Stock Assessment Form

Demersal species

Reference year: 2019

Reporting year: 2021

STOCK ASSESSMENT OF CUTTLEFISH IN GSA17

The Italian, Croatian and Slovenian fleets exploit cuttlefish with several gears: otter trawl, rapido trawl and set gears (trammel nets, pots and fyke nets), with nearly 95% of catches coming from the Italian side. The historical catches trend is generally decreasing and from year 2010 onward were registered the lowest catches of the timeseries.
Fishery independent data collected in the framework of SoleMon survey show a decrease of relative abundance and biomass from 2007 to 2010. Hereinafter the biomass index shown an upward trend until 2014, then it fluctuated between the 33rd and the 66th percentiles up to year 2019.
CMSY production model showed that the exploitation (F current) is slightly below F_{MSY}, but the biomass is smaller than the safe biological limits (B_{MSY}). Therefore, the advice would be to reduce the fishing mortality and to implement a recovery plan to improve the status of the stock in term of biomass.

Stock Assessment Form version 1.0 (February 2021)

Uploader: *Enrico Nicola Armelloni*

Stock assessment form

1 Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Sepia officinalis	Common cuttlefish	57
1st Geographical sub-area:	2nd Geographical sub-area:	3rd Geographical sub-area:
17		
4th Geographical sub-area:	5th Geographical sub-area:	6th Geographical sub-area:
1st Country	2nd Country	3rd Country
Italy	Croatia	Slovenia
4th Country	5th Country	6th Country
Stock assessment method: (direct, indirect, combined, none)		
Indirect: CMSY		
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2 Stock identification and biological information

The Common Cuttlefish (*Sepia officinalis,* Linnaeus, 1758) is one of the best known European cephalopods (Lishchenko et al. 2021) and one of the most exploited cephalopods worldwide, and it represents a valuable resource in the Adriatic Sea. It is a bottom dwelling species that typically inhabits the continental shelf, where it prefers muddy and sandy bottoms covered with seaweed and phanerogams (Relini et al., 1999). The depth limit for this species is around 200 m, after which the shell does not longer support the water pressure (Guerra 2006).

S. officinalis is an opportunistic animal, which diet varies according to the animal size and the ecological characteristics of the environment. The diet includes crustaceans, bony fishes, molluscs, polychaetes and nemertean worms (Guerra 2006), with the ratio crustacean/bony fishes that will decrease during the animal life. Large individuals might show cannibalistic behavior (Fabi et al. 2001).

Its lifecycle in the Adriatic Sea has been analyzed by several authors, which described the local trajectories of the ontogenetic seasonal migrations (i.e.: Vrgoč et al. 2004): in winter cuttlefishes reside in circalittoral zone, where it matures sexually; in spring the mature individuals migrate to the shallower infralittoral region to spawn; in summer the juveniles resides mostly in the infralittoral region and during autumn the recruits withdraws into deeper waters.

2.1 Stock unit

The criteria used to identify the stock unit in the present assessment were (1) genetics, (2) life history traits and dispersal potential and (3) the exploitation patterns.

1- The assessment of spatial patterns of genetic diversity and related demographic features of cuttlefish within the Adriatic basin has been only partially investigated. Results from comparative micro-satellite variation analysis suggests the presence of a panmictic population (Garoia et al. 2004), as the seasonal migrations occurring for reproduction could determine admixture of different cohorts determining genetic disequilibrium and random genetic differentiation. However, data show temporal genetic unstableness, suggesting the need of further analysis and recommending cautionary approach to the management (Garoia et al. 2004).

2- Regarding life-history traits, this species lacks of any planktonic stage in its lifecycle: in fact, eggs are attached to fixed substrates and the hatchlings are already benthic (Nixon and Mangold 1998; Boletzky and Villanueva 2014). The dispersal potential is low (ICES 2019) and the mixing effect within the basin it is reduced, indeed it is likely that some degree of population structure exists. In the future will be advisable to evaluate non-genetic approaches for stock identification (such as morphological analysis or trace element, i.e Jones and Lishchenko 2019).

3- The exploitation pattern was evaluated by analyzing the spatial distribution of trawlers in the basin (Russo et al. 2018; author elaborations based on Galdelli et al. 2019). It results that vessels coming from the GSA 18 often goes in the GSA 17, however they exploit fishing grounds where cuttlefish abundance is low. Vice versa, a low occurrence of vessels coming from GSA 17 was detected in the fishing ground of the southern area of the basin. For this reason, it was concluded that the fleets of the two GSAs scarcely interact for the exploitation of common cuttlefish.

Considering the information described above, in the present assessment the stock has been considered confined to the GSA 17.

2.2 Growth and maturity

Cuttlefish is a fast growing species, which reproductive behavior has been investigated for a long time (i.e.: Boyle 1983). The female produces clusters of eggs (diameter from 6mm to 8mm, (Mandic et al. 1981)), individually enclosed in a though external coating, attaches them to hard substrates and does not provide any parental care. The most typical substrata are plants and leaves, tubes of polychaetas and also crabs. In spite the fact that females might spawn on artificial substrata (including fishing gears; Bloor et al. 2013), the reduction of essential habitats (such as seagrass meadows) might have a negative impact on the recruitment dynamics (Grati et al. 2018).

