (GSAs 22-23); and
- eastern Mediterranean (GSAs 24-25).

The indicators selected by STOCKMED provide valuable information on spatial structure that should be considered in sampling and estimation of size and age composition as well as the development of stock indices, but they are not definitive indicators of population structure boundaries. The multi-disciplinary cluster analysis did not consider the different aspects of population structure that can be inferred from each indicator, and excluded some important information such as genetics, connectivity, and geographic variation in other phenotypic traits or natural tags. Furthermore, the STOCKMED classifications did not include GSAs that had insufficient information on the selected indicators (GSAs 2, 3, 4, 8, 12, 13, 14, 21, 26, 27). GFCM (2015) reviewed the STOCKMED results and stated that “the group acknowledged the exercise, although underlining that the inclusion of data from the southern Mediterranean (non-EU countries) was missing and might provoke some bias.”

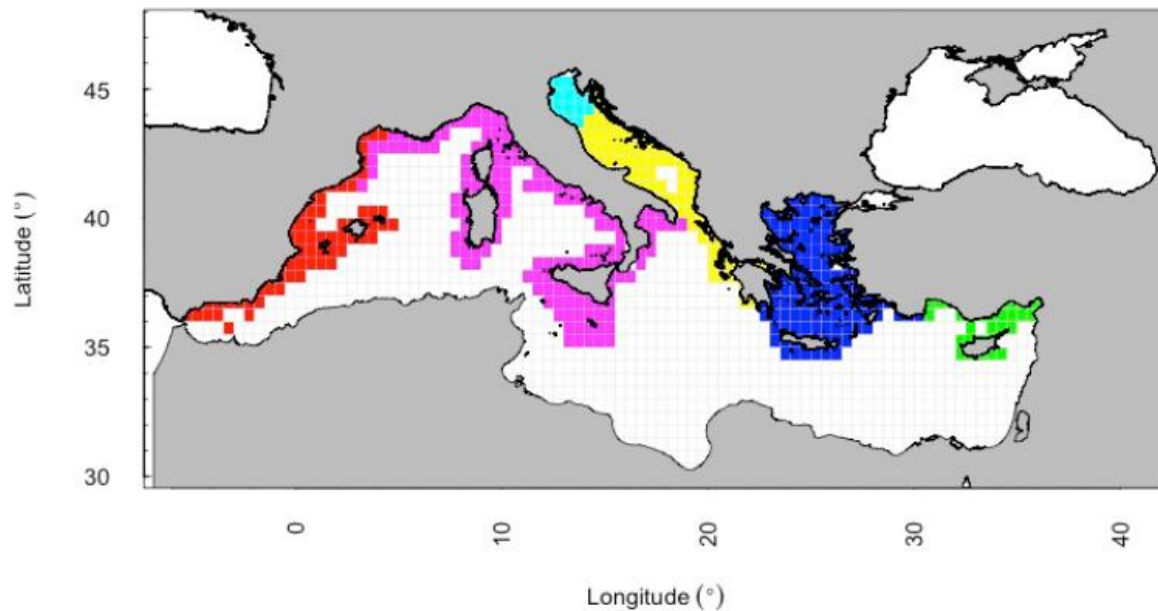
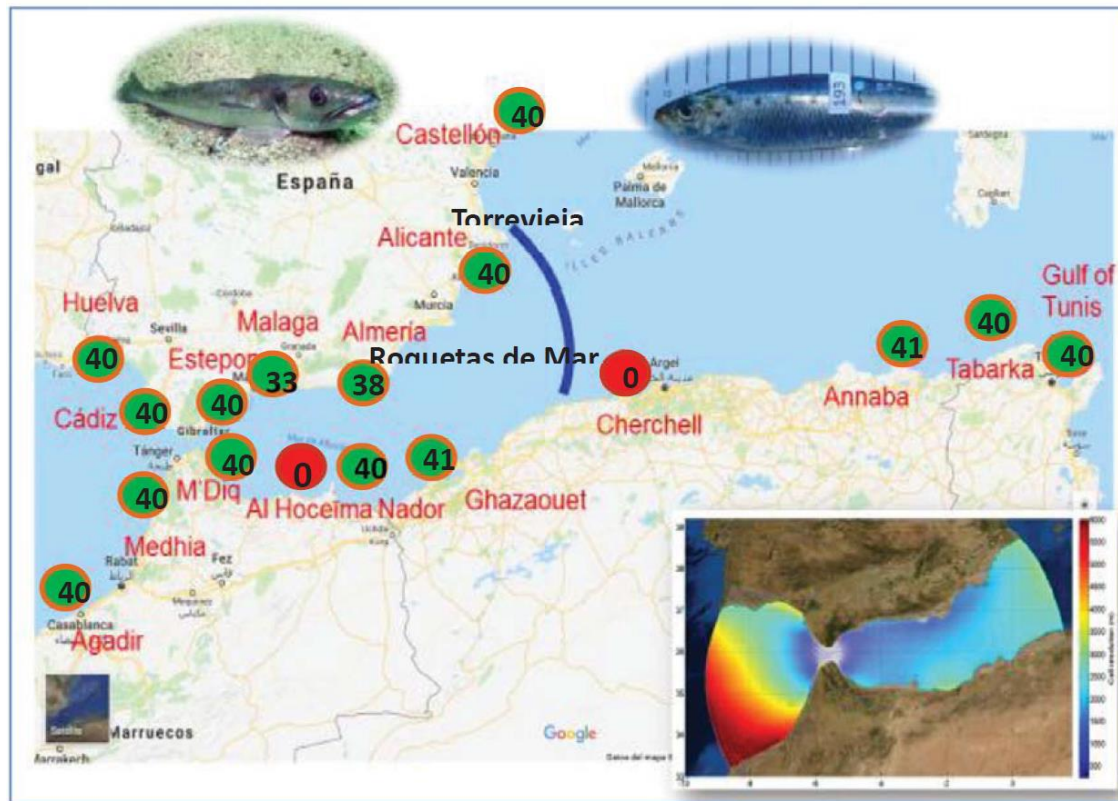


