Stock Assessment Form
Demersal species

Reference year: 2023

Reporting year: 2024

Stock status: Possibly overexploited.

Advice and recommendations: Reduce fishing mortality.

WG comments: Update assessment based on CMSY.

Assessment and advice summary: the group considers the assessment update consistent with previous advice validating the CMSY model for qualitative advice. Sensitivity analysis on time series (long vs short), priors (B/k), and intermediate year were performed as suggested during the data preparation meetings, proving the suitability of current model settings. According to the last year assessment, model started in 1972 with the same settings of last year. The fishing pressure (F) is reducing in the last years but it still within an unsustainable level; the current biomass is critically low exceeding historic lows in the last 2/3 years. The overall results were consistent with those found using LBSPR. The model passed all the diagnostics, and no particular trends are evidenced in residuals; the retrospective models are in accordance providing further evidence of model robustness. As suggested by WGSAD_2023, a SPiCT model was also developed estimating very similar F and biomass values with slightly different outcomes for reference point; the group suggested to allocate a further effort within the SPiCT settings' investigation, particularly the development of a seasonal model aimed to better catch the stock dynamics over years was recommended. Overall, the difficulties to date in the assessment of cephalopods species due to its typical traits (e.g. short living species), uncertainties in the growth rate especially among different areas, and unknow environmental effects on cephalopods stocks dynamics were flagged by the group.

Stock Assessment Form version 1.0

Uploader: *Matteo Chiarini*

Stock assessment form

1 Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Eledone cirrhosa	Horned octopus	57
1st Geographical sub-area:	2nd Geographical sub-area:	3rd Geographical sub-area:
18		
4th Geographical sub-area:	5th Geographical sub-area:	6th Geographical sub-area:
1st Country	2nd Country	3rd Country
Italy	Montenegro	Albania
4th Country	5th Country	6th Country
Stock assessment method: (direct, indirect, combined, none)		
Indirect: BSM-CMSY		
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2 Stock identification and biological information

2.1 Stock unit

The Horned octopus *Eledone cirrhosa* can be found throughout the Mediterranean Sea and in the north-eastern Atlantic. The northern limit of distribution is about 66-67 °N, while the southern limit is in the latitudes of the Moroccan coast. In the southern Adriatic, is it more abundant than the congeneric *E. moschata* (while the opposite is observed in the North Adriatic). The distribution area of these two species partly overlaps, and they are often commercialised together. The horned octopus lives in depths from 25 to 400 m, but it is most abundant over 75 m (Casali *et al.*, 1998). In the southern Adriatic, it is found on muddy sediments in the depth range from 40 to 200 m along the Montenegrin coast (Mandić, 1984) and in a similar range along the Italian coast (Pastorelli *et al.*, 1998). The stock structure of this species in the Mediterranean is not clear. The STOCKMED project assessed the stock structure of *E. cirrhosa*, among other species, to identify plausible stock units. Although the methods suggested subdivision into six units at Mediterranean level, the results were considered not robust enough for proposing new reliable stock units. This assessment focuses on GSA 18 (Figure 2.1-1), assumed to be a unitary stock.

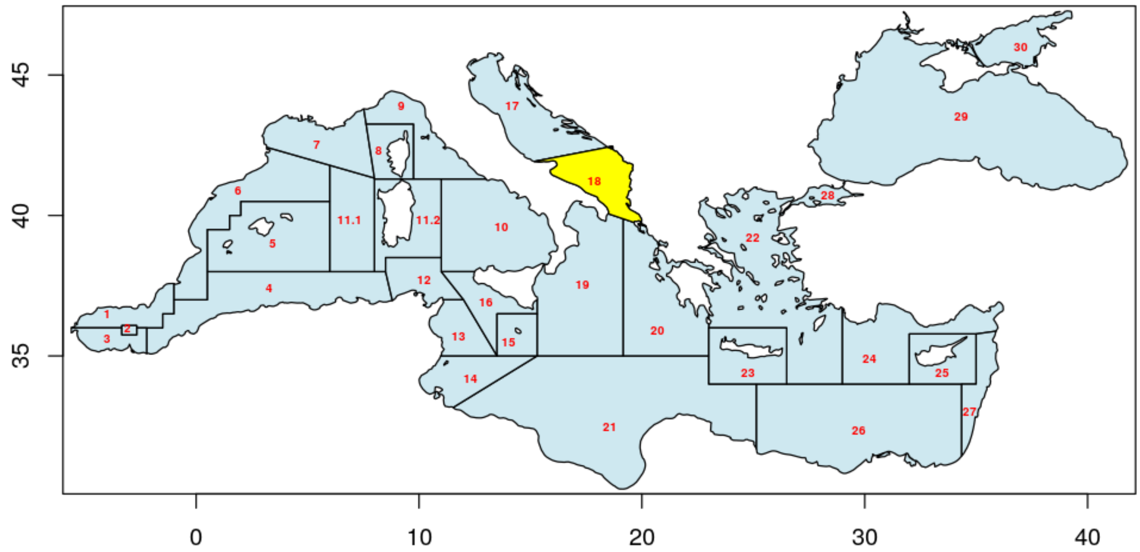


Figure 2.1-1. *FAO Geographical Subdivisions (GSAs). GSAs 18 is highlighted in yellow.*

2.2 Growth and maturity

The horned octopus is a semelparous species, reproducing only once during its lifetime and dying shortly after. Belcari et al. (2002) and Orsi Relini et al. (2006) identify multimodal length frequency distributions and, therefore, relatively long life span up to three years of life. The spawning peak takes place in summer (Donnaloia *et al.*, 2010), while during autumn there are few mature and large specimens defined as “late spawners” (Orsi Relini *et al.*, 2006; Cuccu *et al.*, 2022). The appearance of the recruits of *E. cirrhosa* was recorded in January. The recruits shared coastal bottoms with a cohort of adults for 6 months. After June the adults disappear moving to spawning grounds (Orsi Relini *et al.*, 2006). In the Adriatic, the proportion of young specimens (under 6 cm of mantle length, ML) is highest in the autumn period (Pastorelli *et al.*, 1998). Donnaloia et al. (2010) estimated the size at first maturity of both sexes and analysed the maturity cycle in the South Adriatic, observing that immature individuals were predominant during the autumn-winter period (62-100% from October to May for females; 66-95% from October to January for males), while in spring-summer the occurrence of mature or maturing individuals was higher (89-100% from June to August for females; 74-97% from March to August for males). The lengths at first maturity of females and males (Figure 2.2-1) were respectively 9.7±0.06 (MR= 1.5±0.07 cm) and 7.8±0.05 cm (MR= 1.4±0.07 cm).

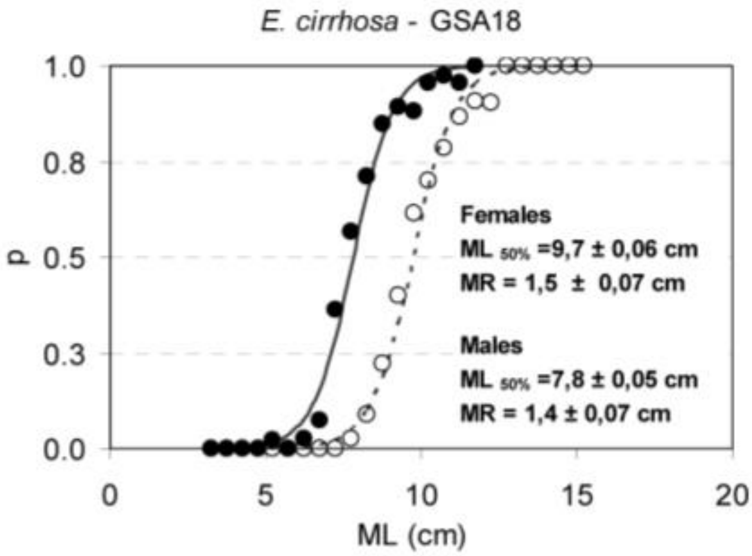


Figure 2.2-1. *Maturity ogives of females (open circles) and males (closed circles) in GSA 18. Source: Donnaloia et al., 2010.*

Table 2.2-1: *Maximum size, size at first maturity and size at recruitment.*

Somatic magnitude measured (LT, LC, etc)				**Units**	cm
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	**Summer**
Maximum size observed			17.5	**Recruitment season**	**Autumn**
Size at first maturity	9.7(±0.06)	7.8(±0.05)		**Spawning area**	
Recruitment size to the fishery			2	**Nursery area**	

Table 2.2-2: Growth and length weight model parameters

			Sex			
		Units	**female**	**male**	**Combined**	**Years**
Growth model	**ML∞**	cm	21	15.6		
	K	$year^{-1}$	0.387	0.422		
	t_0	year	-0.028	-0.071		
	Data source	GSA 18, ITA (DCF data call 2023)				
Length weight relationship	**a**	cm/g	0.3277	0.2903		
	b	-	2.8684	2.9009		
	M (scalar)					
	sex ratio (% females/total)					

3 Fisheries information

3.1 Description of the fleet

The horned octopus is a commercially important species. It is fished mainly with bottom trawl nets. Catch from gillnets and other artisanal gears are minor. The gillnet and set net catch recorded in DCF Italian 2020 data accounts for 0.25%, while demersal trawlers account for 99.75%. From 2021, 100% of Italian landings come from demersal trawlers. The CPUE shows a distinct seasonality with the biggest catches occurring in spring months (Pastorelli, 1995). On the market, horned octopus often appears mixed with *E. moschata*, therefore misreporting between the two species cannot be excluded.

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*	Italy	GSA18	T10-T11-T12	OTB	57	Horned octopus
Operational Unit 2	Italy	GSA18	P05-P06-P07-P08	GNS	57	Horned octopus
Operational Unit 3	Italy	GSA18	P05-P06-P07-P08	GTR	57	Horned octopus
Operational Unit 4	Montenegro	GSA18	T10-T11	OTB	57	Horned octopus
Operational Unit 5	Albania	GSA18	T10-T11	OTB	57	Horned octopus

Table 3.1-2: Catch, bycatch, discards and effort by operational unit in the reference year (2023)

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 (Fishing days)
Operational Unit 1		277.1		0		
Operational Unit 2				0		
Operational Unit 3				0		
Operational Unit 4				0		
Operational Unit 5		45.2		0		
Total		322.3		0		

3.2 Historical trends

Landing records of the horned octopus GSA 18 from Italy, Montenegro and Albania are available (Table 3.2-1). For the Italian fleets, landings are available from 2004 to 2023. Discards recorded for the Italian fleet was only available for one year and one fleet segment, and in negligible amount (0.8% of catch). Catches were thus assumed identical to landings. Differences in the amount of Italian landings among different datasets were identified in 2020, 2021 as result of the updated DCRF data call (i.e. following the GSA of origin; Figure 3.2-1); analysis conducted during the data preparation meeting showed a mean reduction around 10% of reported landings (Reference year 2023). Historical landing (1972-1999) for the Italian fleet were obtained from ISTAT for GSA18. These landing values were recorded as *E. cirrhosa* however are, with all likelihood, a mixture of the two species of *Eledone*. As such, the landing for *E. cirrhosa* were reconstructed based on the reported landings, downweighed with a ratio of the catches of *E. cirrhosa/E. spp.* This ratio was calculated using DCF landing data in GSA 18 for the two species, averaging across the closest five years (2004-2009). The ratio was fairly stable in the years for which both species are available (2004-2019). The ratio is thus likely to reflect well the historical proportion of the two species in the landing. The ratio in the catches was considered to be a better proxy of proportion in the catches compared with the ratio of biomass from the survey, as the survey is considered to capture *E. moschata* less efficiently than *E. cirrhosa*. For the years 2000-2003 for which no landing data are available, the missing values were estimated using a 5-year moving average (Figure 3.2-2, Table 3.2-1). Montenegrin catch data in Fishstat are available only as aggregate *Eledone spp.* between 2006 and 2017. To estimate the proportion in the catch, the median 2006-2019 proportion of *E. cirrhosa* over the two species (47%) in the Italian DFC landings was used to extrapolate catch of *E. cirrhosa* in Montenegrin data. Novel data for the years 2018-2023 were obtained, replacing the assumption of constant catches used in the previous years' assessment. Landings for 2004 and 2005 were assumed identical to the values in 2006. No information about discards was available for Montenegro. Albania recorded landing information for this species only since 2019. The declared catches, reported as *Eledone spp*., are likely to be a mixture of the two species, thus the same criteria for estimating catches for *E. cirrhosa* as for Montenegrin data was applied.

