Stock Assessment Form of

Hake (*M. merluccius*) in combined GSA 12-16

Reference year: 2019

Reporting year: 2020

Merluccius merluccius, is a main species of fisheries in the central Mediterranean Sea (GFCM-GSA12-16). In this area, European hake is fished by 6 fishing fleet components: Italian coastal trawlers, Italian distant trawlers, Tunisian trawlers, Maltese trawlers, Tunisian and Italian artisanal vessels. Annual landings of hake 2019 was over 850 t from Italian and about over 1500 t from Tunisian trawlers . Hake is the main commercial by-catch species of deep water shrimp fisheries and a target species for artisanal vessels using longlines and gillnets. Trawlers catching hake exploit different species assemblages, the main target species being deep water rose shrimp (*Parapenaeus longirostris*), striped mullet (*Mullus surmuletus*) and red mullet (*Mullus barbatus)*. Size structures of hake catches range between 4 and 72cm total length (TL) for the Italian-Malta trawler, 6-68 (TL) for Tunisian trawler and 10-64 for Italian-Tunisian passive gear. (TL). the assessment was performed using Stock Synthesis (SS3) model (Methot & Wetzel 2013). The results showed that the stock was in overfishing and overfished condition.

tock Assessment Form version 1.0 (January 2014)

Uploader: *Fabio Falsone*

Stock assessment form

1 Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Merluccius merluccius	**[European hake]**	**[HKE]**
1st Geographical sub-area:	**2nd Geographical sub-area:**	**3rd Geographical sub-area:**
[GSA_12]	[GSA_13]	[GSA_14]
4th Geographical sub-area:	**5th Geographical sub-area:**	**6th Geographical sub-area:**
[GSA_15]	[GSA_16]	
1st Country	**2nd Country**	**3rd Country**
[TUNISIA]	[ITALY]	[MALTA]
4th Country	**5th Country**	**6th Country**
Stock assessment method: Indirect Method: Stock Synthesis (SS) model (Methot & Wetzel 2013).		

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2. Stock identification and biological information

2.1 Stock unit

The European hake *(Merluccius merluccius*, L. 1758) has a wide distribution from the coastal grounds to the high depth (up to 1000m), the larger individuals preferring the deepest waters. The stock structure of hake in the Strait of Sicily (south-central Mediterranean Sea) is still under investigation. Levi et al., (1994) compared the growth of *M. merluccius* from several Mediterranean areas and found a similar pattern in individuals from the northern side of the Strait of Sicily (GSA15 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 (GSA 12, 13 and 14). Lo Brutto et al., (1998) have also found no evidence of genetic subdivisions or significant differences in allelic frequencies, between samples near Sicily and those from the north Tunisia. Later, Levi et al., (2004) applied electrophoretic, morphometric and growth analyses to test the hypothesis of the existence of a unique stock of hake in the south-central Mediterranean, which includes part of the North African continental shelf off the Tunisian coast and the shelf off the southern Sicilian coast. While no significant differences were found in allozymes, morphometry and growth differ between north-western and south eastern sub-aeras.Milano et al., (2014), working with genetic markers able to identify fine population structure (SNPs), found a main difference between hake inhabiting Western, Central and Eastern Mediterranean. According to the multidimensional definition of stock followed in the STOCKMED project (Fiorentino et al., 2015), European hake of the Strait of Sicily would belong to a single population unit, extending from the Ligurian-North Tyrrhenian Sea (GSA 9) to eastern Ionian (GSA19). Taking into account of available literature and following a parsimonious approach, M. merluccius living in the GSAs 12, 13, 14, 15 and 16 was considered as a single stock unit for the GFCM management purposes.

2.2 Growth and maturity

M. merluccius is considered a long living species reaching at least 25year old (Vitale et al., 2016). However, Hake growth is still a matter of active debate in fishery biology, with some Authors proposing the so called low growth and other the fast growth. On the basis of a preliminary validation of age at size with bomb radiocarbon analysis (Vitale *et al.*, 2016), the so-called low growth hypothesis is considered as the most reliable for the species in the south-central Mediterranean.

***Table 2-2.1**: Maximum size, size at first maturity and size at recruitment.*

Somatic magnitude measured				**Units**	
Sex	**Fem**	**Mal**	**Combined**	**Reproduction**	all the year round
Maximum size observed	90	58		**Recruitment season**	all the year round
Size at first maturity	28.35			**Spawning areas**	Outer shelf and upper slope
Recruitment size to the fishery			8	**Nursery areas**	Identified in the north sector; under investigation in the southern sector

***Table 2-2.2**: M vectors by age (sex combined) according to different methods and corresponding mean of female used in SS3.*

Age	Gulland, 1987	Chen & Watanabe, 1989	Lorenz 1996	Abella et al., 1998 (2009)	Gislason et al., 2010	Brodziak et al., 2011	Mean
0.5	0.56	1.06	1.42	0.98	2.67	0.44	1.19
1.5	0.44	0.56	0.92	0.43	1.21	0.27	0.64
2.5	0.37	0.4	0.66	0.33	0.67	0.2	0.44
3.5	0.32	0.31	0.54	0.28	0.45	0.2	0.35
4.5	0.3	0.27	0.46	0.25	0.35	0.2	0.3
5.5	0.28	0.23	0.41	0.24	0.28	0.2	0.27
6.5	0.26	0.21	0.37	0.22	0.24	0.2	0.25
7.5	0.26	0.19	0.35	0.22	0.21	0.2	0.24
8.5	0.25	0.18	0.33	0.21	0.19	0.2	0.23
9.5	0.24	0.17	0.31	0.2	0.17	0.2	0.22
10.5	0.23	0.16	0.3	0.2	0.16	0.2	0.21
11.5	0.23	0.16	0.29	0.2	0.15	0.2	0.2
12.5	0.23	0.15	0.28	0.19	0.14	0.2	0.2
13.5	0.22	0.15	0.27	0.19	0.13	0.2	0.19
14.5	0.22	0.14	0.27	0.19	0.13	0.2	0.19
15.5	0.22	0.14	0.26	0.19	0.12	0.2	0.19
16.5	0.21	0.14	0.26	0.19	0.12	0.2	0.19
17.5	0.21	0.14	0.25	0.19	0.12	0.2	0.18
18.5	0.21	0.13	0.25	0.18	0.11	0.2	0.18
19.5	0.21	0.13	0.25	0.18	0.11	0.2	0.18
20.5	0.21	0.13	0.24	0.18	0.11	0.2	0.18

Table 2-2.3: *M vectors by age (sex combined) according to different methods and corresponding mean of male used in SS3.*