Figure A4.9. Multidisciplinary clusters of European hake stocks suggested by Fiorentino *et al.* (2014).

The TRANSBORAN project is a multidisciplinary approach to assess the transboundary nature of Mediterranean fish stocks including European hake as well as potential intra-stock structural complexity (Hidalgo *et al.*, 2018). Sampling sites and techniques were selected to address different scales within Alboran and adjacent waters (Figure A4.10). Information from multiple disciplines are being considered: hydrodynamics and connectivity, genetic markers, otolith shape, otolith chemistry, stable isotopes, morphometry, meristics, parasites, fishery patterns, demographic indices, and life history traits. The project is expected to determine if the current GSA boundaries are the appropriate spatial scale for assessment and management. Preliminary results from parasites indicate limited mixing between the northern Alboran Sea (GSA 1), the southern Alboran Sea (GSA 3), and Algeria (GSA 4) and Tunisia (GSA 12; Figure A4.11, CopeMed II 2019). Preliminary results from fishery and life history data (e.g., size distributions) also indicate major differences between the northern Alboran Sea (GSA 1) and the southern Alboran Sea (GSA 3), as well as minor differences between eastern and western parts in the Alboran Sea, which may result from some connectivity between the northern and southern areas (CopeMed II 2019). Recruitment patterns were also asynchronous between Morocco (GSA 3) and Spain (GSA 1), suggesting intermittent connectivity of early life stages between GSAs (CopeMed II 2019).



Mediterranean GSAs (1 to 27). The project includes comprehensive genetic studies at the scale of the Mediterranean Sea, otolith shape and microchemistry, and maps of fishing grounds (CopeMed II 2019).