The length frequency distributions in the catch (Figure 3.2-3) were obtained (for Italian landings) for the years 2008-2023. No LFD data were available before 2008 as this species was not a DCF target species until that year.

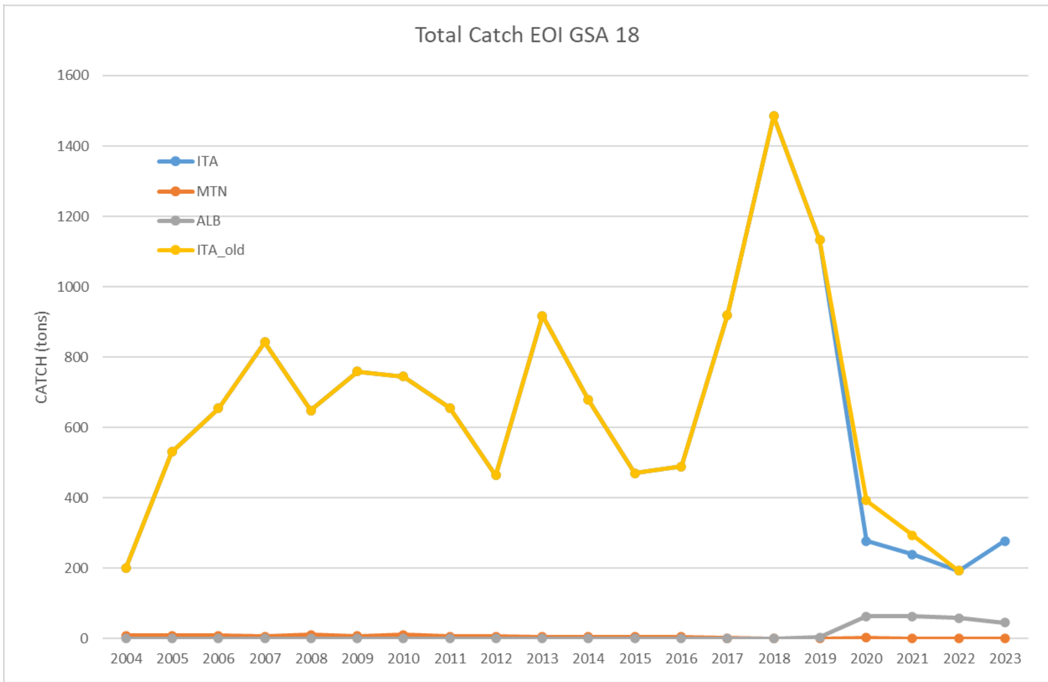


Figure 3.2-1. *Catches (tons) by country (colored lines) for* E. cirrhosa *in GSA 18 from current submission (DCRF, 2024). In yellow the submitted time series of last year (DCRF 2023) is highlighted.*

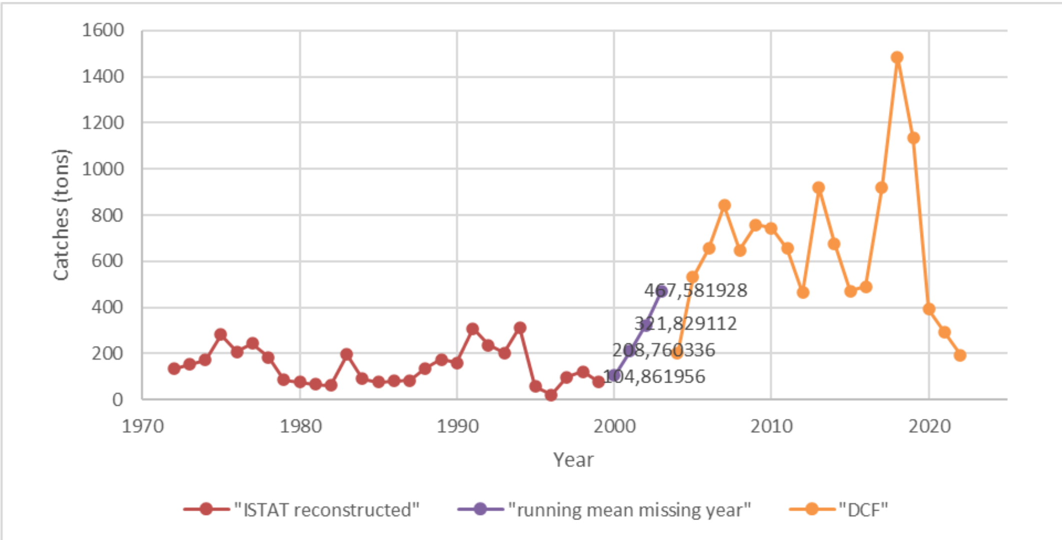


Figure 3.2-2. Reconstructed historical landings of Horned octopus (GSA 18) from ISTAT data (1972-1999), with running means for missing years (2000-2003), for Italian fleets.

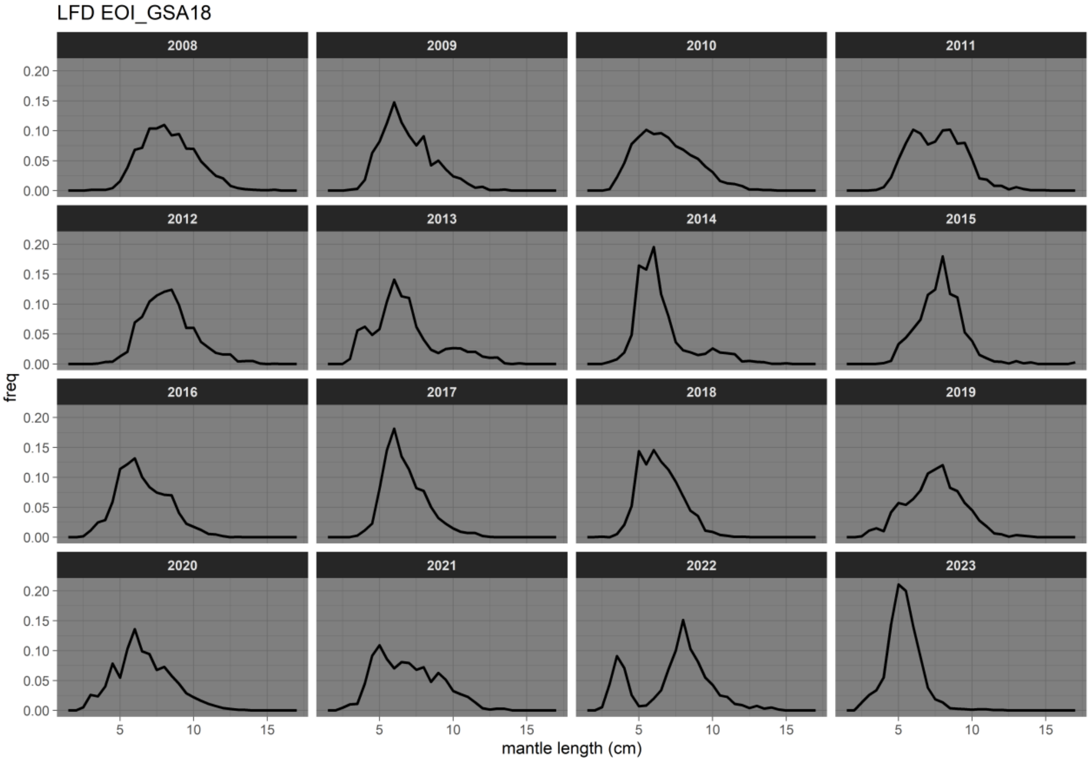


Figure 3.2-3: LFDs by year for E. cirrhosa in the Italian landings. Length expressed as mantle length, in cm. Data are in relative frequency.

Table 3.2-1: Landings by country and GSA. Asterisk (*) indicates the revised Italian landings.

Year	ITALY GSA18	MONTENEGRO GSA 18	ALBANIA GSA 18	Total landings
2004	199.73	8.64		208.37
2005	530.70	8.64		539.34
2006	654.25	8.64		662.89
2007	842.83	6.24		849.07
2008	648.13	10.08		658.21
2009	758.89	7.2		766.09
2010	744.27	10.56		754.83
2011	655.57	6.24		661.81
2012	464.26	5.76		470.02
2013	917.75	4.8		922.55
2014	677.72	4.8		682.52
2015	470.12	4.32		474.44
2016	489.31	4.32		493.63
2017	919.87	1.44		921.31
2018	1485.56	0		1485.56
2019	1132.92	0	3.26	1136.18
2020	277.45*	2.126	62.4	341.97
2021	238.68*	0	62.88	301.56
2022	192.91	0	58	250.91
2023	277.11	0	45.26	322.38

Table 3.2-2: Reconstructed landings (tons) from Montenegro from aggregated landing of E. cirrhosa and E. moschata (data from Fishstat), reconstructed to landing of E. cirrhosa based on proportion between the two species in Italian DCF landing data. Values underlined and in italics (2004-2005) were assumed identical to to closest reconstructed values. Values in bold font (2018-2022) have been updated.

Year	MTN horned octopus landing reconstructed
2004	*8.64*
2005	*8.64*
2006	8.64
2007	6.24
2008	10.08
2009	7.2
2010	10.56
2011	6.24
2012	5.76
2013	4.8
2014	4.8
2015	4.32
2016	4.32
2017	1.44
2018	**0**
2019	**0**
2020	**2.126**
2021	**0**
2022	**0**
2023	**0**

3.3 Management regulations and future management plan

The stock is among the targets of the demersal fisheries of Adriatic and Ionian Sea and of the Multi Annual Management Plan in the Adriatic region (GFCM Recommendations GFCM/43/2019/5; GFCM/44/2021/1). 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 fishing fleet, the Italian fishing licenses have been fixed since the late '80s and the fishing capacity has been gradually reduced. Other measures on which the management regulations are based regard technical measures (mesh size), minimum landing sizes (EC 1967/06) and seasonal fishing ban, that in southern Adriatic has been mandatory since the late '80s. Regarding small scale fishery management regulations are based on technical measures related to the height and length of the gears 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. Two biological conservation zone (ZTB) were permanently established in 2009 (Decree of Ministry of Agriculture, Food and Forestry Policy of 22.01.2009; GU n. 37 of 14.02.2009) along the mainland, offshore Bari (180 km^2, between about 100 and 180 m depth), and in the vicinity of Tremiti Islands (115 km^2 along the bathymetry of 100 m) on the northern border of the GSA where a marine protected area (MPA) had been established in 1989. In the former only the professional small scale fishery using fixed nets and long-lines is allowed, from January 1st to June 30th, while in the latter the trawling fishery is allowed from November 1st to March 31 and the small scale fishery all year round. Recreational fishery using no more than 5 hooks is allowed in both the areas. Since June 2010 the rules implemented in the EU regulation (EC 1967/06) regarding the cod-end mesh size and the operative distance of fishing from the coasts are enforced.

In Montenegro, management regulations are based on technical regulations, such as mesh size (Official Gazette of Montenegro, 8/2011), including the minimum landing sizes (Official Gazette of Montenegro, 8/2011), and a regulated number of fishing licenses and area limitation (no–fishing zone up to 3 NM from the coastline or 8 NM for trawlers of 24+ m LOA). Currently there are no MPAs or fishing bans in Montenegrin waters.

In Albania, a new law "On fishery" has now been approved, repealing the Law n. 7908. The new law is based on the main principles of the CFP, it reflects Reg. 1224/2009 CE ; Reg.1005/2008 CE; Reg. 2371/2002 CE; Reg. 1198/2006 CE; Reg. 1967/2006 CE; Reg. 104/2000; Reg. 1543/2000 as well as the GFCM recommendations. The legal regime governing access to marine resources is being regulated by a licensing system. Regarding conservation and management measures, minimum legal sizes and minimum mesh sizes is those reflected in the CE Regulations. Albania has already an operational vessel register system. It is forbidden to trawl at less than 3 nautical miles (nm) from the coast or inside the 50m isobath when this distance is reached at a smaller distance from the shore.

3.4 Reference points

No reference points are yet agreed for this stock.

4 Fisheries independent information

4.1 Mediterranean International Bottom Trawl Survey (MEDITS)

MEDITS survey was carried out in GSAs 18 since 1994 in the Italian area, since 1996 in Albania and since 2008 in Montenegro (Spedicato *et al.*, 2019). In 2022 the MEDITS survey was not carried out. abundance and biomass indices were calculated for GSA18 using the ad-hoc JRC script (Mannini, 2020). The survey takes place in the summer months with some variability in few years (Figure 4.1-1).