Age	Gulland, 1987	Chen & Watanabe, 1989	Lorenz 1996	Abella et al., 1998	Gislason et al., 2010	Brodziak et al., 2011	Mean
0.5	0.66	0.89	1.4	0.77	2.17	0.66	1.1
1.5	0.53	0.56	0.93	0.47	1.01	0.41	0.65
2.5	0.45	0.43	0.71	0.41	0.62	0.31	0.49
3.5	0.41	0.37	0.61	0.38	0.46	0.26	0.41
4.5	0.39	0.33	0.54	0.37	0.37	0.22	0.37
5.5	0.37	0.3	0.5	0.36	0.32	0.2	0.34
6.5	0.36	0.28	0.47	0.35	0.29	0.19	0.32
7.5	0.35	0.27	0.45	0.35	0.26	0.18	0.31
8.5	0.34	0.26	0.44	0.34	0.25	0.18	0.3
9.5	0.34	0.25	0.43	0.34	0.24	0.17	0.29
10.5	0.33	0.25	0.41	0.34	0.23	0.16	0.29
11.5	0.33	0.24	0.41	0.33	0.22	0.16	0.28
12.5	0.33	0.24	0.41	0.33	0.22	0.16	0.28
13.5	0.33	0.24	0.4	0.33	0.21	0.16	0.28
14.5	0.32	0.24	0.4	0.33	0.21	0.16	0.28
15.5	0.32	0.24	0.39	0.33	0.21	0.16	0.27
16.5	0.32	0.23	0.39	0.33	0.21	0.15	0.27
17.5	0.32	0.23	0.38	0.33	0.2	0.15	0.27
18.5	0.32	0.23	0.38	0.33	0.2	0.15	0.27
19.5	0.32	0.23	0.38	0.32	0.2	0.15	0.27
20.5	0.32	0.23	0.38	0.32	0.2	0.15	0.27

***Table 2.2-5**: Von Bertalanffy growth function and length weight relationship parameters.*

			Sex			
		Units	**Female**	**male**	**Combined**	**Years**
Growth model	**L_∞**	cm	100	55	100	
	K		0.12	0.23	0.116	
	t_0		-0.5	-0.5	-0.6	
	Data source	Tunisian and Italian data				
Length weight relationship	**a**		0.0054	0.006	0.004	
	b		3.08	3.05	3.15	
	M (scalar)				0.20	
	sex ratio (% females/total)	0.37				

3. Fisheries information

3.1 Description of the fleet

Hake is an important demersal species for commercial fisheries in the Strait of Sicily. It is the main commercial by-catch species of trawling targeting deep water rose shrimp and one of the target species for artisanal vessels using longlines and gillnets. In the Strait of Sicily, European hake is exploited by five main fishing fleet segments: Italian trawlers (coastal and distant trawlers), Tunisian trawlers, Maltese trawlers, Italian and Tunisian vessels using fixed nets and longlines. Sicilian coastal trawlers (270 registered vessels in 2018) operate mainly on short-distance fishing trips, which range from 1 to 2 days at sea, and fish e on the outer shelf and upper slope. While, Sicilian distant trawlers over 24 m in length (92 registered vessels in 2018), have longer fishing trips, which may have a duration of up to 4 weeks. These vessels operate offshore, in both Italian and international waters of the Central Mediterranean.

In Maltese Islands small vessels measuring 12 to 24 m in length target rose shrimp very close to land (around 6 km from the coast) at a depth of around 200 m. The number of trawlers targeting rose shrimp

decreased from 13 in 2011 to 8 in 2018. The activity is mainly carried out in winter, when the weather does not allow to fish in deeper waters. Tunisian trawl vessels fishing hake are around 24 m in length, and operate primarily in Northern Tunisia. The great majority of these catches are landed in the town of Bizerte and Kelibia. The number of Tunisian trawlers based in GSAs 12 has increased from 40 in 1996 to about 82 in 2018. Furthermore, about 100 trawlers move seasonally from GSA 14 and GSA 13 to fish DPS in GSAs 12.

***Table 3.1-1**: Description of operational units exploiting the stock.*

	Country	GSA	Fleet Segment	Fishing Gear Class	Group of Target Species	Species
Operational Unit 1	**ITA**	**16**	**T12 - Trawls**	**OTB**	**Demersal slope species**	**HKE**
Operational Unit 2	**ITA**	**16**	**P-07**	**GTR**	**Demersal species**	**HKE**
Operational Unit 3	**TUN**	**12-13-14**	**T12 - Trawls**	**OTB**	**Demersal slope species**	**HKE**
Operational Unit 4	**TUN**	**12-13-14**	**P-07**	**GTR-LLS**	**Demersal species**	**HKE**
Operational Unit 5	**MLT**	**15**	**T11 - Trawls**	**OTB**	**Demersal slope species**	**HKE**

***Table 3.1-2**: Catch and effort by operational unit in 2019.*

	Fleet (n of boats)	Hake Catch (in tons)	Other species caught (names and weight)	Hake discards (tons)	Discards (other species caught)	Effort (units)
Operational Unit 1	123	863		9		tons
Operational Unit 2		103				tons
Operational Unit 3		1530				tons
Operational Unit 4		62.8				tons
Operational Unit 5	10	10.6				tons
Total		2569.4		17.9		tons

3.2 Historical trends

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

- Italian landings: from 1947 to 2001, we used hake landings reported by ISTAT. From 2002 to 2019, we used data collected within the EU data collection framework (DCF);
- Tunisian landings: from 1950 to 2019 we used data provided by the official Tunisian landing statistics (Table 1).
- Maltese landings: from 2007 to 2019 we used data collected within DCF (Table1).

Time series showing the observed trends in landings are shown in fig. 3.2.1.

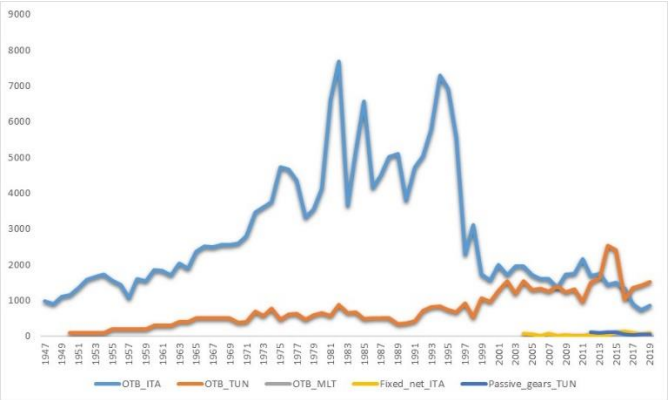


Figure 3.2-1 *–Catch of HKE from in the Strait of Sicily, (GSA12,13,14,15 and 16) by fleet and country(Italian trawlers, OTB_ITA and fixed net Fixed_net_ITA, Tunisian trawlers OTB_TUN and passive gears Passive_gears_TUN, Maltese coastal trawlers OTB_MLT) used in SS3 model.*

3.3 Management regulations

In the south-central Mediterranean, as in other Mediterranean areas, fishery management is based on control of capacity (number of fishing licenses), fishing effort (days at sea, number of vessels), and technical measures (cod-end mesh size for trawlers, temporary or permanent area closures and fish-size limits).

Currently, the Recommendation GFCM/42/2018/5 (repealing Recommendations GFCM/39/2015/2 and GFCM/40/2016/4) on the multiannual management plan for bottom trawl fisheries exploiting demersal stocks in the Strait of Sicily is adopted. This recommendation shall apply to bottom trawlers above 10 metres length overall with the aim to:

- Apply the precautionary approach to fisheries management;
- Ensure that exploitation levels of European hake and deep-water rose shrimp are at MSY by 2020 at the latest;
- Protect nursery areas and essential fish habitats that are important for the stocks of European hake and deep-water rose shrimp in the Strait of Sicily;

- Gradually eliminate discards, by avoiding and reducing, as far as possible, unwanted catches, and by ensuring that all catches are landed;
- Provide measures to adjust the fishing capacity of the fleets to levels of fishing mortality consistent with MSY, with a view to having economically viable fleets and without overexploiting marine biological resources.

Among the most important measures of this recommendations, there is the institution of three Fisheries Restricted Area, two inside the GSA 16 and one in GSA 15.