Summary of previous STECF assessments

1- European hake in GSA 19

Using data from 2003–2015 and age 0-6, STECF used an a4a assessment model to provide an assessment (Figure A5.1.1), a short term forecast (STF), and catch and F advice based on $F_{0.1}$ Proxy for F_{MSY} . In addition the EWG carried out spuplus production model but found that this was in conflict in terms of evaluation of stock status, the EWG accepted the a4a age based assessment. The SSB estimated from the assessment showed a decrease over the time series, with a peak in 2007 and the lowest values in 2016. The recruitment estimated with the a4a model did not show a clear trend over the time series. From the assessment, the 2016 $F_{bar\ 0-3}$ (1.32) is much larger than the F_{MSY} value (0.16). The European hake stock in GSAs 19 was considered to be over exploited.

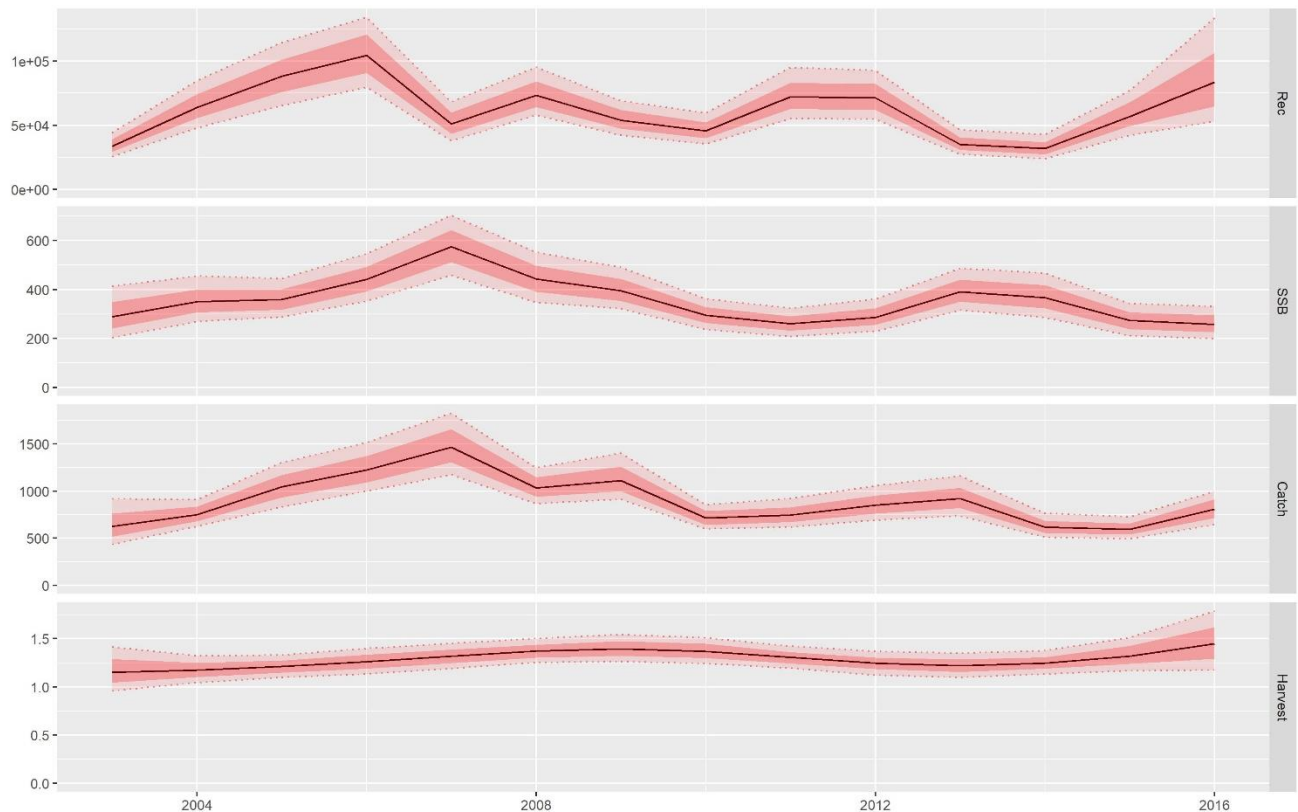


Figure A5.1.1. European hake in GSA 19: F, SSB, recruitment, and catch are simulated and fitted for the a4a assessment model with SSB and catch in tonnes, recruitment in 1000s individuals, and harvest referring to fishing mortality for ages 0 to 3