Figure 4.1-2. *Timing of the MEDITS survey in GSA 18 through the years.*

Table 4.1-3: Trawl survey basic information

Survey	Mediterranean International Bottom Trawl Survey (MEDITS)	**Trawler/RV**	Mizard
Sampling season	Spring-Summer		
Sampling design	Random Stratified		
Sampler (gear used)	GOC 73		
Codend mesh size as opening in mm	20		
Investigated depth range (m)	10 - 800		

4.1.1 Spatial distribution of the resources

The following maps show the biomass indices (kg/km^2) of the MEDITS survey carried out last year (*Figure 4.1-1*).

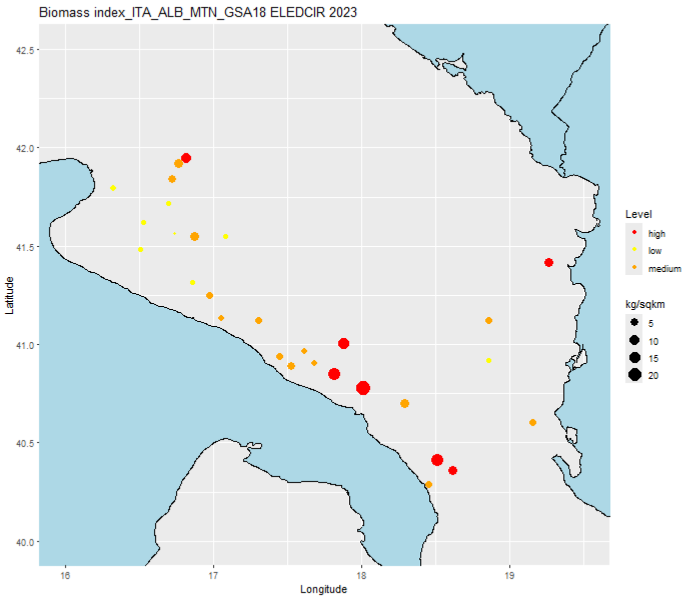


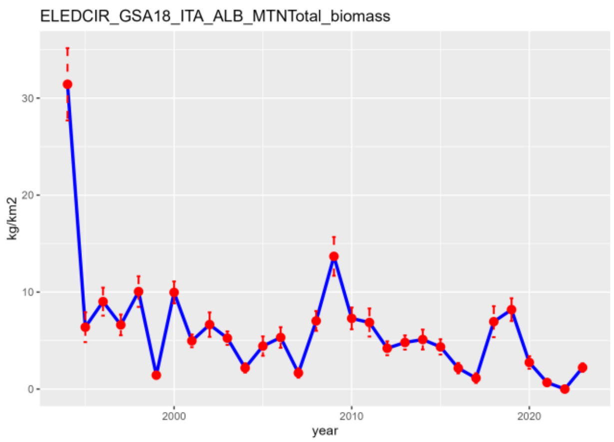
Figure 4.1-1. Biomass index from the hauls performed in 2023.

4.1.2 Historical trends

The survey indices are available from 1996 to 2023 (Table 4.1-4). The indices show large oscillations and no apparent trend in time. There is an increase in biomass in 2018 and 2019 compared to previous years, however this does not reach the historical peak biomass and is followed by a decline in 2020 and 2021 with a slight increase in 2023 (Figure 4.1-1). As requested during the data preparation meeting (WKDATAPREP_2024), a comparison between MEDITS' biomass and density indices was carried out by: (i) selecting the years with an occurrence of the species upon 50%, (ii) computing the Euclidean distance between the values of biomass index against the density one, (iii) and finally years with dissimilarity >75% were highlighted. Finally, a comparison of the indices by selected years with the corresponding length frequency distributions was carried out; looking for a temporal pattern in recruitment, such an analysis does not provide enough evidence to directly relate the peaks in recruitment with the increases in density index (Figure 4.1-2).

Table 4.1-5: biomass and density indices derived from MEDITS survey with associated standard error (sd). The survey was not carried out in 2022.

Years	GSA 18 (biomass)		GSA 18 (density)	
	Kg/km^2	sd	N/km^2	sd
1996	13.47	2.84	60.13	12.83
1997	10.15	2.14	54.18	10.42
1998	17.46	3.31	84.51	16.28
1999	1.64	0.58	21.47	5.60
2000	15.78	2.27	88.98	11.81
2001	7.97	1.40	39.77	6.39
2002	9.56	2.39	71.41	13.33
2003	8.19	1.20	39.11	5.18
2004	3.23	0.90	35.10	6.95
2005	5.25	1.63	36.68	9.08
2006	9.20	2.13	77.84	17.49
2007	2.85	0.96	87.84	43.27
2008	11.99	2.34	52.67	10.50
2009	1.60	0.60	11.63	3.98
2010	10.63	1.98	59.04	10.89
2011	10.46	2.80	49.14	11.50
2012	6.90	1.39	40.87	11.51
2013	6.48	1.14	80.84	14.53
2014	7.16	1.90	60.64	16.86
2015	6.52	1.47	34.99	10.84
2016	3.47	0.98	41.06	9.58
2017	1.89	0.77	47.64	17.53
2018	12.00	3.03	95.78	20.20
2019	13.05	2.19	73.69	14.05
2020	3.98	1.09	95.87	36.16
2021	1.39	0.49	12.08	3.48
2022	3.01	0.78	64.33	24.25
2023	13.47	2.84	60.13	12.83



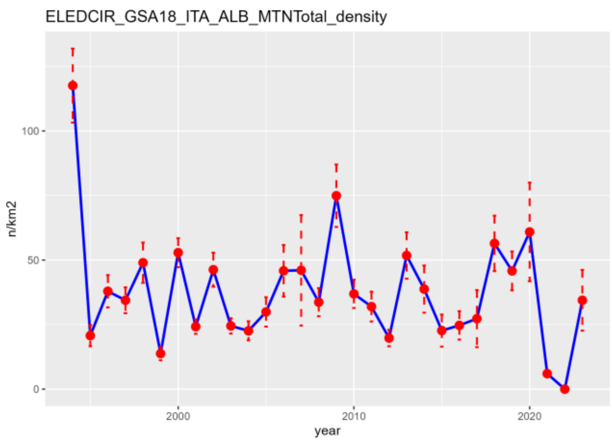


Figure 4.1-1: Relative biomass (left) and density (right) time series for horned octopus in GSA 18.

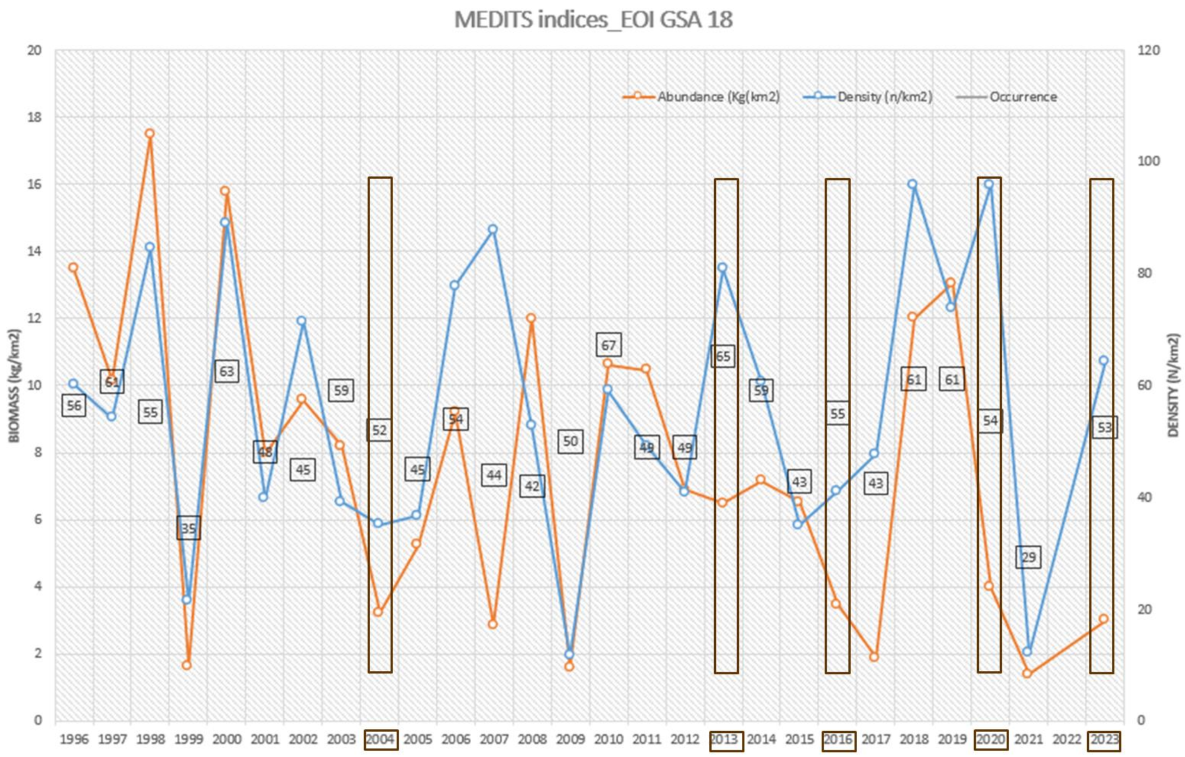


Figure 4.1-2: Medits survey in GSAs 18 indices comparison between biomass (orange line) and density (blue line). The numbers inside the black squares represent the occurrence rate (in percentage). The years (i.e. 2004,2013,2016, 2020, 2023) with dissimilarity of Euclidean distance >75% are highlighted with black rectangles.

5 Ecological information

5.1 Protected species potentially affected by the fisheries

No analysis was carried out on this aspect.

6 Stock Assessment

6.1 Model used for advice_ BSM-CMSY

CMSY is a Monte-Carlo method that estimates fisheries reference points (MSY, Fmsy, Bmsy) as well as relative stock size (B/Bmsy) and exploitation (F/Fmsy) from catch data and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (= fragmented) abundance data. The CMSY version used in the present assessment (CMSY++_16.R) is newer than the one used in Froese et al. (2017). The main differences are (i) the use of a full Bayesian approach with MCMC (Markov chain Monte Carlo) modelling also for the catch-only (i.e. CMSY) analysis, (ii) faster execution, (iii) the use of an AI (Artificial Intelligence) neural network to predict default biomass priors from catch, and (iv) more emphasis on graphical outputs including various analytical plots. A major improvement for both CMSY and BSM is the introduction of multivariate normal priors for r and k in log space, replacing the previous uniform prior distributions. This allowed also for a simplified determination of the 'best' r-k pair in CMSY and faster run times, as reported in the User Guide for CMSY++ (Froese *et al.*, 2021).

6.1.1 Model assumptions

The CMSY model utilizes parameter estimation through Monte-Carlo. The Bayesian production model can also include CPUE or biomass data. These are not utilized by the CMSY model. The two models are run in parallel to provide a benchmark of the parameter estimates. The user decides whether the final management reference points should be calculated using CMSY or BSM. Based on the fact that the CPUE time series is based on MEDITS survey, which is known to sample the species assessed efficiently, the BSM model was chosen for this assessment.

6.1.2 Scripts

Scripts are provided in the GFCM share point: here.

6.1.3 Input data and Parameters

Following the previous year´s assessment, priors were based on expert opinion and on the methods advised by Froese et al. (2017).

6.1.3.1 Resilience

Prior for Resilience (r) was set based on the carrying capacity of the Von Bertalanffy (using data reported above). The resilience can be assumed to approximate 3*K. Using both male and female K provided, r values of 1.16-1.27 were assumed, corresponding to a high resilience according to the criteria provided by Froese et al. (2017) and CMSY user guide (Table 6.1.3.1-1).

Table 6.1.3.1-1. *Ranges of prior r range and Resilience level to set in CMSY input file.*

Resilience	prior *r* range
High	0.6 – 1.5
Medium	0.2 – 0.8
Low	0.05 – 0.5
Very low	0.015 – 0.1

6.1.3.2 Setting of initial, intermediate and final biomass:

The initial and final relative biomass compared to unexploited biomass (k) is required, based on the likely status of the stock: lightly fished, fully exploited or overfished. In addition, an intermediate year can also be set, and relative biomass for the intermediate year is set following the same criteria. Table 6.1.3.1-2 provides suggested ranges for relative biomass to be used as input parameters, depending on the depletion status of the stock.