Cuttlefish, as most cephalopod species, has a flexible reproductive framework: generally females die soon after breeding (Goff and Daguzan, 1991), however some examples of intermittent spawning has been documented (Laptikhovsky et al. 2003). Even if cuttlefish is a terminal spawner, terminal reproduction might be drawn out over a relatively long time during which the spawning female feeds regularly (Mangold 1983).

The spawning period of this species in the northern and central Adriatic have its peak in April and May, but females with mature eggs can be found throughout the year (Vrgoč et al. 2004). The 50% mature size has been identified was as 6 cm for males and 7 cm for females (Bettoso et al. 2016), however there are cases when maturity is attained at large sizes. Longevity of the common cuttlefish strictly depends on the reproductive behavior: within European waters might last from 14 to 24 months (Pierce et al. 2010), although there is no specific information on the Adriatic sea population. This species can grow to a maximum of 35 cm (mantle length), but the usual length ranges between 15 to 20 cm (Piccinetti Manfrin and Giovanardi 1984).

The recruitment and availability of cuttlefish, similarly to the majority of cephalopod species, it is likely to be affected by the environmental characteristics (Pierce et al. 2008; Rodhouse et al. 2014). In particular, cephalopods might exhibit quick responses to environmental changes "actively", by migrating in search of more favorable conditions (e.g.: Doubleday et al. 2016), and "passively", being affected hatchlings characteristics (e.g.: Villanueva et al. 2016; Armelloni et al. 2020). For this reason, in the future will be crucial to considering the effects of the environment on the species distributions and on the recruitment success in support to cephalopod fisheries management (ICES 2019).

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

Somatic magnitude measured (LT, LC, etc)			ML	Units	mm
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	Spring - Summer
Maximum size observed			350	**Recruitment season**	Fall
Size at first maturity	70	60	-	**Spawning area**	
Recruitment size to the fishery			60-80	**Nursery area**	

Table 2.2-2: Growth and length weight model parameters

			Sex			
		Units	**female**	**male**	**Combined**	**Years**
Growth model	L_∞					
	K					
	t_0					
	Data source					
Length weight relationship	**a**				0.22041	
	b				2.773	
	M (scalar)					
	sex ratio (% females/total)	53				

3 Fisheries information

3.1 Description of the fleet

Like in many areas of the Mediterranean Sea (Belcari et al. 2002), Cuttlefish in the Adriatic Sea is targeted by both demersal trawl fleet (bottom trawl and "rapido" trawl) and artisanal fleet (trammel nets, fyke nets and specific pots; e.g. Fabi et al. 2001). Discards of this species is virtually absent (Sartor et al. 1998), so it can be assumed that catches are equal to landings. While weights of landings are similar among the fleets, the gears selectivity is related to the ontogenetic seasonal migrations (**Figure 1** Length frequencies distributions of the Italian landings by gear in GSA 17. Source: DCF 2020 Italian data call.

Trammel nets, fyke nets and pots, fishing in coastal waters during reproductive period, mainly exploit sexually mature individuals. In particular, pots are equipped with plastic materials used to attract spawning females for eggs clusters deposition (Fabi et al. 2001; Grati et al. 2018). One possible impact of traps, though, is the high mortality of the eggs attached inside in cases when the fisherman employ destructive devices (i.e. pressure washers) to clean up the fishing gear (Blanc and Daguzan 1998; Melli et al. 2014).

Trawling gear are not selective for either recruits or spawners (Bettoso et al. 2016), and landings from those metiérs prevail during autumn-winter.

Effort data (STECF 2020) are available for Italian (2008-2018), Croatian (2012-2019) and Slovenian (2008-2019) fleets, showing three different patterns (**Figure 2**): (1) almost linear decline (Croatian DRB and DTS; Slovenian DTS); (2) oscillating but generally declining (Italian PGP); (3) oscillating but comparable values at beginning and at the end of the timeseries (Italian TBB and DTS).