2- European hake in GSA 20

Using data from 2003–2015 and age 0-4, STECF used an a4a assessment model to provide an estimate of the state of the stock (Figure A5.2.1). However, there were gaps in the data in both catch length and survey abundance. Therefore, in addition, the EWG carried out spuplus production model using $CMSY$ and $SPiCT$ but found that these were in conflict in terms of evaluation of stock status, and the EWG accepted the a4a age based assessment. STECF considered that the stock status was uncertain due to gaps in data collection, there were differences between different methods, the results were considered only indicative of status but

also considered that details were unlikely to change until more data became available. Based on the assessment, the SSB of European hake fluctuated over the time period examined (2003–2016) from 440 tonnes (in 2003) to 284 tonnes in 2016. A decline in SSB was observed from 2008 when the highest SSB was observed in 2015 when the lowest biomass was observed. The assessment showed a continuous decline in the number of recruits from 2006 to 2012 and an increase thereafter. F_{bar} (1-3) shows a continuously increasing trend from 2003 to 2008 and from 2013 to 2016 reaching the value of 1.42 in 2016. The current F (1.42) is much higher than $F_{0.1}$ (0.504), which indicates that European hake in GSA 20 was being over fished.

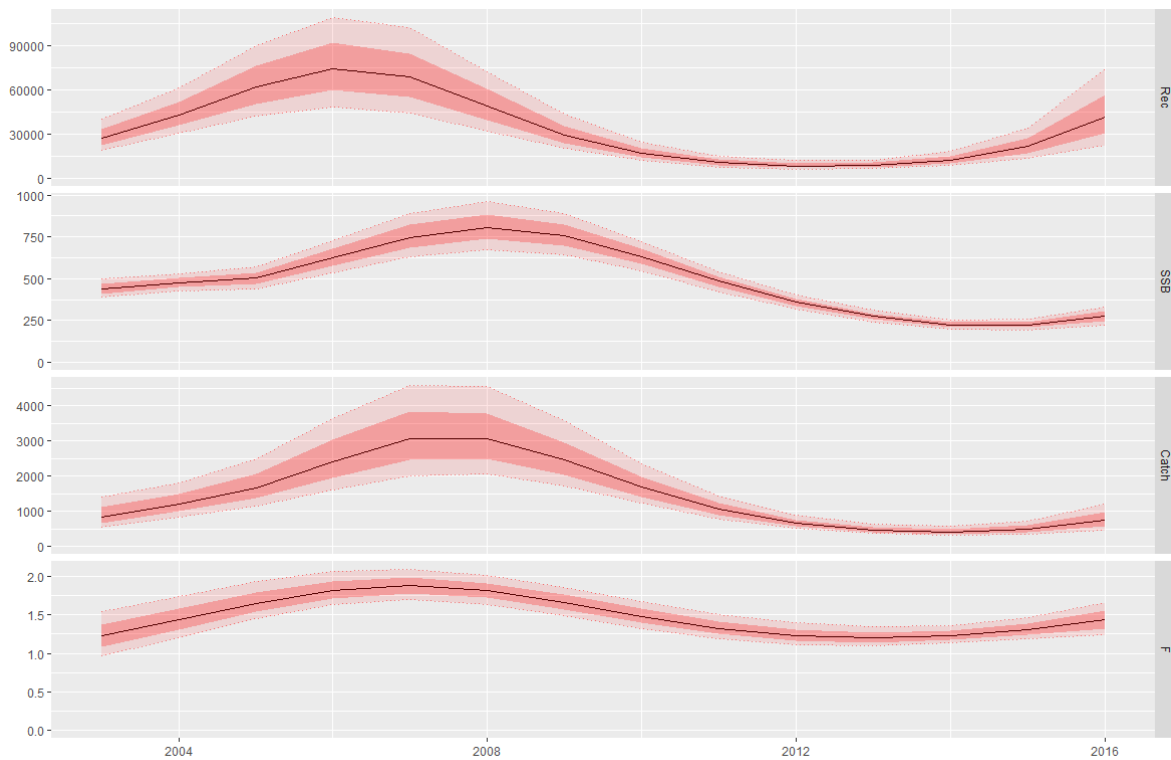


Figure A5.2.1. A4A assessment of European hake in GSA 20: main outputs with confidence intervals