Table 6.1.3.1-2. *Prior relative biomass (B/k) ranges for CMSY.*

Very strong depletion	Strong depletion	Medium depletion	Low depletion
0.01 – 0.2	0.01 – 0.4	0.2 – 0.6	0.4 – 0.8

According to Froese et al. (2017) setting rules and since our data starts in 2004 when the fishery was already developed, the initial biomass prior was set as **medium depletion (0.2-0.6).** Following these rules, year 1996 is the minimum (19.8 tons) when using the ISTAT data, and year 2004 (208.4 tons) when using the DCF data; and year 2018 the maximum (1487 tons) in the catch time series. Hence, the increase in catch was steep (0.045 long time series; 0.06 short time series). We thus assumed biomass in 2017 to be in a high state, and the intermediate biomass prior was set to **high (0.4-0.8)**. The model was allowed to estimate freely the terminal biomass based on data, and no prior was set on the terminal B/k. The priors used in the main run are summarized in Table 6.1.3.1-3.

Table 6.1.3.1-3. *Parameters used for the model. Endb.low and Endb.hi were not set and the model estimated the terminal biomass.*

Species	Start year	End year	Resilience	Stb.low	Stb.hi	Int.yr	Intb.low	Intb.hi	Endb.low	Endb.hi	Model
E. cirrhosa	1972	2022	High	0.2	0.6	2017	0.4	0.8	-	-	BSM

Alternative settings are explored in sensitivity analysis in order to gauge the robustness of results to the model setup.

6.1.4 Results

Figure 6.1.4-1 shows the CMSY assessment for horned octopus in GSA 18. The black curve in **A** shows the time series of catches and the blue curve shows the smoothed data with indication of highest and lowest catch in red, as used in the estimation of prior biomass by the default rules. Panel **B** shows the explored log *r-k* space and in dark grey the *r-k* pairs which were found by the model to be compatible with the catches and the prior information. The dotted rectangle indicates the range of the priors provided in the ID file. The point in the center of the blue cross is the most likely r-k pair predicted by CMSY and horizontal and vertical error bars approximate 95% confidence limits for *r* and *k,* respectively, which are again closer view in Panel **C**. The blue curve in **D** shows the median of the biomass trajectories estimated by CMSY. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. Panel **E** shows median exploitation (*F/Fmsy*) as blue curve, with the dotted curves indicating 2.5th and 97.5th percentiles. The steep increase in the upper confidence limit in the last year results from catch relative to the lower confidence limit of biomass in panel **D**. Panel **F** shows the Schaefer equilibrium curve of catch/MSY relative to *B/k*, indented at *B/k* < 0.25 to account for reduced recruitment at low stock sizes. The blue curve shows the predictions by CMSY, from first year (square) to last years (triangle).

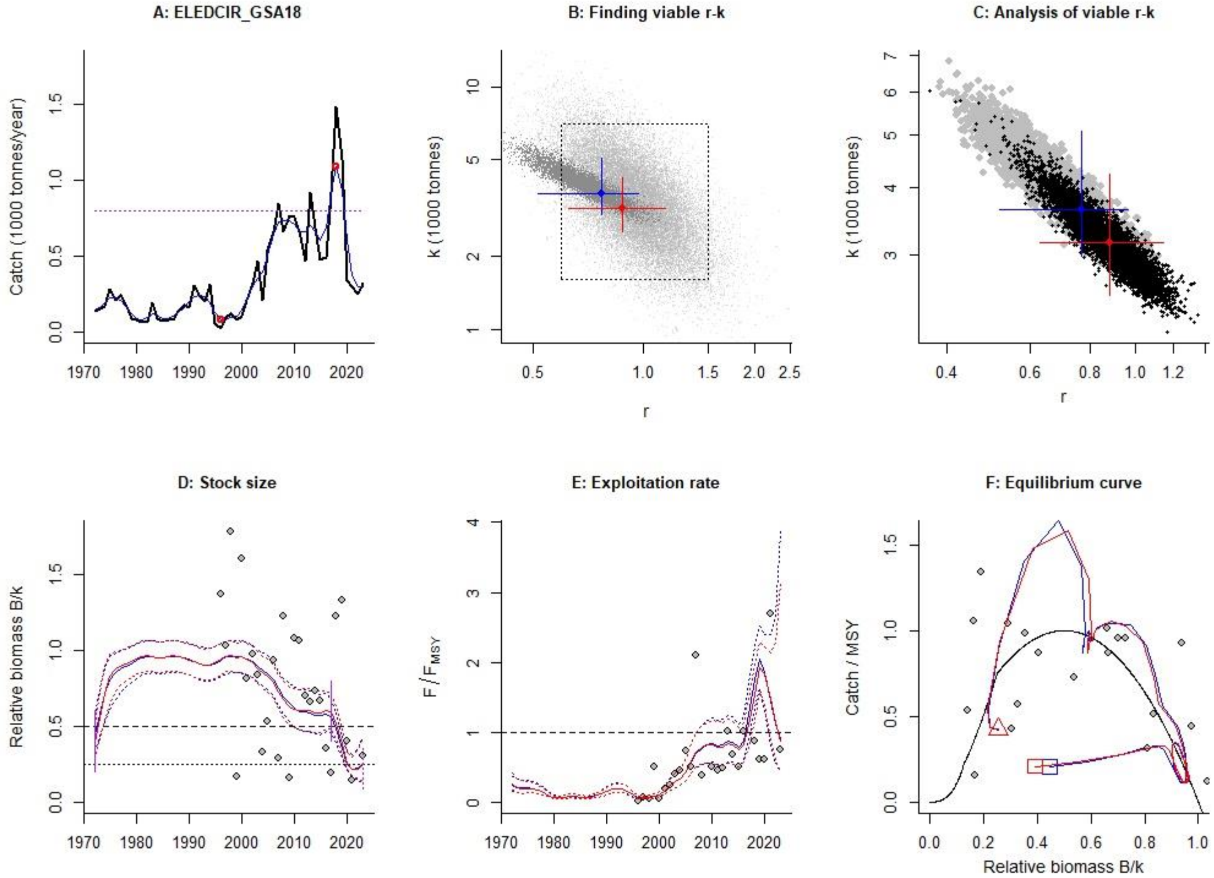


Figure 6.1.4-1. *Diagnostics results of the final model run.*

Figure 6.1.4-2 shows the summary information relevant for management. The upper left panel shows catches relative to the BSM estimate of MSY, with indication of 95% confidence limits in grey. The upper right panel shows the development of relative total biomass (B/Bmsy), with the grey area indicating uncertainty. The horizontal dashed lines in the Catch graph indicate MSY and the fine dotted line indicates the lower confidence limit of MSY. The lower left graph shows relative exploitation (F/Fmsy). The lower right panel shows a KOBE plot indicating current and past state of the stock compared to reference points F/FMSY and B/BMSY. The “banana” shape around the assessment of the final year triangle indicates uncertainty with beige for 50%, grey for 80% and dark grey for 95% confidence levels.

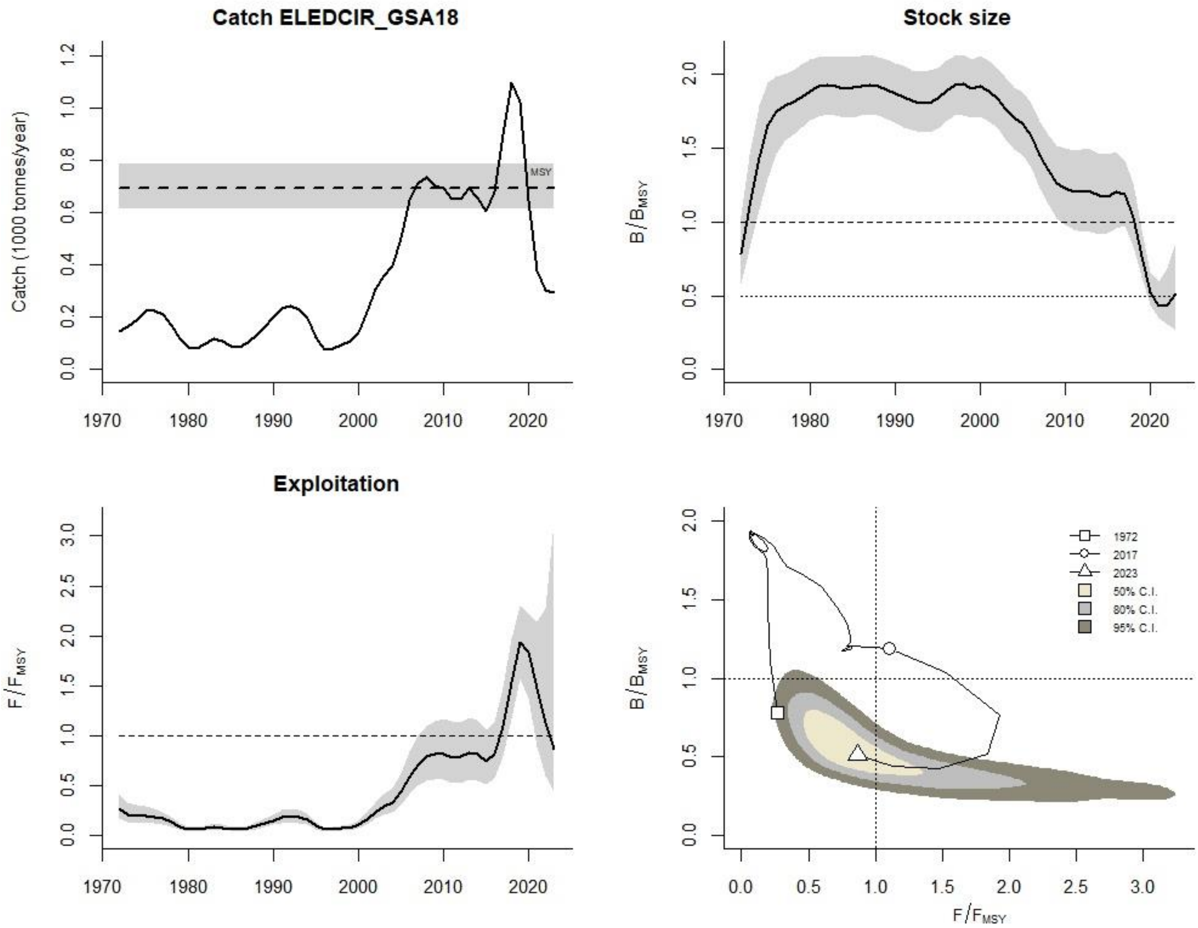


Figure 6.1.4-2. *Results of the final model run.*

Figure 6.1.4-3 shows the analytical results. The upper left panel shows the fit represented by the median of predicted catch posterior, with 95% confidence limits (grey shaded area), compared to the observed catch (points). The upper right panel shows a similar graph for predicted versus observed CPUE. The lower left panel shows the deviation between deterministic expectation (surplus production minus catch) and the stochastic realization (after adding process error), where a strong deviation of the bold curve from the dashed line would indicate that changes in biomass diverge from the Schaefer model expectations due to, e.g., (1) strong environmental variation, (2) CPUE not properly describing the abundance or (3) the priors are mis-specified and require re-evaluation. The lower right graph shows an analysis of the log-CPUE residuals, with a white or green background if autocorrelation of residuals is deemed negligible (and red otherwise), as judged by a non-parametric Runs test for testing randomness in time series. In our case, all values are within the limits of the autocorrelation for residuals.