In Italy, at present a multiannual national plan is in force where the stock management is based on the reduction of fishing days. In particular, in 2018 the measures included the extension of a biological resting period up to 30 days while for the years 2019 and 2020 a reduction of fishing days by 5% and 10% respectively compared to the level observed in 2018 was established. In Italy as well as in Malta, as reported by Mediterranean Regulation EC 1967, the trawling activities are allowed at a distance greater than 3 miles and at a bathymetry deeper than 50 meters. However, Maltese trawling is allowed within the 25 miles only by vessels not exceeding an overall length of 24 m and only within designated areas. In addition, the Regulation above mentioned fixed a minimum mesh size of 40 mm square or 50 mm diamond for EU bottom trawling vessels (i.e. Italian and Maltese trawlers) and a minimum landing size for the hake of 20 cm total length.

In Tunisia, trawling is not permitted within 3 nautical miles from the coast and at less than 50 m depth in GSAs 12-14. Moreover, in GSA 14, a three-month closed season for trawling (from July to September) is in place. The objective of the measure is to protect recruits of a large number of species. In addition, a trawling ban of 11 months is in place in the Gulf of Tunis (GSA 12) and trawling in this area is allowed only during July. Also, minimum landing size of 20 cm total length in Tunisia has been established.

4 Fisheries independent information

4.1 MEDITS Trawl Survey

In order to collect fisheries independent data, according to the Regulation (EU) 2017/1004 on Data Collection Framework (DCF), the MEDITS (MEDiterranean International Bottom Trawl-Surveys) trawl survey is carried out in GSAs 15 & 16 on an annual basis. In July 2011 an inter-calibration experiment was carried out to standardize MEDITS indices from GSAs 15-16 with those of Tunisian surveys. A MEDITS campaign was carried out in the GSA 12 and 13 during 2019.

4.1.1 Brief description of the direct method used

Distribution, abundance and demographic information of the stock at sea were derived from data collected during the MEDITS trawl surveys carried out annually in the northern sector of the Strait of Sicily from 1994 to 2019 in spring/early summer. A total of 45 hauls in GSA 15 and 120 hauls in GSA 16 were performed yearly. The bottom trawl surveys covered an area of about 10,600 km^2 in GSA 15 and 34,000 km^2 in GSA 16 within a depth-range 10-800 m in both areas. The sampling design is random stratified with allocation of hauls proportional to strata extension (depth strata: 10-50 m, 51-100 m, 101-200 m, 201-500 m, 501-800 m). Roughly the same haul positions were kept each year. A GOC 73 gear is used with mesh size in the cod-end 20 mm opening and the vertical opening of the mouth of 2.4-2.9 m. More details on the MEDITS protocol is reported in the MEDITS-Handbook. Version n. 9 (2017).

4.1.2 Direct methods: trawl based abundance indices

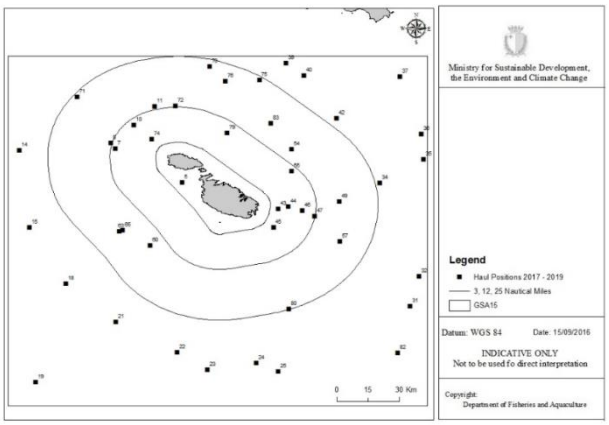
***Table 4.1.2.1**: Trawl survey basic information.*

Survey	MEDITS	**Trawler/RV**	TRAWLER
Sampling season	MAY-JULY		
Sampling design	Stratified with number of haul by stratum proportional to stratum surface (see MEDITS-Handbook. Version n. 9, 2017, MEDITS Working Group: 106 pp.)		
Sampler (gear used)	Bottom trawl made of four panels (IFREMER reference GOC 73)		
Cod –end mesh size as opening in mm	10 mm mesh size, which corresponds to ~ 20 mm of mesh opening		
Investigated depth range (m)	10-800m		

***Table 4.1-2**: Trawl survey sampling area and number of hauls (GSAs 15&16).*

Stratum	Total surface (km^2) GSA15	Total surface (km^2) GSA16	Trawlable surface (km^2) GSA16	Swept area (km^2) GSA16	Trawlable surface (km^2) GSA15	Swept area (km^2) GSA15	Number of hauls GSA 15	Number of hauls GSA 16
a	152	2979	2979	0.49	n.a	n.a	n.a	11
b	1473	5943	5943	1.06	n.a	n.a	n.a	23
c	3076	5563	5563	1.03	n.a	n.a	n.a	21
d	3353	6972	6972	2.79	n.a	n.a	n.a	27
e	2526	9927	9927	3.85	n.a	n.a	n.a	38
Total	**10580**	**31384**	**31384**	**9.23**	n.a	n.a	**45**	**120**

a)



b)

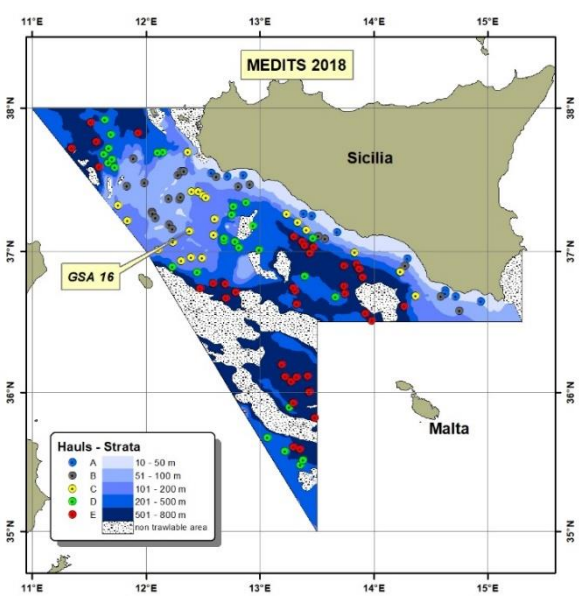


Figure 4.1.2.1*-Map of hauls positions from Medits survey in GSAs 15(a) &16 (b).*

***Table 4.1.2.2**: Trawl survey biomass results (GSAs 16 and 15).*

Depth Stratum(10-800 m	Kg/km2 (GSA 16)	CV Kg/km2 (GSA 16)	Kg/km2 (GSA15)	CV Kg/km2 (GSA15)
1994	34.9	20.4	n.a	n.a
1995	26.3	27.6	n.a	n.a
1996	15.4	21.8	n.a	n.a
1997	21.9	24.3	n.a	n.a
1998	15.8	16.8	n.a	n.a
1999	17	23.6	n.a	n.a
2000	24.5	22.4	n.a	n.a
2001	18	17.8	n.a	n.a
2002	20.6	22.8	n.a	n.a
2003	21.7	29.3	n.a	n.a
2004	28.8	27.1	n.a	n.a
2005	49.1	34.2	38.5	n.a
2006	37	21	31.8	n.a
2007	35.2	22.1	44.1	19.08
2008	38.4	38.6	51.6	13.86
2009	35	27.2	46.3	12.83
2010	38.7	26.2	25.2	12.92
2011	30.6	28.8	31.9	14.07
2012	46.5	21	41	15.54
2013	54.3	23.8	42.3	14.18
2014	44.37	31.4	49.3	14.24
2015	31.47	30.93	33.8	13.52
2016	25.7	30.2	28.65	13.06
2017	19.4	24.33	24.9	18.8
2018	22.4	28.6	29.9	21.04
2019	28.7	25.0	49.6	22.3

4.1.3 Spatial distribution of the resources

The spatial distribution of main Essential Fish Habitats in terms of stable nursery areas in the northern sector of the Strait of Sicily are well known (Fiorentino et al., 2003; Abella et al., 2008; Garofalo et al., 2011; Colloca et al., 2015). Data collected during MEDITS trawl survey were used to map the distribution of stable nurseries in GSA 15 and 16.