3- European hake in GSA 22

Using data from catch data from 1970–2016, STECF used a surplus production (SPiCT, Figure A5.3.1) but found that this was uncertain and provided no evaluation of stock status. The stock's relative and absolute biomass showed declining trends in the last 10 years and 2016 biomass levels were estimated to be close to B_{msy} . However, the confidence intervals of the estimates are high. 2016 fishing mortality was estimated to be close to F_{msy} , and was observed to be at higher levels than those observed in the early 2000s. However, the confidence intervals of the estimates are wide, so these conclusions were weak, and STECF did not give advice on this stock.

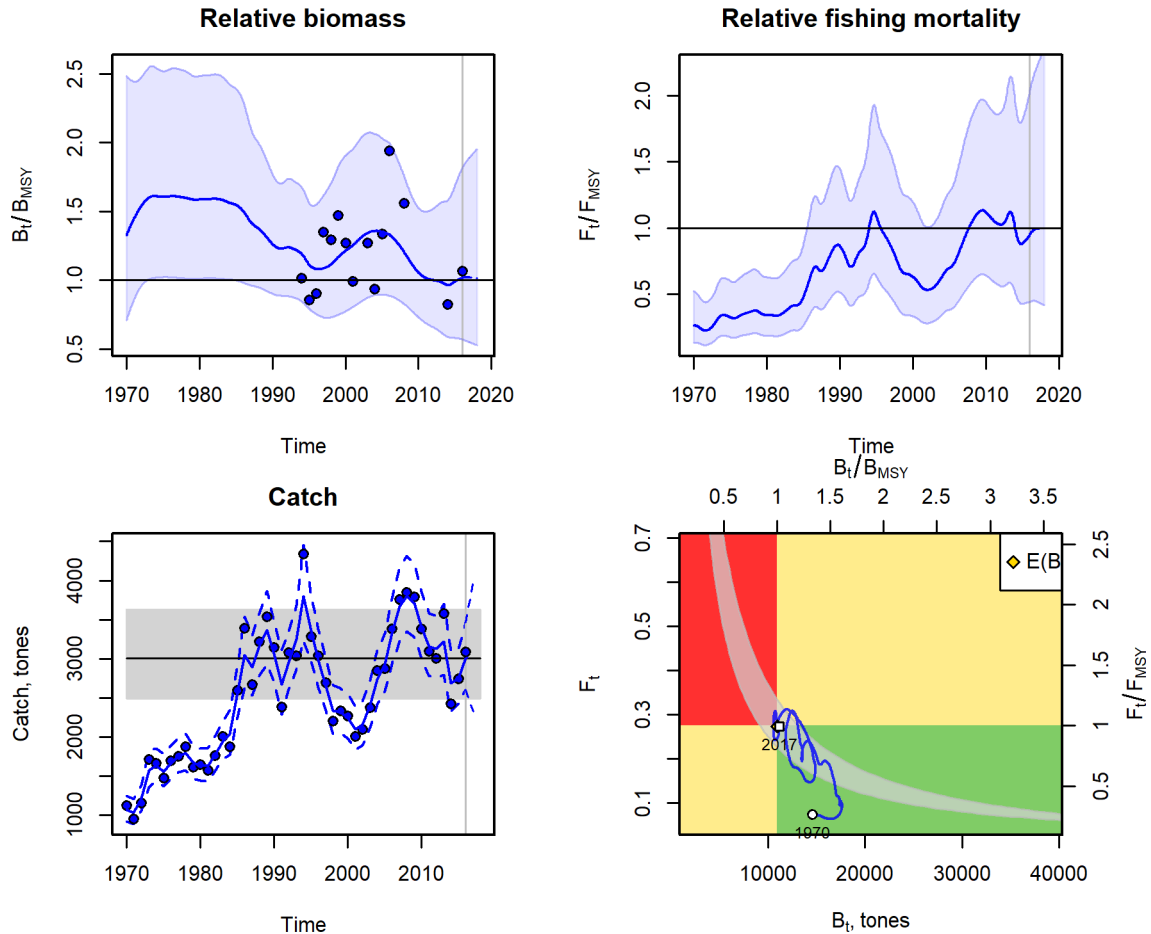


Figure A5.3.1. European hake in GSA 22

The upper row shows the absolute and relative biomass prediction with 95 percent CI (solid line) and observed biomass (points), i.e. abundance index scaled by catchability, q , and B_{msy} (left) and absolute and relative fishing mortality prediction with 95 percent CI (right). The bottom row features the observed (points) and predicted catch (solid line) with 95 percent CI (dotted lines) and average estimate of MSY (black solid line) with 95 percent CI (grey shaded area) (left) and the Kobe plot (right).

4- European hake in GSA 23

Using data from catch data from 1970–2016, STECF used a surplus production method (SPiCT, Figure A5.4.1) but found that this was uncertain and provided no evaluation of stock status. The stock's relative and absolute biomass showed declining trends in the last 10 years and 2016 biomass levels were below B_{msy} . However, this result was quite sensitive to the most recent observation of both, abundance index and landings value. The fishing mortality is generally increasing in the period 1970–2016. Currently, it is well above F_{msy} , although the uncertainty of this estimate was very high. However, the confidence intervals of the estimates are wide, so these conclusions were weak, and STECF did not give advice on this stock.