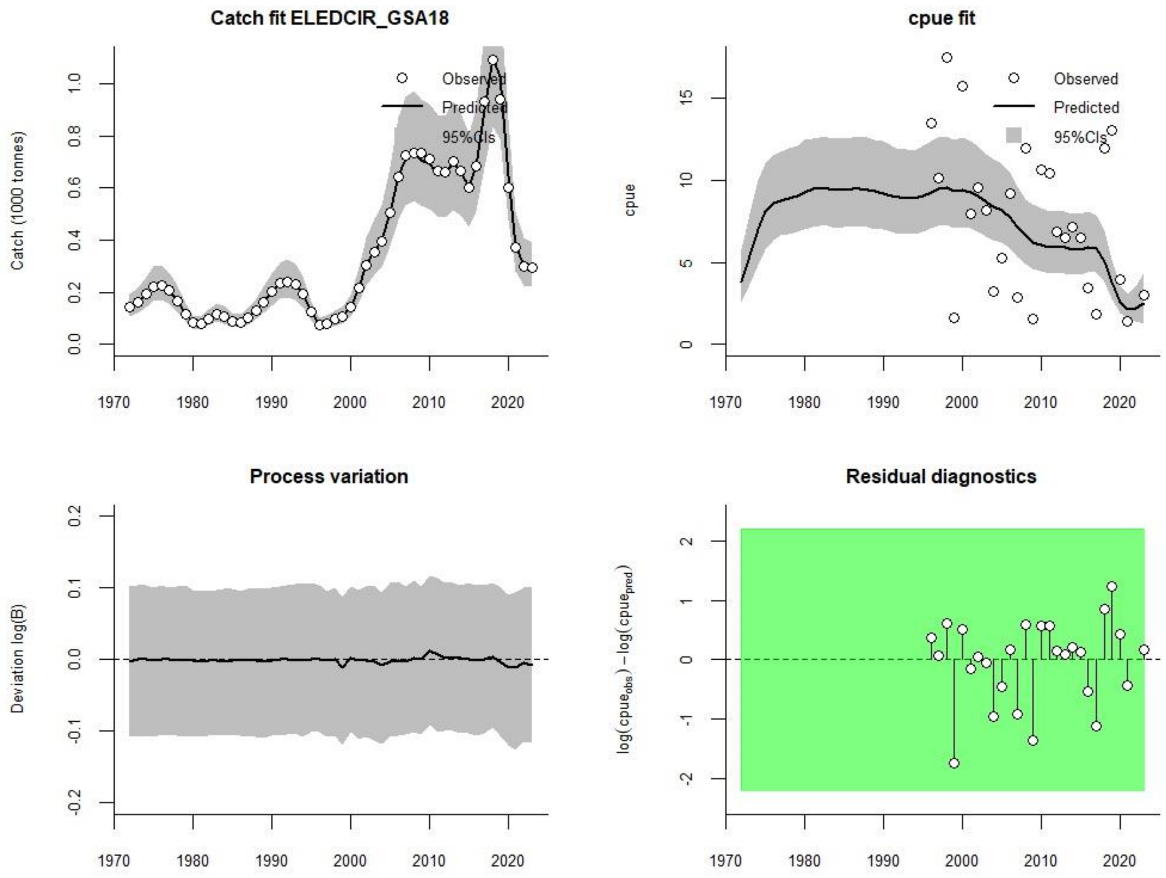


Figure 6.1.4-3. *Analytical Results of the final model run.*

Figure 6.1.4-4 shows the comparison of prior and posterior densities (same area under curves) for productivity (r, top-left), maximum stock size (k, top-central), maximum sustainably yield (MSY, top-right), and relative stock size (B/k) at the beginning, the end, and an intermediate (bottom left, central and right panels) year of the available time series of catch data. The priors (light grey) inform the results, with posterior understanding (dark grey) of the stock clearly improved compared to prior perceptions. The lower the prior-posterior variance ratio (PPVR), the more the posterior knowledge is improved relative to prior knowledge.

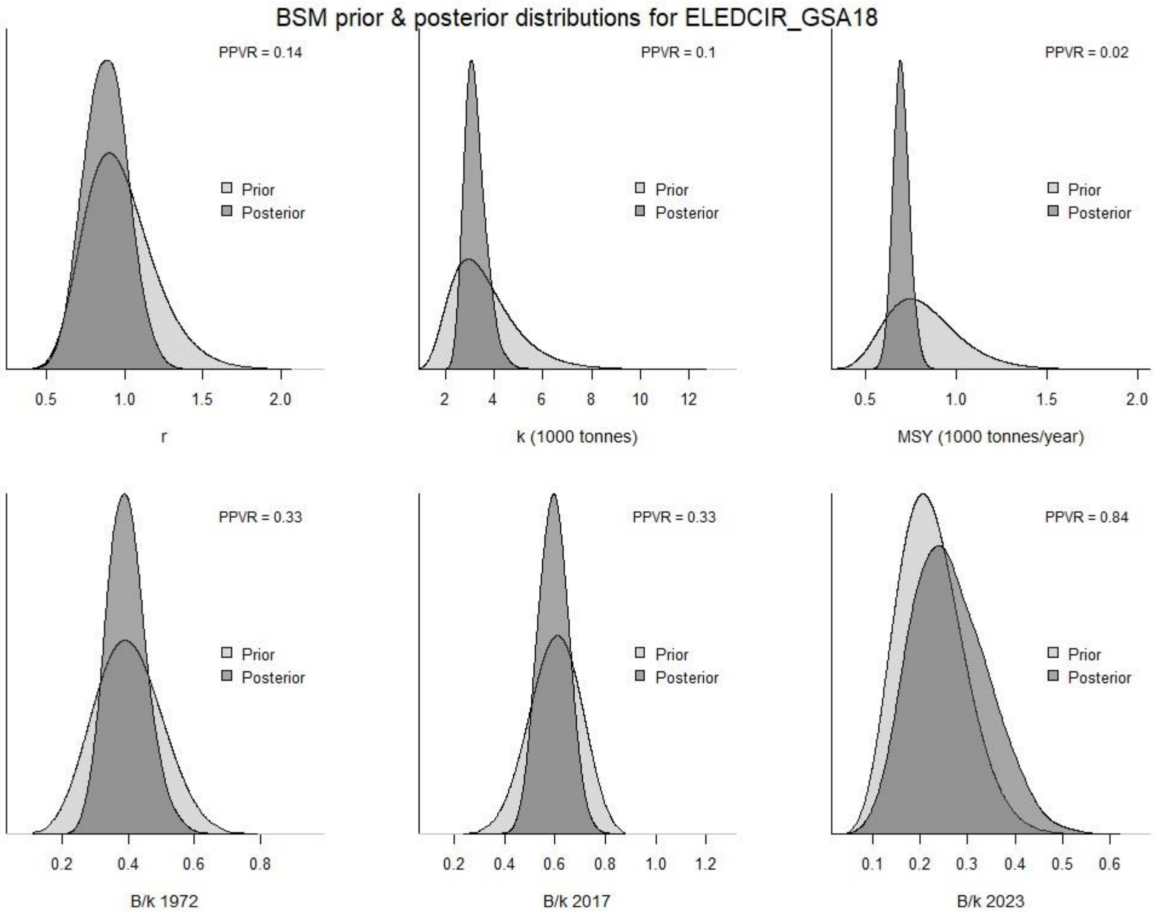


Figure 6.1.4-4. *Prior-posterior densities comparison for final model run.*

Figure 6.1.4-5 shows a Kobe phase plot, representing the time series of pressure (*F/FMSY*) on the Y-axis and of state (*B/BMSY*) on the X-axis. The plot is divided into four quadrants, defined for the stock biomass and fishing mortality relative to *BMSY* and *FMSY*, respectively. Panel colours follow a traffic-light approach. Shades of grey indicate levels of confidence. The "banana" shape around the assessment of the final year triangle indicates uncertainty with beige for 50%, grey for 80% and dark grey for 95% confidence levels. In the legend, percentage probability of the current year to fall under the four panels (indicated by respective colours) is shown. Here, the model estimates a probability of 61% to fall in the yellow area, and 38.7% in the red area.

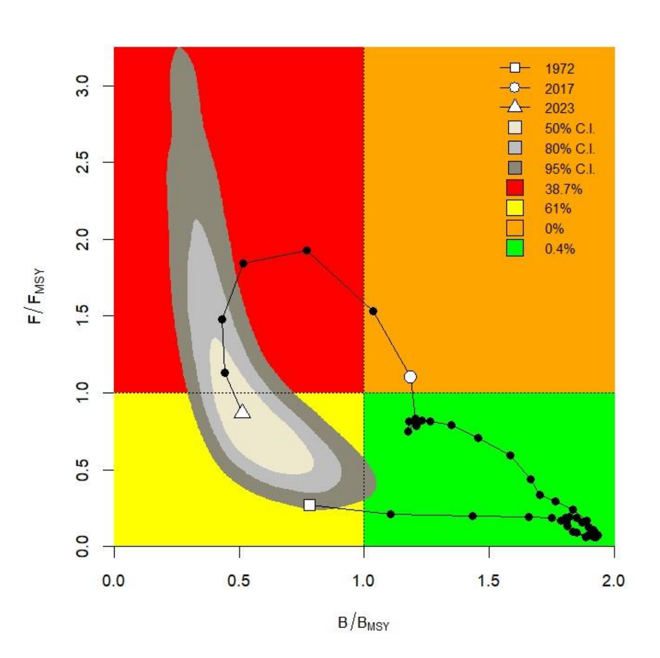


Figure 6.1.4-5. *KOBE plot of the final model run. Current (triangle) and past position of the stock respective to reference points B/BMSY and F/FMSY, with intervals of confidence (grey areas).*

Exploitation varied without any trend in the years between 1972 and 2015, with an increase since 2017. In 2019, it reached the historical high level in terms of F/FMSY, with a decline in the last four years, with a value of 0.867 (95% CI: 0.44- 3.15). The biomass was stable and in a good state until 2016, to then decrease rapidly until 2020, with values for 2021, 2022 and 2023 being very similar to those of 2020. Biomass has been above BMSY throughout the time series (except the first year) until 2018 to then drop below this threshold in 2019. In the terminal year, B/BMSY is estimated at 0.807 (95% CI: 0.408-1.51).

Results of the stock assessment are reported below in Figure 6.1.4-6.

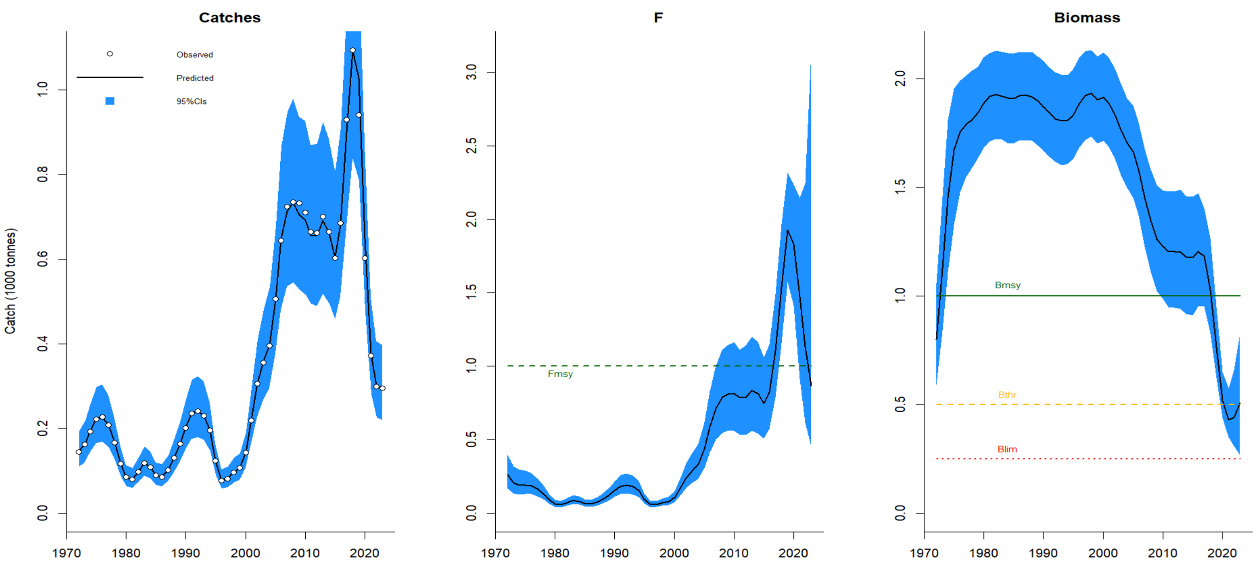


Figure 6.1.4-6 *Stock summary of the CMSY assessment results for Horned octopus (Eledone cirrhosa) in GSA 18. Evolution of biomass, total catches and fishing mortality (F) stock trajectories with uncertainties with CI at 95% (blue shaded areas) relative to the reference points.*

6.1.5 Model diagnostics, retrospective and sensitivity analysis

Retrospective analyses of the model (Figure 6.1.5-1) show relatively similar patterns across runs for the whole time series, with absolute values being influenced by the terminal year but patterns being conserved, exhibiting relatively consistent dynamics among retrospective runs.