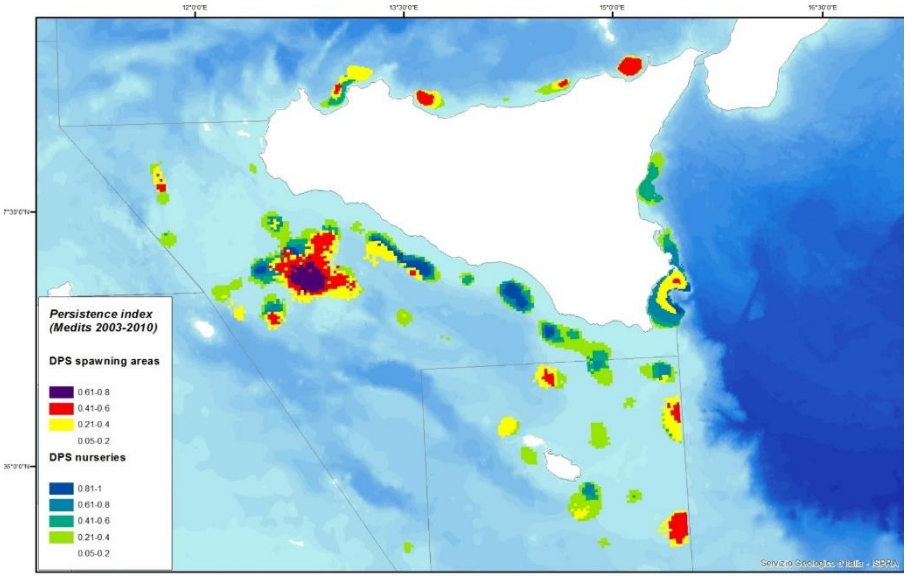


Figure 4.1.3.1: Temporal persistence of nursery areas of hake in GSAs 15-16, from MEDISEH - MAREA project (from Colloca et al., 2015).

A contribution to the identification of the spatial distribution of potential nurseries in the southern Strait of Sicily (SoS) was given by niche (Druon et al., 2015) and habitat (Garofalo et al, 2018) modelling. The probabilistic occurrence of recruits in the entire Strait of Sicily, according to GAM using depth and seafloor features as predictors, obtained by Garofalo et al. (2018) is reported in figure 4.1.2.2. This potential distribution, which was preliminary verified by Local Ecological Knowledge of high sea trawlers of Mazara del Vallo within the EU MANTIS project, needs to be validated by an ad hoc trawl survey program.

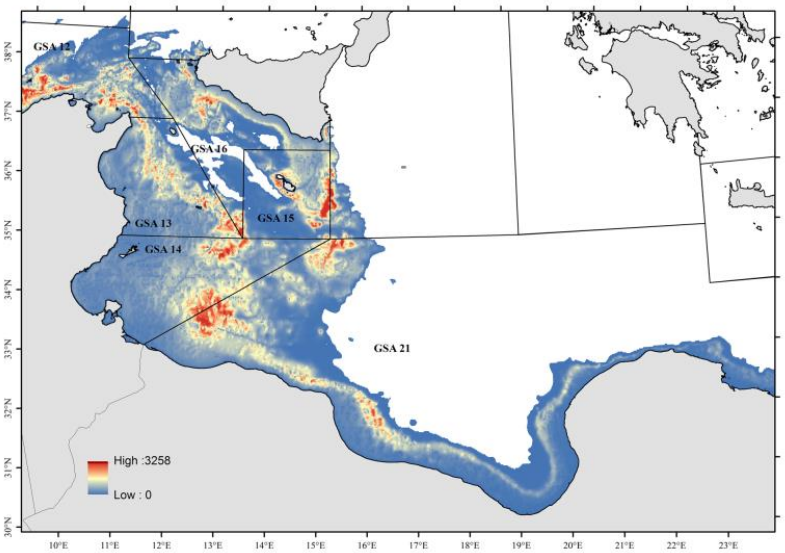


Figure 4.1.3.2: Probabilistic occurrence of Hake recruits according to GAM using depth and seafloor features as predictors (from Garofalo et al., 2018).

4.1.4 Historical trends

The trends in biomass and density of European hake (HKE) during the MEDITS survey in GSA 15 and GSA 16 showed large fluctuations showing a cyclic pattern in GSA 15 (Fig. 4.1.4.1).

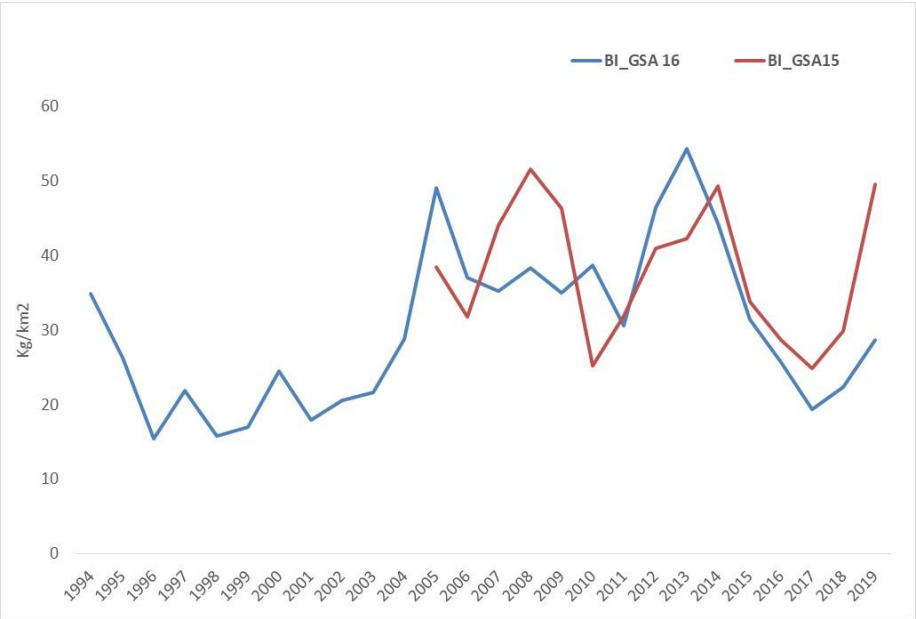


***Figure 4.1.4.1**: Medits Biomass Index (BI) in GSA15 & 16. Sex combined.*

5 Stock Assessment

Assessment of hake in GSAs 12-16 was conducted using the Stock Synthesis (SS) model (Methot & Wetzel 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.

5.1 Model assumptions

The assessment model of 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% of the average of three initial years (1947-1949) for all fleets. For the Italian-Tunisian passive gears an initial fishing mortality was not estimated as the fishery was assumed for simplicity to starts 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 & Wetzel 2013), which is the preferred method because hybrid F method has high gradients that limit pace of convergence when F is high.