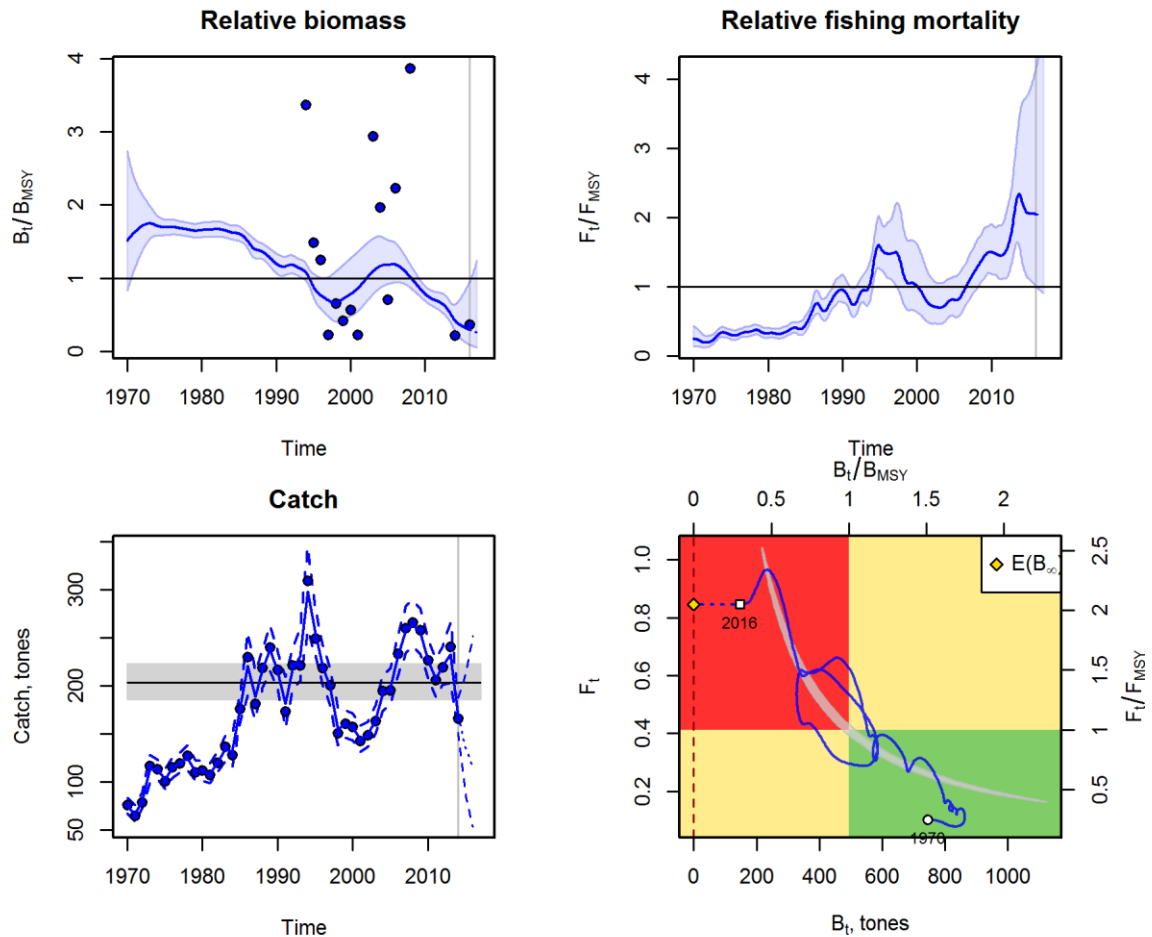


Figure A5.4.1. European hake in GSA 23

The upper row shows the absolute and relative biomass prediction with 95 percent CI (solid line) and observed biomass (points), i.e. abundance index scaled by catchability, q , and B_{msy} (left) and absolute and relative fishing mortality prediction with 95 percent CI (right), while the bottom row shows the observed (points) and predicted catch (solid line) with 95 percent CI (dotted lines) and average estimate of MSY (black solid line) with 95 percent CI (grey shaded area) (left) and the Kobe plot (right).

5- European hake in GSAs 1, 5, 6, and 7

Using data from 2007–2018 and age 0-5, STECF used an a4a assessment model to provide an assessment (Figure A5.5.1), a STF, and catch and F advice based on $F_{0.1}$ proxy for F_{MSY} . Catches and SSB of European hake show a decreasing trend from 2009 to 2016, with a slight increase in 2017 and 2018. The assessment shows a decreasing trend in the number of recruits in the time series, with the minimum value reached in 2014. F_{bar} (1-3) shows a sharp increasing to 2010 with a slight upward trend through to 2018 when estimated F is 1.84 as mean of last three years (2016–2018). The STECF accepted the a4a age based assessment and estimated $F_{0.1} = 0.38$ with $F/F_{MSY} = 4$.