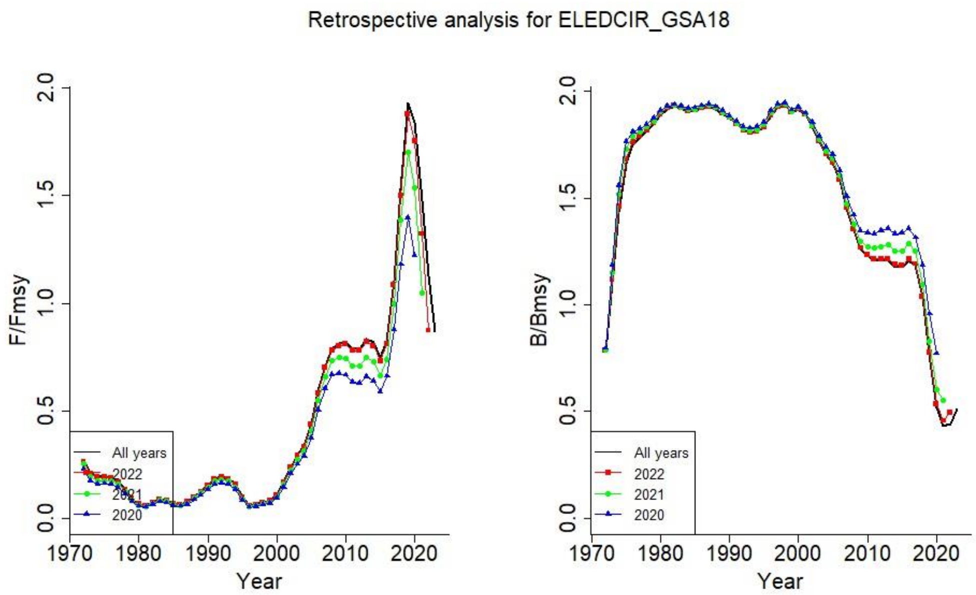


Figure 6.1.5-1. *Retrospective analyses of the final model.*

Following the suggestions provided at the last WGSAD (2023) and in accordance with the WKDATAPREP_2024 comments, multiple alternative model runs were performed to test the sensitivity of the model results to some of the key assumptions. In particular, two sensitivity runs are highlighted (and presented in the following sections 6.1.5.1 and 6.1.5.2), modifying (i) the length of time series, using the most recent data of catch from 2004 ("UPDATE1"); (ii) removing B/k priors ("UPDATE4"). A summary of all the sensitivity runs is reported in Table 6.1.5-1.

Table 6.1.5-1. *Summary of sensitivity model runs. In red, the parameters modified in each sensitivity run.*

RUN	Start year	End year	Int. year	IntB.low	IntB.hi	Endb.low	Endb.hi	**B/k prior**
MAIN RUN	1972	2023	2017	0.4	0.8	estimated	estimated	
UPDATE 1	2004	2023	2017	0.4	0.8	estimated	estimated	
UPDATE 2	1972	2023	2017	estimated	estimated	estimated	estimated	
UPDATE 3	2004	2023	2017	estimated	estimated	estimated	estimated	
UPDATE 4	1972	2023	2017	0.4	0.8	estimated	estimated	removed
UPDATE 5	2004	2023	2017	0.4	0.8	estimated	estimated	removed
LAST YEAR	1972	2022	2017	0.4	0.8	estimated	estimated	

6.1.5.1 Sensitivity to length of time series (UPDATE 1)

The sensitivity using the year 2004 as the starting year, provided results similar to those of the main run in terms of both B/Bmsy and F/Fmsy, with higher probability for the final year to fall in the yellow and red quadrants compared to the main run (Figure 6.1.5.1-1), but an overall consistent pattern in time.

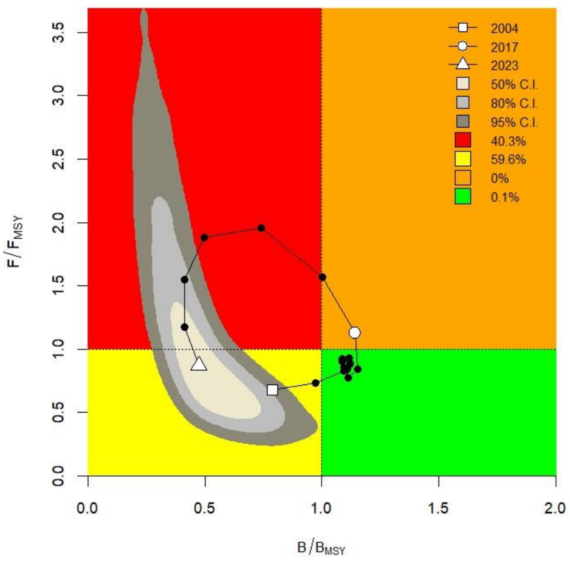


Figure 6.1.5.1-1. *KOBE plot of the sensitivity run using a shorten time series*

6.1.5.2 Sensitivity to B/k prior removal (UPDATE 4)

The sensitivity analysis developed by removing the B/k priors from the main model resulted, in terms of both B/Bmsy and F/Fmsy, in a very different stock status with higher uncertainties compared to the main model. Indeed the probability for the final year to fall in the yellow and red quadrants has reduced drastically (20.5%), while the probability to fall in the green quadrant is now around 80% (Figure 6.1.5.2-1)

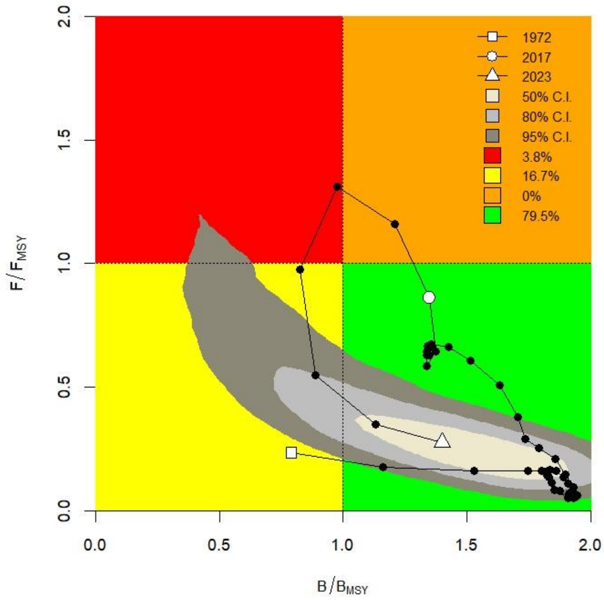


Figure 6.1.5.2-1. KOBE plot of the sensitivity run by removing B/k priors

6.1.6 Assessment quality

The retrospectives analyses show some patterns in the time series, which are however considered acceptable. The sensitivity analyses confirm the robustness of the main model run, with consistent patterns observed in the last few years in the general trends. The absolute results are not so sensitive to the temporal settings. As suggested by WGSAD_2023 and WKDATAPREP_2024, a series of sensitivity analysis were carried out confirming the robustness of the choice of including the longer time series of reconstructed catches and the current CMSY settings (especially for the B/k priors), which does not influence substantially the outcome on the stock status at the terminal year.

In conclusion, due to the proximity of the last year F estimates with the reference point (F_{MSY}), and to follow a precautionary approach the group agreed to accept this assessment as qualitative. Overall, the difficulties to date in the assessment of cephalopods species due to its typical traits (e.g. short living species), uncertainties in the growth rate especially among different areas, and unknow environmental effects on cephalopods stocks dynamics were flagged by the group.

6.2 Length-Based Spawning Potential Ratio (LBSPR)

The Length-Based Spawning Potential Ratio (LBSPR) method (Hordyk *et al.*, 2016) has been developed for data-limited fisheries, where a representative sample of the size structure of the vulnerable portion of the population (i.e., the catch) as well as a basic understanding of the life history of the species are available.

6.2.1 Model assumptions

The LBSPR model relies on a number of simplifying assumptions. In particular, the LBSPR models are equilibrium based, and assume that the length composition data is representative of the exploited population at steady state. The LBSPR method does not require knowledge of the natural mortality rate (M), but instead uses the ratio of natural mortality and the von Bertalanffy growth coefficient (K) (M/K), which is believed to vary less across stocks and species than M.

6.2.2 Scripts

The R code for LBSPR was obtained from: https://github.com/AdrianHordyk/LBSPR

6.2.3 Input data and Parameters

The length frequency distribution (2008-2023) from DCF was used as input values. The LBSPR model requires setting some life-history parameters, which were set based on available information from DCF, such as a, b, L_{inf}, L_{mat50} and L_{mat95} (aggregated sexes), and M which was calculated based on Then et al. (2015). The values used in the model are reported in Table 6.2.3-1.

Table 6.2.3-1. *Parameters and values used, based on DCF data for aggregated sexes.*

Parameters	Values
a	0.486

b	2.683
Linf	18.5
Lm50%	8.75
Lmat95%	13
M/K	1.92

6.2.4 Results

The results (Figure 6.2.4-1) show a good fit of the model to data of length distribution per year. In particular, the model results in Figure 6.2.4-2 shows that the selectivity pattern has remained fairly stable in time with the exception of 2022. The F/M has increased up to 2019 when started decreasing for the following 2 years. F/M in 2022 and 2023 is quite high. This shows that the fishing pressure is quite high and increased in the last two year. The stock in 2023 was exploited above length at maturity (SPR<0.4), a pattern that has been maintained through the time series (Figure 6.2.4-3).

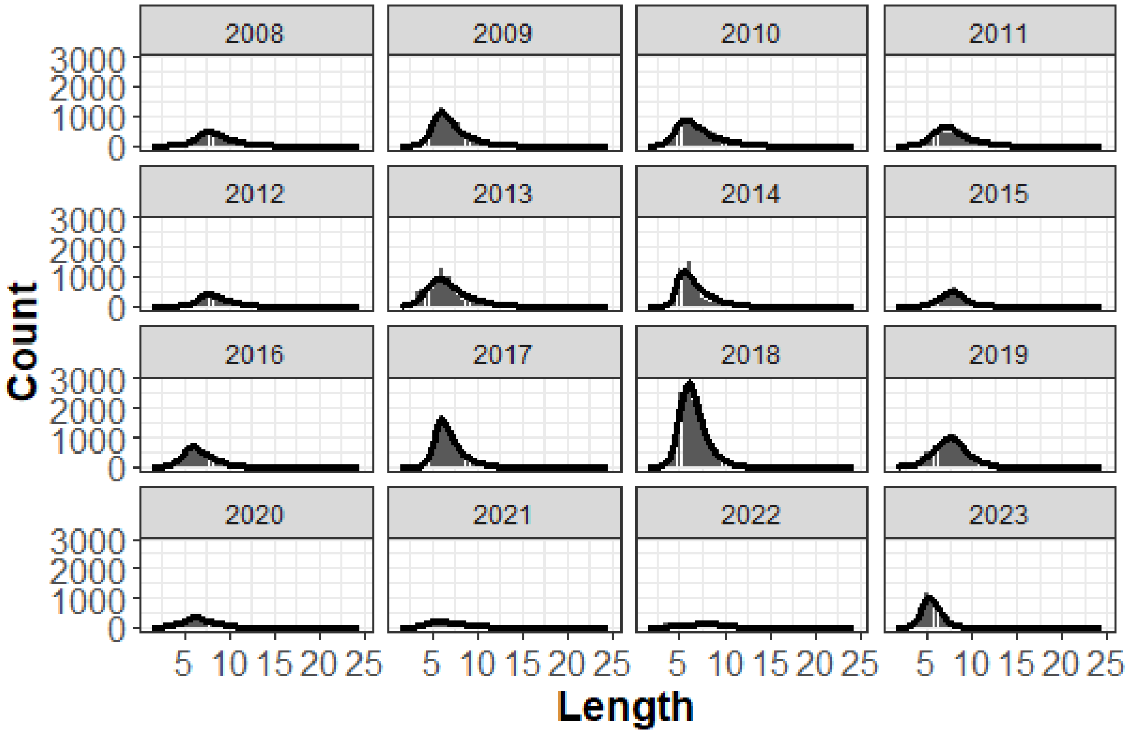


Figure 6.2.4-1. *LBSPR model fits (black lines) to length frequency data (bars) per year.*