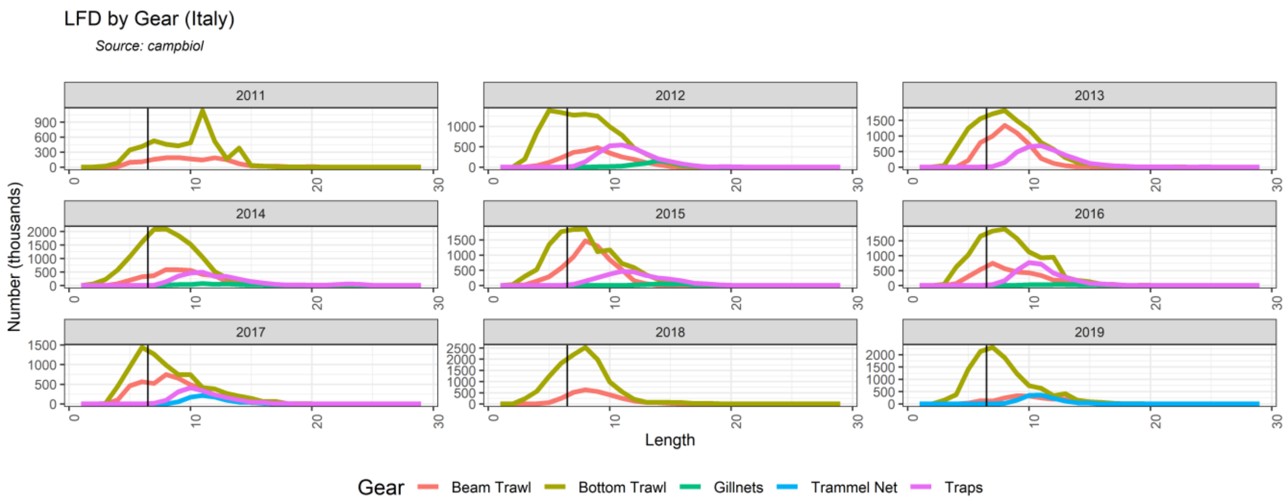

Figure 1 Length frequencies distributions of the Italian landings by gear in GSA 17. Source: DCF 2020 Italian data call. Vertical line indicates size at first maturity (6.5 cm).

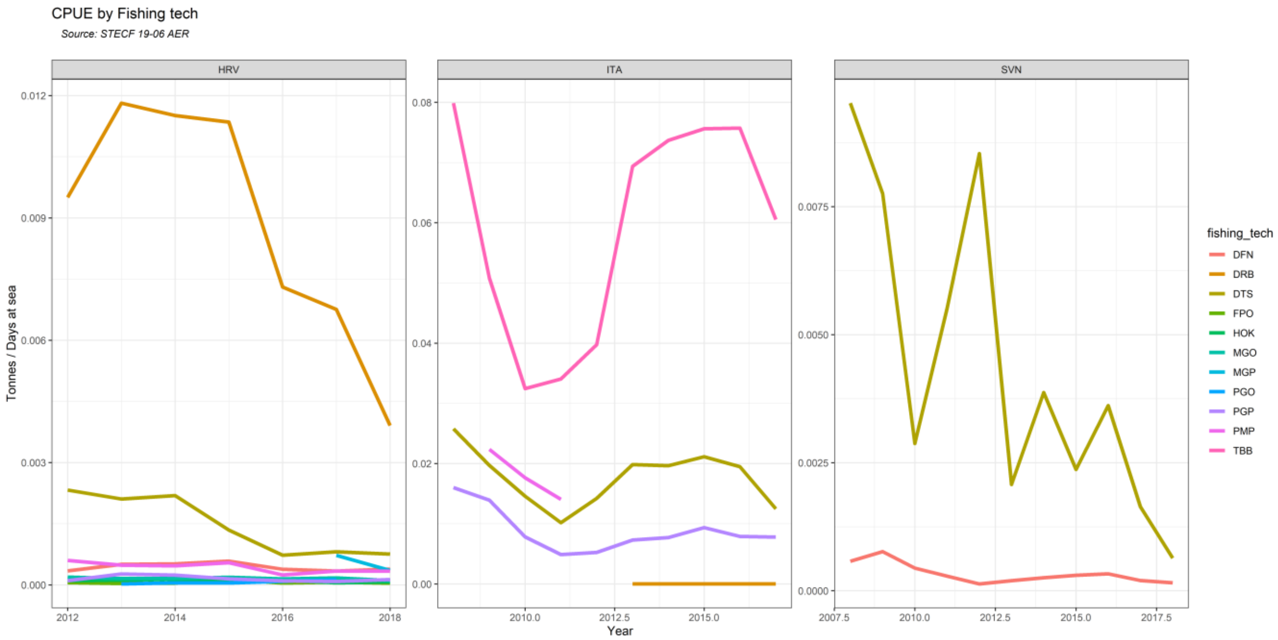

Figure 2 CPUE by gear in GSA 17. Source: STECF, 2019

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	17	E - Trawl (12-24 metres)	98 - Other Gear (rapido trawl)	33 - Demersal shelf species	
Operational Unit 2	ITA	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	
Operational Unit 3	ITA	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets Traps	33 - Demersal shelf species	
Operational Unit 4	HRV	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	
Operational Unit 5	SVN	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	

Operational Unit 6	HRV	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	
Operational Unit 7	SVN	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	

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

Operational Units*	**Fleet (n° of boats)***	**Catch (T or kg of the species assessed)**	**Other species caught (names and weight)**	**Discards (species assessed)**	**Discards (other species caught)**	**Effort (days at sea)**
Operational Unit 1		392.7				10270 (Year 2018)
Operational Unit 2		1103.9				76737 (Year 2018)
Operational Unit 3		829.8				134979 (Year 2018)
Operational Unit 4		49.7				113024
Operational Unit 5		1.2				5296
Operational Unit 6		40				37450
Operational Unit 7		3.7				817
Total		2421				397739

3.2 *Historical trends*

Landings dataset was reconstructed by exploring different data source (**Figure *3***), however it should be considered that reliability can differ among countries and period considered due to changes in the level of accuracy of fishery statistic reporting (Mannini and Massa 2000). Nonetheless, it is assumed that overall trend patterns in fisheries landings are reflected in the provided timeseries.