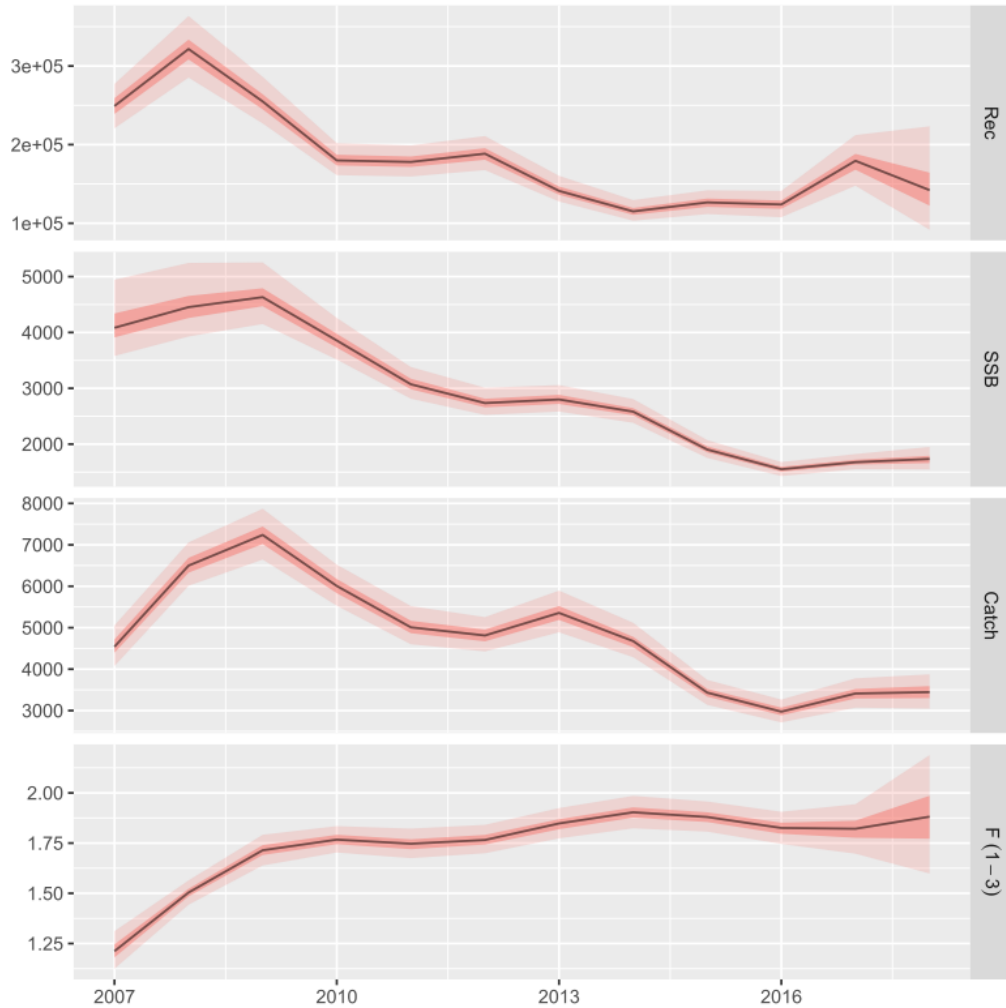


Figure A5.5.1. European hake in GSAs 1, 5, 6 and 7: trends in catch, recruitment, fishing mortality and SSB resulting from the a4a model

6- European hake in GSAs 9, 10, and 11

Using data from 2005–2018 and age 0-6, STECF used an a4a assessment model to provide an assessment (Figure A5.6.1), a STF, and catch and F advice based on $F_{0.1}$ proxy for F_{MSY} . Catches and SSB of European hake showed a decreasing trend in the whole time series. The assessment showed a decreasing trend in the number of recruits with the minimum value reached in 2017. $F_{bar}(1-3)$ showed a fluctuating pattern with a quite stable trend in the time series. $F_{0.1}$ was estimated as 0.22 and $F/F_{MSY} = 3.3$.

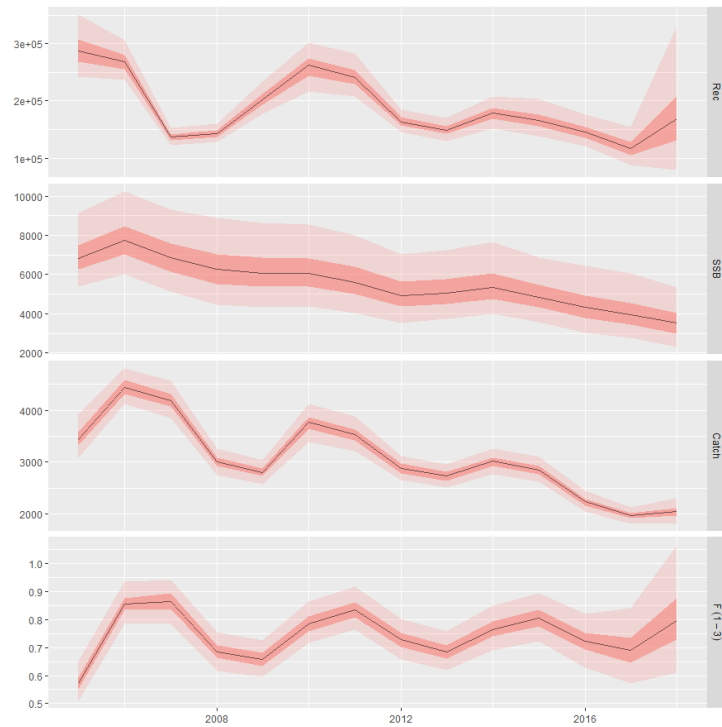


Figure A5.6.1. European hake in GSAs 9, 10 and 11: trends in catch, recruitment, and fishing mortality resulting from the a4a model