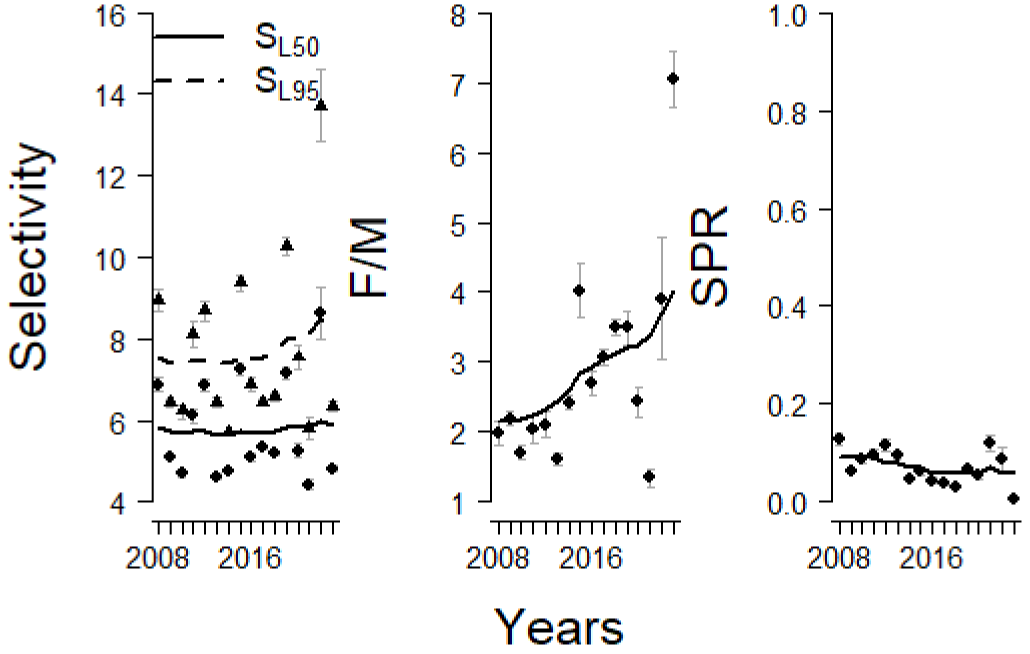


Figure 6.2.4-2. *LBSPR model results (lines) and data (dots). Left: Selectivity (in cm, mantle length); Center: F/M ratio; right: Spawning Potential Ratio.*

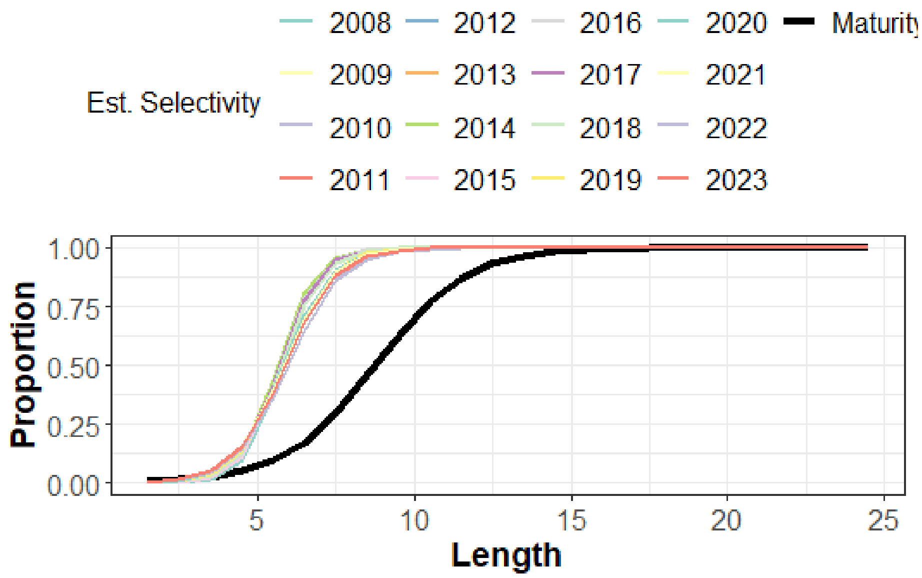


Figure 6.2.4-3. *LBSPR model estimated selectivity per year compared to the maturity curve.*

6.2.5 Assessment quality

The LBSPR model results are influenced by the short time series with limited contrast, however they clearly show a strong signal. The outcome is partially in line with the other models, namely showing the decrease in fishing pressure in the past few years with the exception of the last two (i.e. 2022 and 2023). The assessment is used in a comparative way to support the conclusions of the other models.

6.3 Stochastic surplus production model in continuous time (SPiCT)

The stochastic surplus production model in continuous time SPiCT (Pedersen et al., 2016) in R environment (R core team, 2023) was used for the assessment. SPiCT does a state-space implementation of the Pella-Tomlinson surplus production model in continuous time, which assumes that the biomass (process equation), the survey index equation (observation equation) and the catch equation are subject to errors.

6.3.1 Model assumptions

Surplus production models assume 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.

6.3.2 Input data and Parameters

An annual model from 1972 was developed including aggregated catches from Italian and Albanian OTB fleets in GSA 18 (Figure 6.3.2-1) together with MEDITS biomass indices (Figure 6.3.2-2).

The settings are the following:

- inp$priors$logn <- c(log(2),0.2, 1)
- inp$priors$logalpha <- c(log(1),0.2, 1)
- inp$priors$logbeta <- c(log(1),0.2, 1)
- priors$logr ~ c(log(0.54),0.2,1) #SeaLifeBase
- priors$logbkfrac ~ c(log(0.7),0.5,1) #medium initial depletion level
- inp$priors$logBBmsy ~ c(log(0.65),0.2,1,2015)

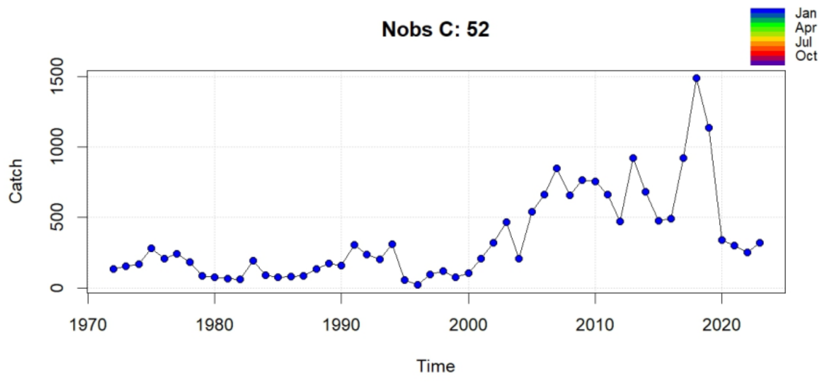


Figure 6.3.2-1. *Catch data input in tons for SPiCT model (1972-2023). Italian and Albanian OTB catches were aggregated.*

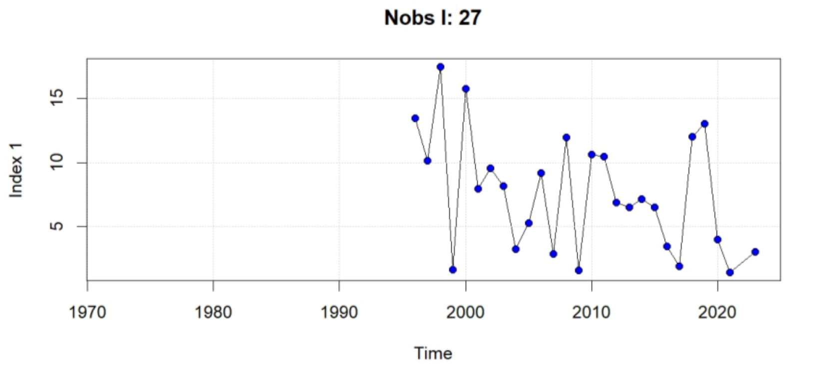


Figure 6.3.2-2. *Survey data input for SPiCT model (1996-2023). MEDITS was not conducted in 2022.*

6.3.3 Results

The results (Figure 6.3.3-1) are quite in accordance with the BMS-CMSY and LBSPR ones, particularly the stock biomass showed an overall progressive decreasing trend with many oscillations among years; such a decrement leads to the lowest historical biomass estimates from 2020 onwards. Indeed, catches of horned octopus decreased in the last 4 years (~ 300 tons). To note that biomass trend showed a sudden steep decrease from 1996, the initial year of the MEDITS survey time series. On the other side, the fishing mortality was estimated above reference point since 2008 with an increasing trend; from 2019 onwards, F starts to reduce reaching a stable value in 2023 which is, however, above estimated reference point. The stock resulted in overexploitation with low biomass level, between B_{pa} and B_{lim} (Figure 6.3.3-2).

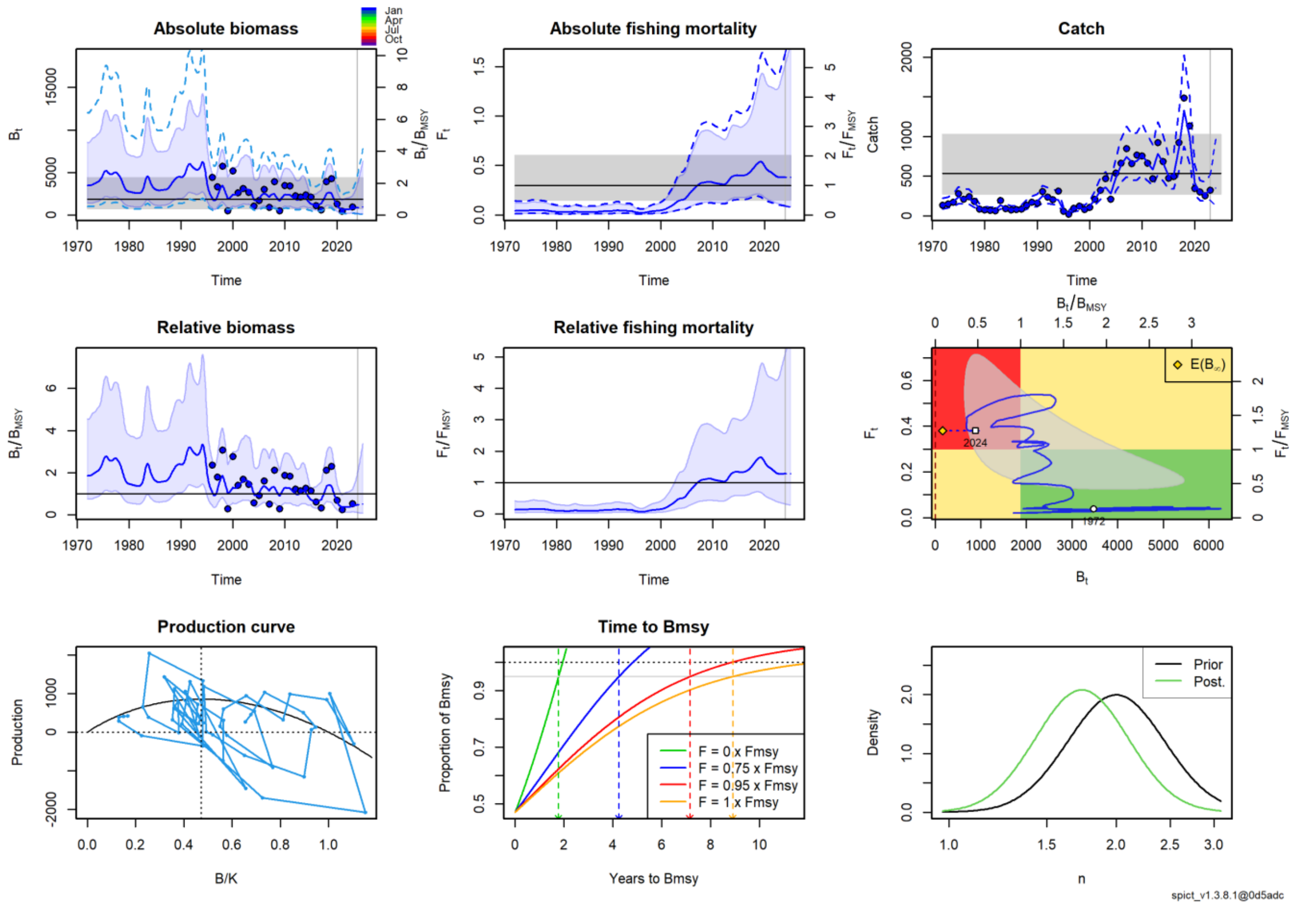


Figure 6.3.3-1. *Results of the best SPiCT annual model (1996-2023).*

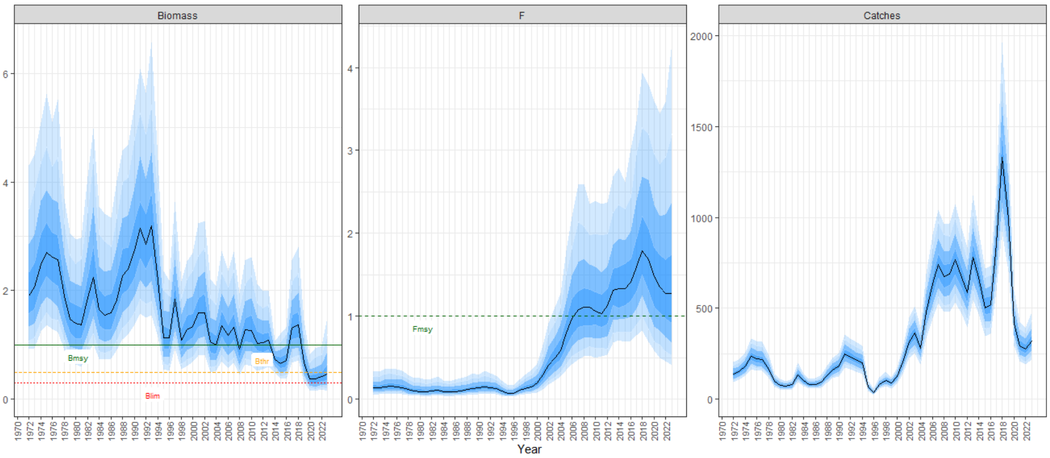


Figure 6.3.3-2. *Stock summary of the SPiCT assessment results showing the estimated stock trajectories for biomass, fishing mortality (F) and total catches relative to the reference points. Darker and lighter blue shaded areas illustrated the 80% and 90% Confidence Intervals.*