5.1.1 Spawning stock biomass and recruitment

Spawning biomass was estimated at the beginning of the year and it was considered proportional to fecundity. 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 2019 (35 annual deviations). Recruitment deviates were assumed to have a standard deviation (σR) 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 σR were derived using the likelihood profile function in r4ss.

5.1.2 Growth and weights

Growth parameters were fixed for the whole period using values provided by MEDSUDMED working group (Gancitano et al., 2013) (Fig. 5.1.2.1). Numbers of fish in 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 (Amin) was estimated for both sex within the model. Parameters of the length-weight relationships (a and b) were from Gancitano et al. (2013).

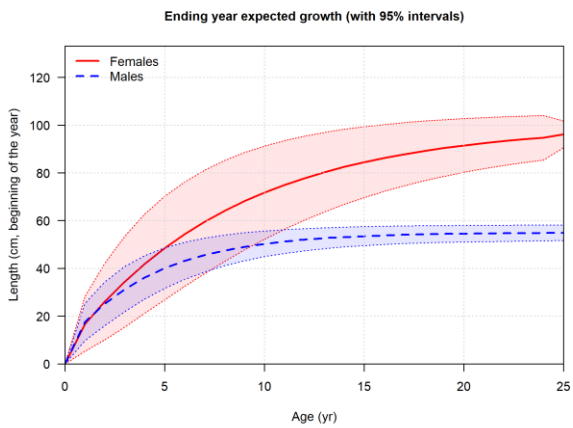


Figure 5.1.2.1 *Hake GSA 12-16. Growth curve used for the entire time series (1947 - 2019).*

5.1.3 Maturity

The values of L50% and the slope are assumed to be constant for the entire time period. The maturity ogives based macroscopic inspection of the gonads for female indicates that the onset of maturation (L50%) occurs at about 28 cm (Fig. 5.1.3.1).

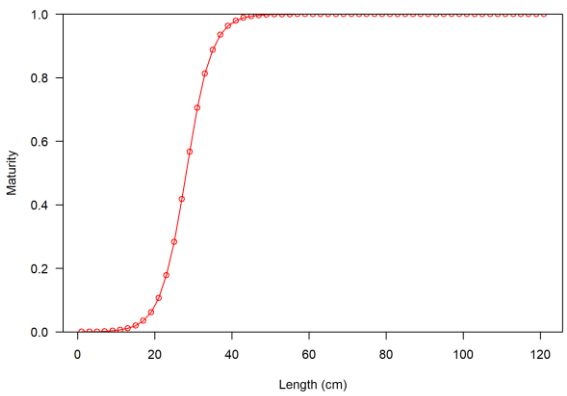


Figure 5.1.3.1 *Hake GSA 12-16. Length-based maturity ogive used for the entire time series (1947 - 2018).*

5.1.4 Natural mortality

Natural mortality at age is assumed to be constant for the entire time series (Figure 4, Table 1). For the assessment, an average of six different methods (Gulland (1987), Chen & Watanable (1989), Lorenzen (1996), Albella 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 (Fig.5.1.4.1). In order to reduce the number of parameters to be used in the model, natural mortality was set using 4 breaks: age 0, 1, 5 and 20, where M for the other ages is simply linearly interpolated using the values estimated for the age breaks.

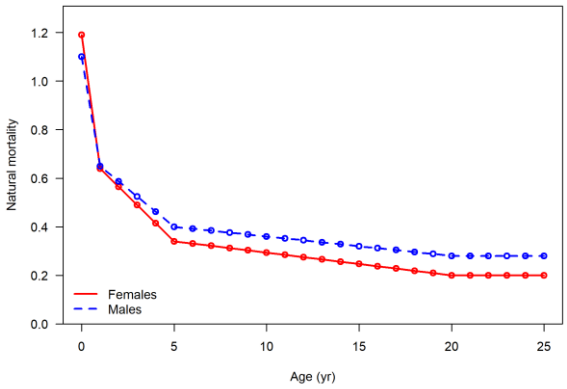


Figure 5.1.4.1 *Hake GSA 12-16. The age-specific natural mortality schedule used in the model.*

5.1.5 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 2019, while for Italian-Tunisian passive gears they were estimated between 2010 and 2019. 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 gears. 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 7 while in table 8 is reported the configuration of the reference model.

5.1.6 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 standard error 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 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.

5.2 Scripts

The scripts are available to the WG

5.3 Input data and Parameters

Table 5.3.1: *Fishery as used in the assessment model.*

Fishery	Data type	Fleet	Period
Italian-Maltese trawlers	Commercial landings (tons)	Italian trawlers	1947-2019
		Maltese trawlers	2009-2019
	Discards (tons)	Italian trawlers	2009-2019
	Length composition of commercial landings (N. thousand)	Italian trawlers	2009-2019
		Maltese trawlers	2009-2019
	Length composition of discards (N. thousand)	Italian trawlers	2009-2019
Tunisian trawlers	Commercial landings (tons)	Tunisian trawlers	1950-2019
	Length composition of commercial landings (N. thousand)	Tunisian trawlers	2007-2019
	Discards (tons)	Tunisian trawlers	2007-2019
Italian-Tunisian passive gears	Commercial landings (tons)	Italian fixed nets	2004-2019
		Tunisian passive gears	2014-2019
	Length composition of commercial landings (N. thousand)	Italian fixed nets	2010-2019
		Tunisian passive gears	2010-2019

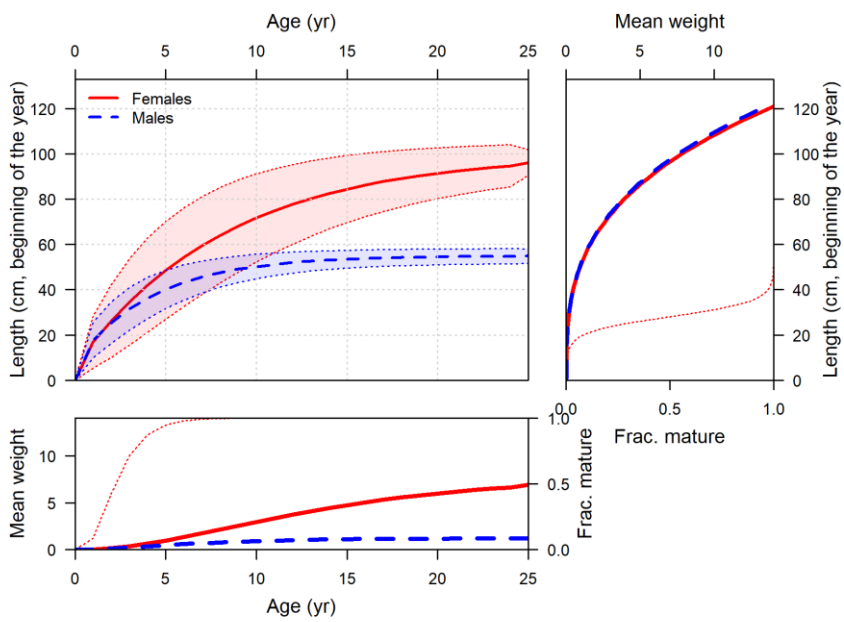


Figure 5.3.1: *Length at age (top-left panel) with weight (tick line) and maturity (thin line) show in the top-right panel and in the lower-left panel.*

Table 5.3.2: *Natural mortality vectors divided by breaks and sex used within the Stock Synthesis 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

Table 5.3.3: *Settings of the Stock Synthesis assessment model. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, the priors used. Parameters in bold are set and not estimated by the model.*