For the Italian side data from 1972 to 1999 were obtained from Fortibuoni et al. (2018), which digitalized Italian official data for the considered period. For the period 2000-2003 the data were provided by the Italian government and for the period 2004-2019 data were available from the EU DCF (Data call Med).

For the Croatian side, data from 1992 to 2011 were available from EUROSTAT database (https://ec.europa.eu/eurostat/web/fisheries/data/database) and from 2012 to 2018 from (STECF 2020).

For the Slovenian side, data from 1992 to 1999 were obtained from FishStatJ (FAO 2017), from 2000 to 2007 from EUROSTAT database and from 2008 to 2019 from STECF 2020. Data for Croatia and Slovenia for the period 1972-1991 were reconstructed using the formula $L_{Year} = L\ ITA_{Year} * r$, were L are aggregated landings for Croatia and Slovenia, L ITA are landing for Italy and r is the average of the ratio (Croatia + Slovenia) / Landings Italy for the period 1992-2002.

Considering the aggregated landings timeseries (**Figure 4**), the trend is highly oscillatory according to a possible correlation between recruitment success and environmental characteristics already documented for a number of cephalopod species (Pierce et al. 2008; Rodhouse et al. 2014; ICES 2019). Nonetheless, the trend is generally declining and the high spikes observed in the past have been registered less frequently in recent years. From 2010 were registered some of the lowest values of the timeseries.

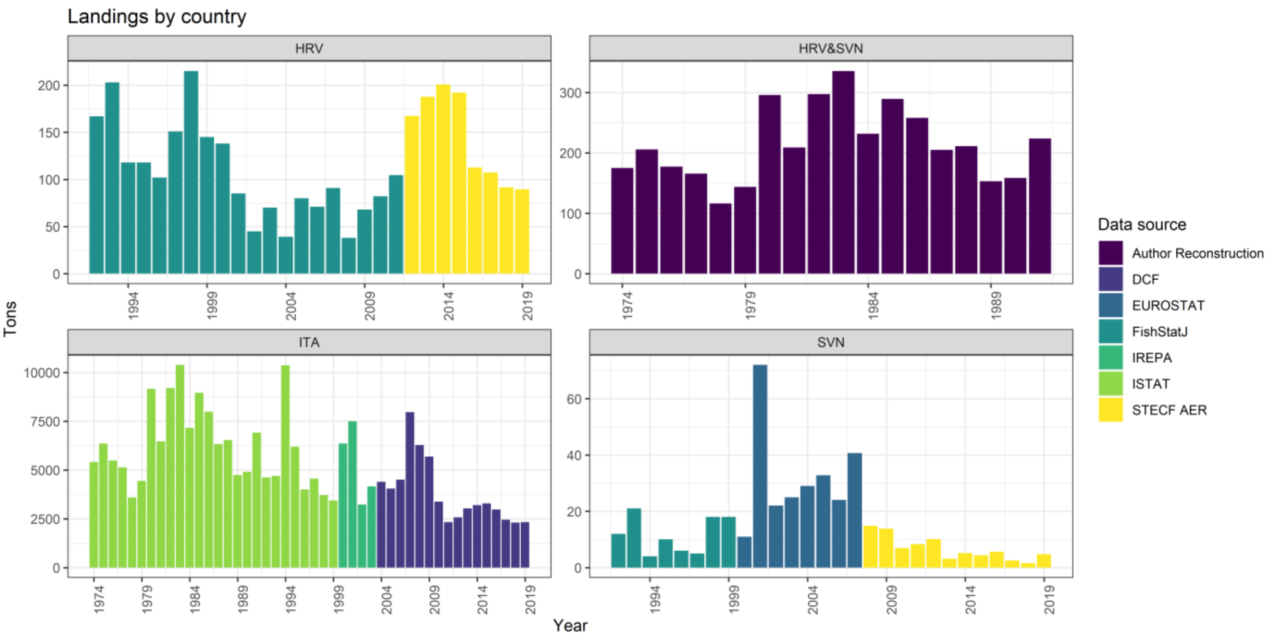

Figure 3: in the panels are shown annual landings by country, with colors referring to the data source