6.3.4 Model diagnostics, retrospective and robustness analysis

The trend analysis in residuals highlights no trend and no correlation (Figure 6.3.4-1). No particular patterns were evidenced in the retrospective analysis at five years and Mohn's Rho metric resulted in acceptable range since it resulted below the 0.2 threshold (Figure 6.3.4-2). However, the total stock biomass seems to be shifted progressively to higher values by removing 3 years or more (i.e. from 2020 onwards); the fishing mortality (F) also seems to react in the same way, but in relative terms the F resulted in a more uncertain state compared to the biomass one. The hindcast at five years on survey indices resulted in quite high prediction skills (MASE<1; Figure 6.3.4-3).

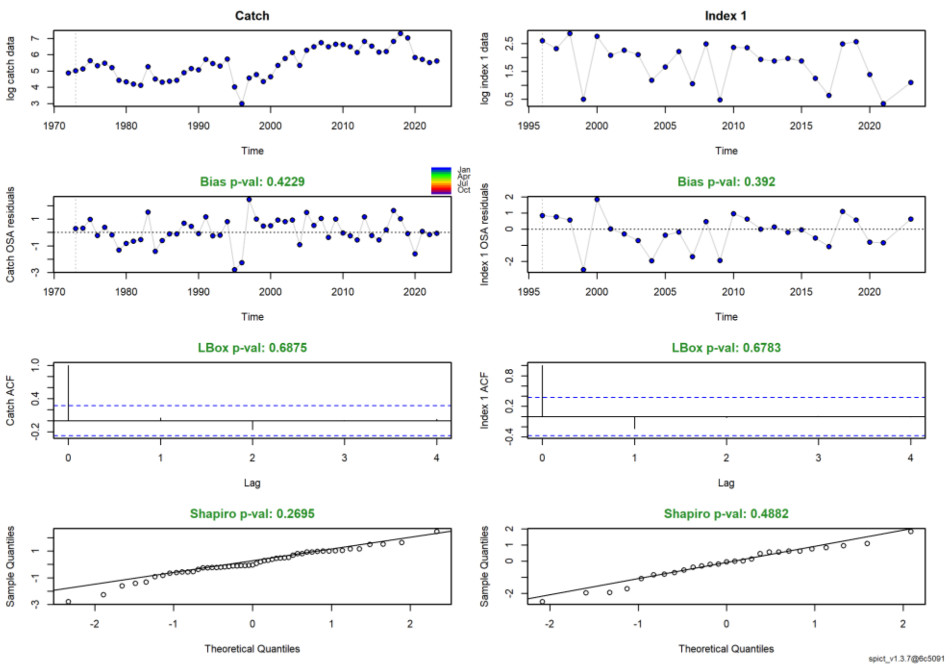


Figure 6.3.4-1. *Analysis of residuals.*

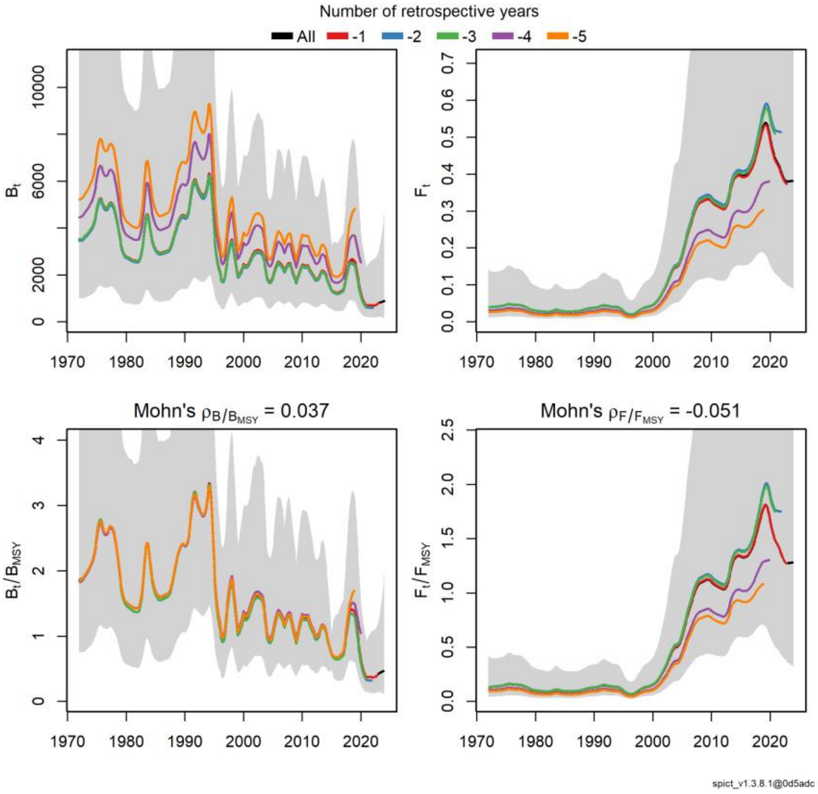


Figure 6.3.4-2. *Retrospective plots for total (top) and relative (bottom) biomass and Fishing mortality. The different trajectories are obtained by removing 0 to 5 final years of data and re-running the assessment. Mohn's Rho values as performance metric to evaluate estimates.*

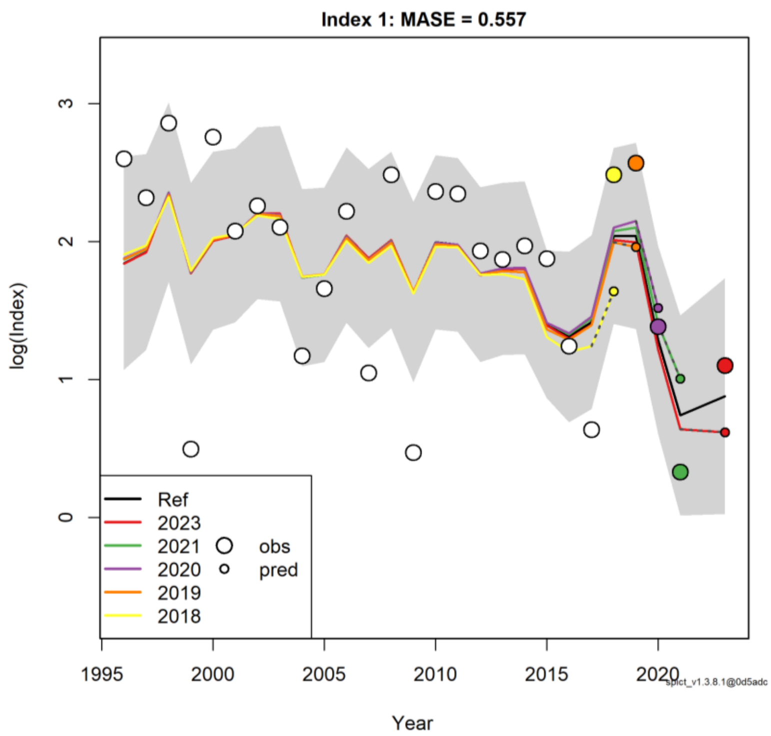


Figure 6.3.4-3. *Hindcasting analysis on survey index (MEDITS), including MASE score.*

6.3.5 Sensitivity analysis

In accordance with the WKDATAPREP_2024 comments and suggestions, multiple alternative model runs were performed to test the sensitivity of the model results to some of the key assumptions, as done for the BSM-CMSY model (section 6.1.5). Hence two different runs were tested: (i) shortening the time series using the more recent data (i.e. 2004-2023), (ii) removing the B/k prior to investigate the model behaviour, using the entire time series (i.e. 1972-2023). The resulted quantities and trends are pretty much the same compared to the official model, with the final stock status for F oscillating on the reference point, while biomass still below reference points in all the runs (Figure 6.3.5-1).

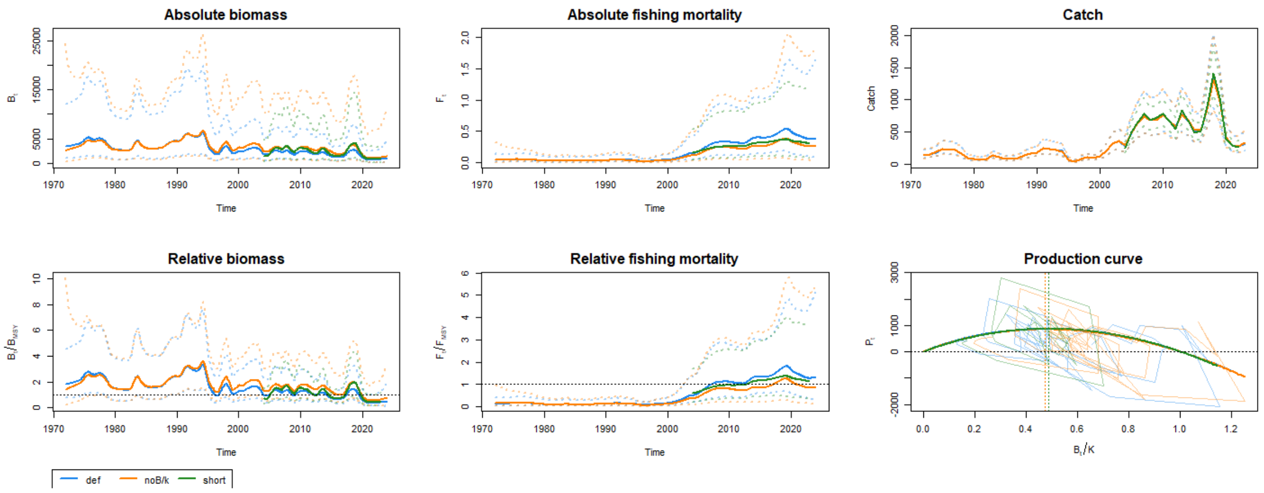


Figure 6.3.5-1. *Comparison plots of the main models' outputs from SPiCT sensitivity analysis. In blue the reference case, in orange the run without B/k prior, and in green the one with shorter time series.*

6.3.6 Assessment quality

SPiCT models presented good stability and robustness with F depicting a stock in overexploitation status which is in accordance with the BSM-CMSY results. Nevertheless, the estimated biomass from SPiCT is lower compared to the BSM-CMSY outputs, resulting in a more pessimistic status (i.e. estimates below B_{lim}); however, some sensitivity runs showed a more optimistic stock status in line with BSM-CMSY results. Therefore the group suggested to better investigate the SPiCT model settings in order to stabilise the biomass estimates, eventually developing a seasonal model that should be able to better catch the stock dynamics over years.

Overall, the difficulties to date in the assessment of cephalopods species due to its typical traits (e.g. short living species), uncertainties in the growth rate especially among different areas, and unknow environmental effects on cephalopods stocks dynamics were flagged by the group.

7 Draft scientific advice

The scientific advice in the following table is based on the BSM-CMSY model results.

Table 7-1 Draft scientific advice

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 (2020-2023)	Stock Status
Fishing mortality	Fishing mortality				D	
Stock abundance	Biomass				D	
Recruitment						
Final Diagnosis		Possibly overexploited				
Scientific Advice		Reduce fishing mortality				

WG Comments: Updated assessment. Validated Qualitative advice based on CMSY.

8 References

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