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)
Natural mortality (age classes 0, 1, 5, 20)		**Females: 1.19, 0.64, 0.34, 0.20** **Males: 1.10, 0.65, 0.40, 0.28**			
Stock and recruitment					
Ln(R_0)	1	12.5	(10, 15)	No_prior	12.08
Steepness (h)		**0.88**			
Recruitment variability (σ_R)		**0.50**			
Ln (Recruitment deviation): 1947 - 2018	72				
Recruitment autocorrelation		**0**			
Growth					
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)	No_prior No_prior	12.80 11.92
CV of young individuals		**Females: 0.37** **Males: 0.25**			
CV of old individuals		**Females: 0.03** **Males: 0.03**			
Weight (kg) at length (cm)					
a		**Females: 5.4e-06** **Males: 6e-06**			
b		**Females: 3.08** **Males: 3.05**			
Maturity					
Length (cm) at 50% mature		**28.1**			
Slope of the length at maturity ogive		**-0.3**			
Initial fishing mortality					
Fishery one	1	0.01	(0, 1.5)	No_prior	0.07
Fishery two	1	0.01	(0, 1.5)	No_prior	0.006
Selectivity (double normal)					
Fishery one					
Peak	1	20	(3, 35)	No_prior	29.6
Asc-width	1	2.0	(-2, 6)	No_prior	2.25
Desc-width	1	6	(5, 8)	No_prior	5.83
Fishery two					
Peak	1	20	(10, 30)	No_prior	21.87
Asc-width	1	3.0	(0, 6)	No_prior	3.56
Desc-width	1	6.0	(2, 10)	No_prior	6.56

Fishery three					
Peak	1	20	(3, 52)	No_prior	15.20
Asc-width	1	4.0	(0, 10)	No_prior	3.82
Desc-width	1	5.5	(3, 9)	No_prior	5.65
MEDITS survey					
Peak	1	5	(3, 8)	No_prior	5.00 (LO)
Asc-width	1	-9	(-14, 9)	No_prior	-11.98
Desc-width	1	-1	(1, 6)	No_prior	3.66
Catchability					
MEDITS survey					
Ln(Q) – catchability		**-3.46414**			
Extra variability added to input standard deviation		**0.001**			

5.4. Results

The stock status and the trends in SSB, R and F is based on the maximum likelihood estimation (MLE) model. The spawning stock biomass (SSB) is estimated to be below B_{MSY} since the middle of the 1980s. A slight recover in SSB in recent years has been estimated since the lowest value observed around 2000, although SSB has started to decline again in the last 2 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 F_{MSY} since the beginning of the 1980s. Recruitment (R) has been declining in concomitance to the decline in SSB and in 2019 the model estimates the lowest value over the entire time series (Figure 5.4.1 and table 5.4.1). Interesting, the develop of the SSB is mirroring very closely the develop of the fleet capacity of the main fleet (i.e. the Italian trawlers), which increased from just after WWII to the middle of the 1980s and decreased thereafter (Ben-Yehoyada et al., 2016).

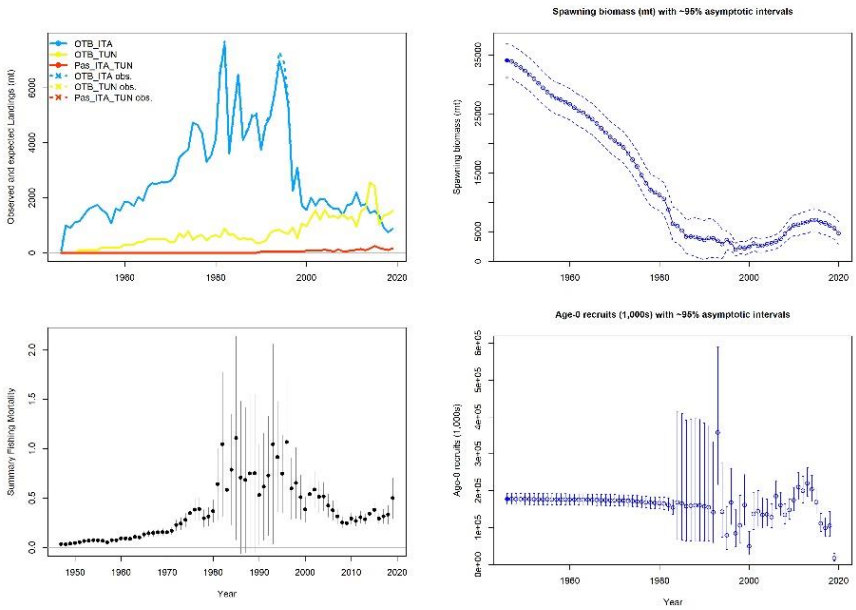


Figure 5.4.1: *Summary of the stock assessment for the final model agreed at the Benchmark. SSB, F and R with 95% confidence intervals. Catches by fleet are in tons.*

Table 5.4.1: *Summary table of the final model agreed at the Benchmark. Landings, discards and SSB are in tons. Recruitment is in 1000s individuals.*

Years	Landing estimated	Landing observed	Discard observed	SSB	sd	Recruitment	sd	F	sd
1947	990	990		33846.1	1443	177297	7725	0.034	0.004
1948	910	910		33328.1	1445	177202	7725	0.032	0.004
1949	1109	1109		32839.1	1441	177111	7725	0.040	0.005
1950	1246	1246		32262.1	1436	176999	7723	0.046	0.005
1951	1464	1464		31639	1428	176874	7722	0.056	0.006
1952	1686	1686		30937.3	1420	176727	7720	0.065	0.008
1953	1772	1772		30164.8	1412	176558	7719	0.070	0.008
1954	1840	1840		29403.8	1404	176383	7717	0.074	0.009
1955	1761	1761		28674.4	1395	176207	7715	0.072	0.008
1956	1635	1635		28058.7	1386	176052	7713	0.068	0.008
1957	1273	1273		27584.1	1378	175928	7712	0.053	0.006
1958	1811	1811		27378.7	1370	175873	7710	0.075	0.008
1959	1735	1735		26950.8	1367	175756	7710	0.072	0.008
1960	2163	2163		26599.4	1363	175657	7709	0.091	0.010
1961	2132	2132		26053.8	1362	175498	7710	0.092	0.010
1962	2000	2000		25548.8	1360	175345	7710	0.087	0.010
1963	2437	2437		25155.8	1357	175222	7711	0.108	0.012