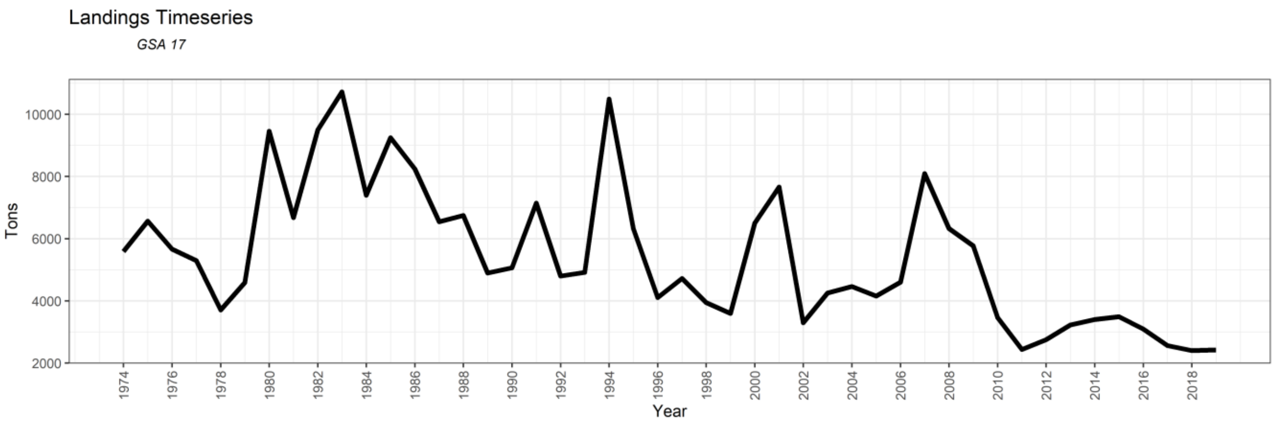

Figure 4: the reconstruction of aggregated landings timeseries

3.3 Management regulations

In Italy, Slovenia and Croatia the main rules in force are based on the applicable EU regulations (mainly EC regulation 1967/2006 and 1380/2013):

- Minimum landing sizes: NA
- Codend mesh size of trawl nets: 40 mm (stretched, diamond meshes) till 30/05/2010. From 1/6/2010 the existing nets have been replaced with a codend with 40 mm (stretched) square meshes or a codend with 50 mm (stretched) diamond meshes.
- Towed gears are not allowed within three nautical miles from the coast or at depths less than 50 m when this depth is reached at a distance less than 3 miles from the coast.
- Set net minimum mesh size: 16 mm stretched.
- Set net maximum length x vessel x day: 5,000 m

Temporal bans for trawling gears (OTB, TBB and PTM):

- Minimum of 45 days of absolute ban during summer, whitin a period varying according to maritime compartments (Fully observed).
- In the period following the ban, for approximately 30 days, trawling gears are not allowed to operate whitin six nautical miles or at depth less than 60 m. (Not fully observed). Are excluded from this regulation those vessels operating in maritime compartments of Trieste and Monfalcone.

Numerous regulations have been adopted in Croatia to regulate fishing gears' technical characteristics and their use with regard to commercial, small-scale and sport fishing. An Ordinance of 1996 on commercial fishing (46/96) prescribes, according to the type of license granted to a vessel, the quantities and types of gear that can be carried on board and used from that vessel. Mesh sizes of nets and other fishing gears as well as their area and time of use have also been determined in Regulations on Commercial Fishing of 2000 (83/2000) and are summarized in Table 1.

Table 3.3-1 Specific characteristic for the trammel net used in Croatia to target common cuttlefish

	Allowed quantities per license in pieces or length (m)	**Minimum Mesh size in mm or number of hooks**	**Time of use (open season)**	**Area of use**
Trammel net for cuttle fish (*Sepia officinalis*)	800	32 - 38 mm (middle layer) and 150 – 170 mm (outer layer)	1/9 to 1/6	

3.4 Reference points

Table 3.4-1: List of reference points and empirical reference values previously agreed (if any)

Indicator	Limit Reference point/empirical reference value	Value	Target Reference point/empirical reference value	Value	Comments
B			Bmsy		
SSB					
F			Fmsy		
Y					
CPUE					
Index of Biomass at sea					

4 Fisheries independent information

4.1 SoleMon

Solemon survey is a trawl fishing survey conducted with a modified beam trawl (Rapido; **Figure 5**), carried out in GSA 17 from 2005 to 2019 (**Figure 6**): one systematic "pre-surveys" (fall 2005) and the rest random surveys (fall 2006 to fall 2017) stratified on the basis of depth (0-30 m, 30-50 m, 50-100m). Hauls were carried out by day using 2-4 *rapido* trawls simultaneously (stretched codend mesh size = 46). The following number of hauls was reported per depth stratum (Tab. 4.1.1). Due to the low representation of HRV stratum, these hauls are not used to calculate the index.