1964	2293	2293		24569.6	1357	175032	7712	0.103	0.011
1965	2879	2879		24090.3	1355	174870	7713	0.133	0.015
1966	3027	3027		23336.3	1355	174602	7717	0.144	0.017
1967	3005	3005		22529.4	1356	174296	7722	0.148	0.017
1968	3066	3067		21783.1	1356	173994	7726	0.154	0.018
1969	3058	3059		21067.6	1355	173686	7732	0.157	0.018
1970	2984	2985		20423.4	1354	173391	7737	0.155	0.019
1971	3215	3216		19891.2	1353	173134	7742	0.169	0.021
1972	4170	4172		19309.7	1353	172837	7748	0.228	0.028
1973	4183	4185		18262	1357	172259	7767	0.243	0.031
1974	4549	4552		17222	1362	171619	7791	0.280	0.036
1975	5205	5210		16051.7	1365	170807	7826	0.349	0.050
1976	5262	5267		14596.9	1372	169630	7890	0.385	0.057
1977	4997	5002		13210.1	1373	168287	7971	0.390	0.060
1978	3776	3779		12072.1	1370	166975	8059	0.295	0.045
1979	4134	4138		11669	1370	166454	8083	0.313	0.047
1980	4765	4772		11237.1	1371	165859	8125	0.369	0.057
1981	7126	7201		10545.7	1375	164816	8226	0.642	0.184
1982	8464	8575		8704.62	1461	161327	8696	1.046	0.372
1983	4278	4306		6325.23	1480	154289	10077	0.584	0.202
1984	5794	5855		5960.28	1478	167914	81834	0.788	0.286
1985	6958	7062		5190.73	1428	164721	80708	1.110	0.526
1986	4619	4665		4168.14	1440	157820	77117	0.709	0.394
1987	4957	5014		4148.41	1581	159010	77459	0.683	0.376
1988	5456	5531		4073.99	1694	159964	77922	0.749	0.411
1989	5362	5443		3815.53	1712	159114	77457	0.751	0.407
1990	4164	4213		3620.2	1683	156768	75361	0.532	0.259
1991	5114	5199		3927.01	1715	154356	74037	0.617	0.277
1992	5688	5795		3869.13	1646	140991	64998	0.728	0.308
1993	6671	6646		3469.54	1483	357171	92821	1.046	0.517
1994	7853	8178		2919.59	1250	142789	48833	0.917	0.285
1995	7155	7715		3552.72	800	78898.7	28251	0.747	0.200
1996	6088	6281		3142.82	714	167690	37759	1.068	0.324
1997	3213	3241		1985.68	562	84185.9	24774	0.598	0.158
1998	3649	3696		2351.02	536	105718	31462	0.655	0.184
1999	2818	2829		2214.63	553	160946	34297	0.510	0.113
2000	2613	2618		2431.14	587	48873.3	15477	0.386	0.066
2001	3367	3368		2998.85	596	136577	25413	0.541	0.091
2002	3338	3332		2661.13	596	144214	24535	0.587	0.095
2003	3247	3240		2614.72	573	133781	20795	0.513	0.081
2004	3630	3618		2896.22	588	135486	18492	0.517	0.074
2005	3108	3101		3038.36	602	128063	16464	0.425	0.059
2006	2995	2980		3344.51	628	184958	19221	0.377	0.049
2007	2992	2984		3787.74	666	160368	15891	0.315	0.039
2008	2841	2825		4634.77	738	134473	13666	0.254	0.029
2009	3040	3032	185	5554.26	826	147494	14028	0.246	0.024
2010	3172	3161	243	6075.23	883	174289	15951	0.293	0.029

2011	3253	3239	902	6182.32	915	209688	18753	0.270	0.026
2012	3369	3361	297	6482.93	941	199337	18178	0.307	0.031
2013	3503	3497	204	6651.51	964	220181	19553	0.286	0.027
2014	4164	4138	47	6977.2	980	203200	17979	0.342	0.032
2015	4190	4185	109	6986.38	989	168802	16438	0.381	0.036
2016	2560	2565	134	6600.44	988	111064	12578	0.292	0.030
2017	2396	2399	61	6407.06	978	98908.6	12589	0.315	0.037
2018	2261	2274	18	6034.17	964	105085	16686	0.333	0.048
2019	2562	2569	9	5621.01	969	16616.8	5147	0.500	0.107
2020				4744.15	1006				

5.5 Retrospective analysis

The SS3.3 framework allows to carry on the retrospective analysis, the results are showed in the figure below (Figure 5.5.1). The retrospective analysis was carried out considering the removals of five years. The Mohn's rho index (Mohn, 1999) values were (SSB: 0.19) in the limits as suggested in Hurtado-Ferro (2015) for long lived species as hake (-0.15 - 0.20)

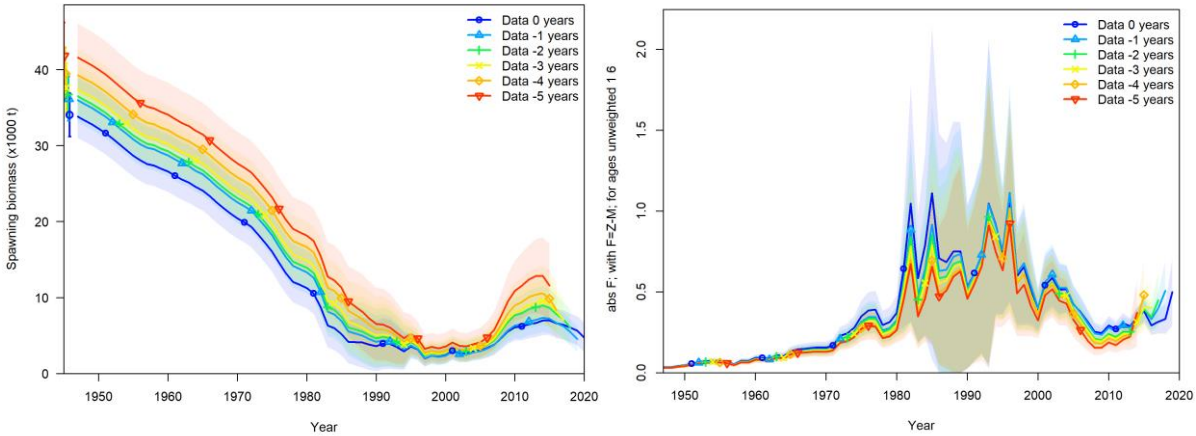


Figure 5.5.1: *Retrospective analyses of the final model*

5.6 Comparison among the benchmark assessment and the update 2019 assessment

This assessment represents an updated stock assessment of the benchmark model presented last year. The inclusion of 2019 does not change the performance of the model, that appears still stable. Figure 5.6.1 shows the comparison between the estimated SSB, recruitment and F among the benchmark assessment and the update 2019 assessment.

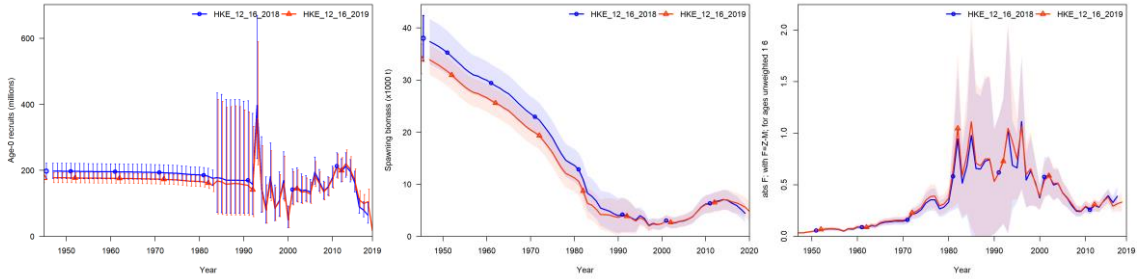


Figure 5.6.1: *Comparison of the estimated Recruitment, SSB and fishing mortality among the benchmark assessment (blue line), the assessment updated in 2019 (red line)*

5.7 Stock predictions

5.7.1 Short term predictions (SS3)

The short term results are showed in figure 5.7.l.1 and in table 5.7.1.1. The short term was run applying different fishing catch options (i.e. catch at 10%, 30%, 40%, 50% 70% and 100% of the catches in 2019).

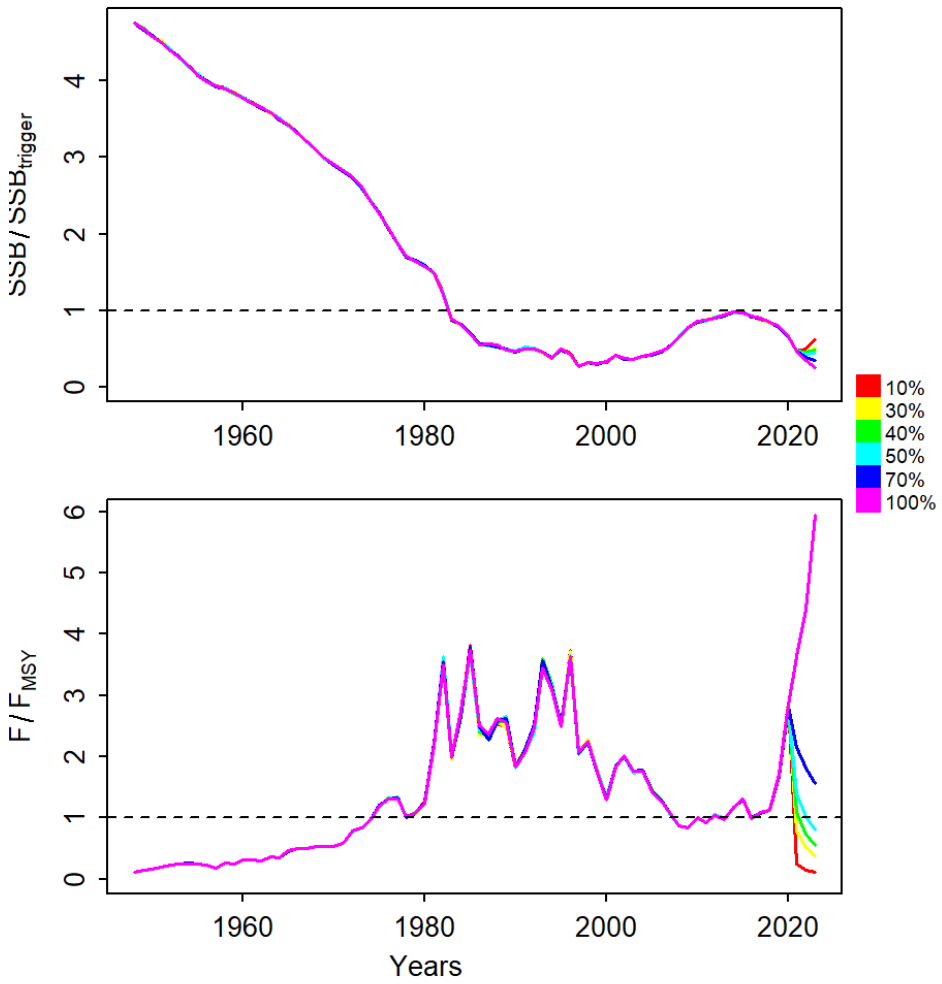


Figure 5.7.1.1: *Stochastic forecast conducted applying different fishing catch options. In the upper the trend of spawning biomass (SSB) relative to* $SSB_{trigger}$ *(*$SSB_{trigger}$*=*SSB_{MSY}*), while in the below the*

trend of F relative to F_{MSY}.

Table 5.7.1.1: *Short term forecast table. Catch % is the catches expressed as proportion of the catches estimated for 2019.*

Catch %	Year	SSB	Catch	F
10	2021	3385	257	0.242
10	2022	3489	257	0.139
10	2023	4311	257	0.100
30	2021	3338	771	0.792
30	2022	3231	771	0.499
30	2023	3681	771	0.367
40	2021	3245	1028	1.106
40	2022	3159	1028	0.738
40	2023	3424	1028	0.558
50	2021	3256	1284	1.385
50	2022	3081	1284	1.027
50	2023	3081	1284	0.812
70	2021	3310	1798	2.162
70	2022	2772	1798	1.827
70	2023	2573	1798	1.556
100	2021	3324	2569	3.508
100	2022	2433	2569	4.401
100	2023	1766	2569	5.801

5.8 Draft scientific advice

The results of the model indicated that the stock of European hake is in overexploitation and overexploited

Based on	Indicator	Analytic al reference point (name and value)	Current value from the analysis (name and value)	Empirical reference value (name and value)	Trend (time period)	Stock Status
Fishing mortality	Fishing mortality	F_{MSY} = 0.29	F_{curr} =0.50 F/F_{MSY} = 1.72		I	IO
	Catch				N	

Stock abundance	SSB (tons)	BMSY=7021	$B_{curr.}$=4744 B/BMSY = 0.68	$SSB_{current\ SS3}$	4744	O
Recruitment				Rec 2019 SS3=16616.8 thousand		
Final Diagnosis		The stock status in overexploitation and overexploited.				

10 Explanation of codes

Trend categories

1) N - No trend
2) I - Increasing
3) D – Decreasing
4) C - Cyclic

Stock Status

Based on Fishing mortality related indicators

1) **N - Not known or uncertain** – Not much information is available to make a judgment;
2) **U - undeveloped or new fishery** - Believed to have a significant potential for expansion in total production;
3) **S - Sustainable exploitation**- fishing mortality or effort below an agreed fishing mortality or effort based Reference Point;
4) **IO –In Overfishing status**– fishing mortality or effort above the value of the agreed fishing mortality or effort based Reference Point. An agreed range of overfishing levels is provided;

Range of Overfishing levels based on fishery reference points

In order to assess the level of overfishing status when $F_{0.1}$ from a Y/R model is used as LRP, the following operational approach is proposed:

- If $Fc^*/F_{0.1}$ is below or equal to 1.33 the stock is in **(O_L): Low overfishing**
- If the $Fc/F_{0.1}$ is between 1.33 and 1.66 the stock is in **(O_I): Intermediate overfishing**
- If the $Fc/F_{0.1}$ is equal or above to 1.66 the stock is in **(O_H): High overfishing**

*Fc is current level of F

5) **C- Collapsed**- no or very few catches;

Based on Stock related indicators

1) **N - Not known or uncertain:** Not much information is available to make a judgment
2) **S - Sustainably exploited:** Standing stock above an agreed biomass based Reference Point;
3) **O - Overexploited**: Standing stock below the value of the agreed biomass based Reference Point. An agreed range of overexploited status is provided;

Empirical Reference framework for the relative level of stock biomass index

- **Relative low biomass:** Values lower than or equal to 33rd percentile of biomass index in the time series **(O_L)**
- **Relative intermediate biomass:** Values falling within this limit and 66th percentile **(O_I)**
- **Relative high biomass:** Values higher than the 66th percentile **(O_H)**

4) **D – Depleted**: Standing stock is at lowest historical levels, irrespective of the amount of fishing effort exerted;
5) **R –Recovering:** Biomass are increasing after having been depleted from a previous period;

Agreed definitions as per SAC Glossary

Overfished (or overexploited) *- A stock is considered to be overfished when its abundance is below an agreed biomass based reference target point, like B0.1 or BMSY. To apply this denomination, it should be assumed that the current state of the stock (in biomass) arises from the application of excessive fishing pressure in previous years. This classification is independent of the current level of fishing mortality.*

Stock subjected to overfishing (or overexploitation) *- A stock is subjected to overfishing if the fishing mortality applied to it exceeds the one it can sustainably stand, for a longer period. In other words, the current fishing mortality exceeds the fishing mortality that, if applied during a long period, under stable conditions, would lead the stock abundance to the reference point of the target abundance (either in terms of biomass or numbers)*