Table 4.1-1 Number of hauls per year and depth stratum in GSA 17, 2005-2017

Depth strata	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0-30	30	35	32	39	39	39	39	35	37	39	39	39	38	40	39
30-50	12	20	19	18	18	18	18	18	18	18	18	18	16	15	16
50-120	15	8	11	10	10	10	10	10	10	10	10	10	10	11	11
HRV	5	4	0	0	0	0	0	0	0	0	0	7	6	0	0
Total	62	67	62	67	67	67	67	63	65	67	67	74	70	66	68

Abundance and biomass indexes from *rapido* trawl surveys were computed using TRUST software (https://www.kosmosambiente.it/scientifictrawlsurveys/). The abundance and biomass indices by GSA 17 were calculated through stratified means (Cochran et al. 1954; Saville 1977). This implies weighting of the average values of the individual standardized catches and the variation of each stratum by the respective stratum area in the GSA 17:

$Yst = \Sigma (Yi*Ai) / A$

$V(Yst) = \Sigma (Ai^2 * si^2 / ni) / A^2$

Where:

A=total survey area

Ai=area of the i-th stratum

si=standard deviation of the i-th stratum

ni=number of valid hauls of the i-th stratum

n=number of hauls in the GSA

Yi=mean of the i-th stratum

Yst=stratified mean abundance

V(Yst)=variance of the stratified mean

The variation of the stratified mean is then expressed as the 95 % confidence interval: Confidence interval = Yst ± t(student distribution) * V(Yst) / n

It was noted that while this is a standard approach, the calculation may be biased due to the assumptions over zero catch stations, and hence assumptions over the distribution of data. A normal distribution is often assumed, whereas data may be better described by a delta-distribution, quasi-poisson. Indeed, data may be better modelled using the idea of conditionality and the negative binomial. Length distributions represented an aggregation (sum) of all standardized length frequencies over the stations of each stratum. Aggregated length frequencies were then raised to stratum abundance and finally aggregated (sum) over the strata to the GSA. Given the sheer number of plots generated, these distributions are not presented in this report.

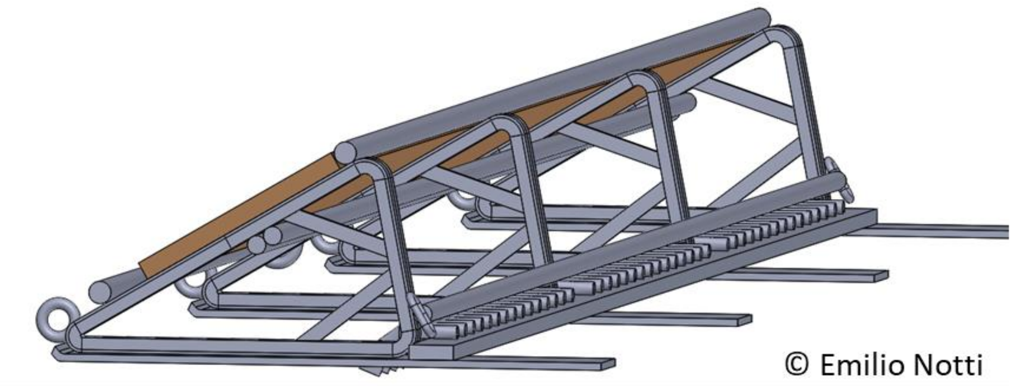

Figure 5: the mouth of the "Rapido" gear

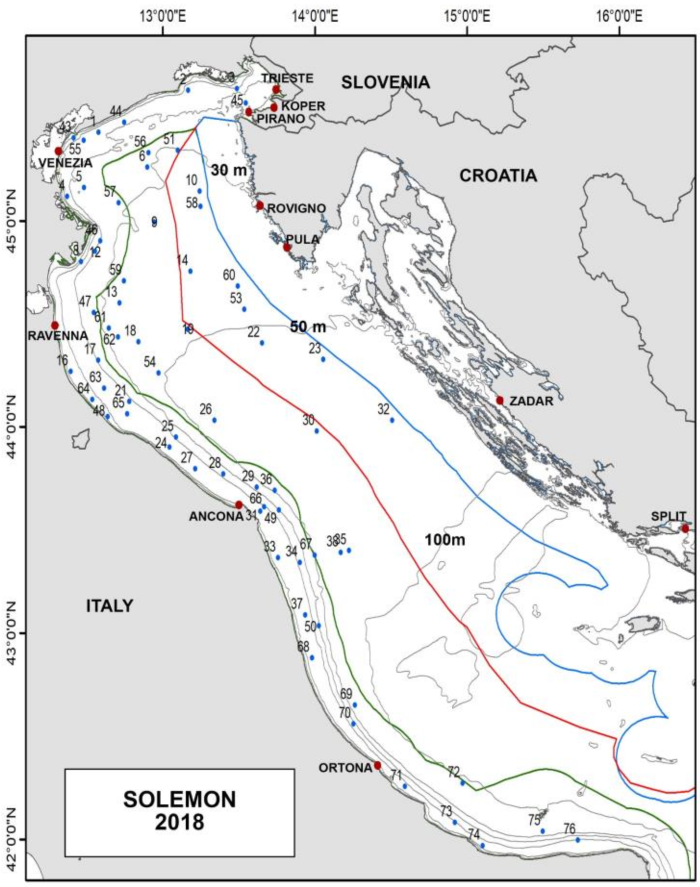

Figure 6: Solemon map of hauls positions in 2018. Image credits: C. Ferrà

Direct methods: trawl based abundance indices

Table 4.1-2 Trawl survey basic information

Survey	SoleMon	**Trawler/RV**	Dallaporta
Sampling season	Fall		
Sampling design	Random stratified		
Sampler (gear used)	Rapido trawl		
Codend mesh size as opening in mm	46		
Investigated depth range (m)	5-120		

Table 4.1-3 Trawl survey sampling area and number of hauls 2018. Note that hauls in HRV stratum have been removed from the analyses.

Stratum	**Total surface (km^2)**	**Trawlable surface (km^2)**	**Swept area (km^2)**	**Number of hauls**
1	11512		1.343	39
2	8410		0.55	16
3	22466		0.36	11
HRV	6000		0.09	0

Table 4.1-4 Trawl survey abundance and biomass results

Years	kg per km^2	St Dev	Relative * biomass All age groups	CV	N per km^2	St Dev	Relative * abundance All age groups	CV
2005	28.35	6.18		21.79	328.09	128.55		39.18
2006	62.55	11.45		18.30	618.69	90.99		14.71
2007	92.89	16.81		18.10	523.46	98.89		18.89
2008	39.56	6.22		15.72	308.17	51.58		16.74
2009	37.90	6.26		16.52	218.29	31.71		14.52
2010	16.57	2.98		17.97	101.06	17.70		17.51
2011	26.28	4.41		16.78	151.62	31.41		20.72
2012	44.78	8.93		19.95	314.97	65.42		20.77
2013	31.35	5.87		18.72	247.82	51.88		20.93
2014	58.13	10.78		18.54	337.62	59.05		17.49
2015	31.14	5.56		17.85	250.95	49.94		19.90
2016	38.50	5.63		14.61	286.23	51.19		17.88
2017	25.63	5.53		21.57	204.19	47.17		23.10
2018	35.84	5.44		15.18	266.31	42.19		15.84
2019	36.73	6.28		17.11	239.18	51.59		21.57

Direct methods: trawl based length/age structure of population at sea

Slicing method

No slicing method was used in the present assessment

Table 4.1-5 Trawl surveys; recruitment analysis summary

Survey	**SoleMon**	**Trawler/RV**	**Dallaporta**
Survey season		Fall	
Cod –end mesh size as opening in mm		46	
Investigated depth range (m)		0-120	
Recruitment season and peak (months)		September-October-November	
Age at fishing-grounds recruitment		0	
Length at fishing-grounds recruitment		5	

Table 4.1-6 Trawl surveys; recruitment analysis results

Years	**Area in km²**	**N of recruit per km²**	**St DEv**
2005		47.71	14.07
2006		224.91	32.41
2007		69.93	16.26
2008		104.37	23.21
2009		37.98	7.65
2010		17.34	4.65
2011		20.17	4.14
2012		64.86	14.37
2013		72.49	20.85
2014		61.37	12.08
2015		53.01	14.32

2016		86.26	23.68
2017		51.17	13.38
2018		56.64	13.50
2019		53.42	21.63

The recruitment is mainly localised in the coastal close to Po river mouth. The recruits have been estimated on the base of the LFD observed from the survey (0-8 cm; **Figure 7**)

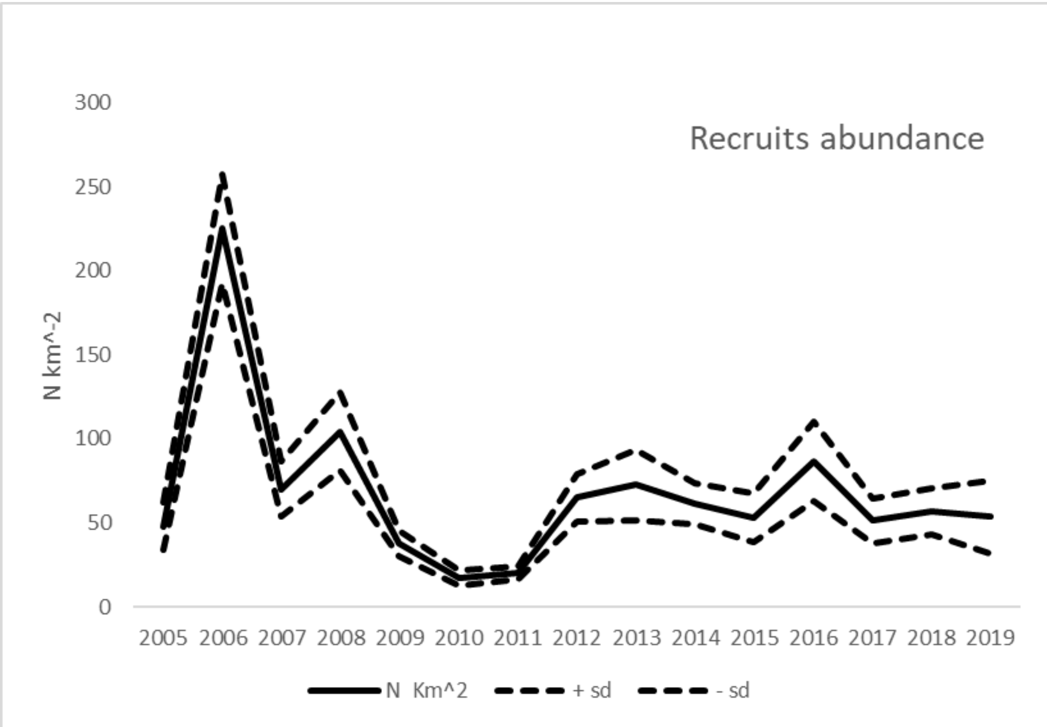

Figure 7: Abundance indices (± s.d.) of cuttlefish recruits obtained from SoleMon surveys

Direct methods: trawl based Spawner analysis

Table 4.1-7 Trawl surveys; spawners analysis summary

Survey	SoleMon	Trawler/RV	Dallaporta
Survey season			Fall
Investigated depth range (m)			0-120
Spawning season and peak (months)			November-December

Table 4.1-8 Trawl surveys; spawners analysis results

Surveys	Area in km^2	N (N of individuals) of spawners per km^2	St Dev	SSB per km^2	St Dev	Relative SSB	CV or other
2005		35.92	11.07				
2006		165.71	38.05				
2007		296.14	61.13				
2008		118.25	21.74				
2009		132.08	20.54				
2010		57.87	10.22				
2011		99.17	20.15				
2012		151.94	32.97	30.33	6.34		
2013		97.59	18.76	18.97	3.37		
2014		192.32	34.28	46.63	10.49		
2015		93.39	16.72	18.77	3.38		
2016		110.67	15.17	25.12	3.8		
2017		69.94	14.60	14.82	2.98		
2018		113.47	19.54	23.59	3.78		

Surveys	Area in km²	N (N of individuals) of spawners per km²	St Dev	SSB per km²	St Dev	Relative SSB	CV or other
2019		118.45	21.04	27.67	4.20		

The spawners aggregates in the north sector of the sub-basin mainly in front of the Istria peninsula, the trend of spawners abundance are showed in **Figure 8** (> 10 cm).

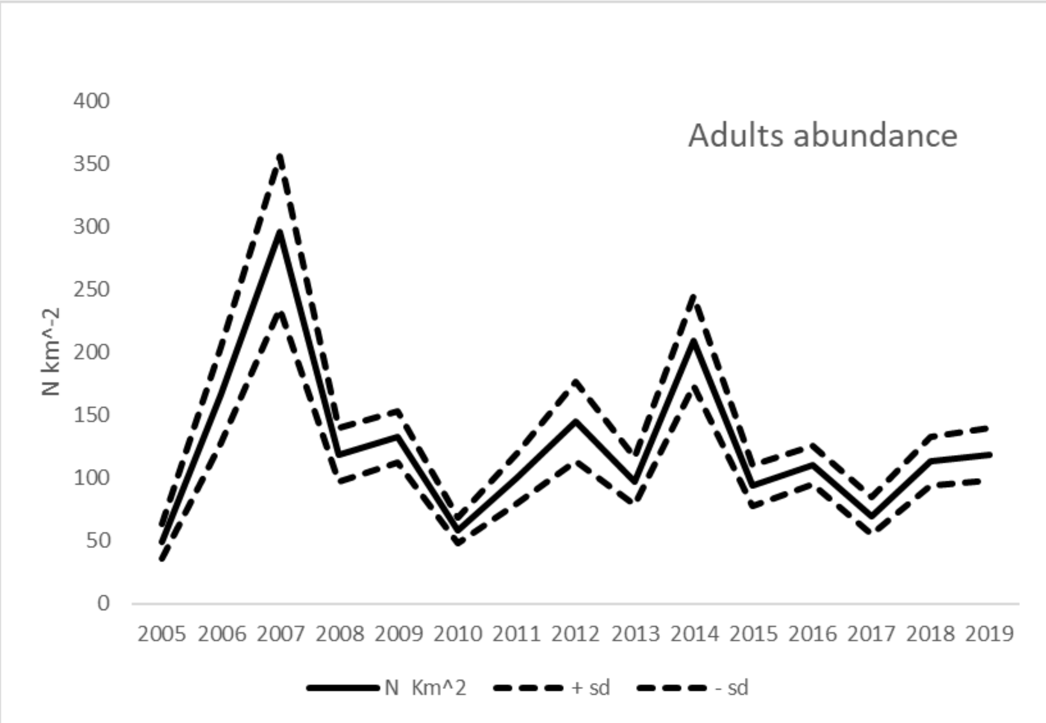

Figure 8: Abundance indices (± s.d.) of cuttlefish adults obtained from SoleMon surveys.

4.1.1 Spatial distribution of the resources

According to data collected during SoleMon surveys, cuttlefish aggregates in the northern sector of GSA 17 (**Figure** 9).

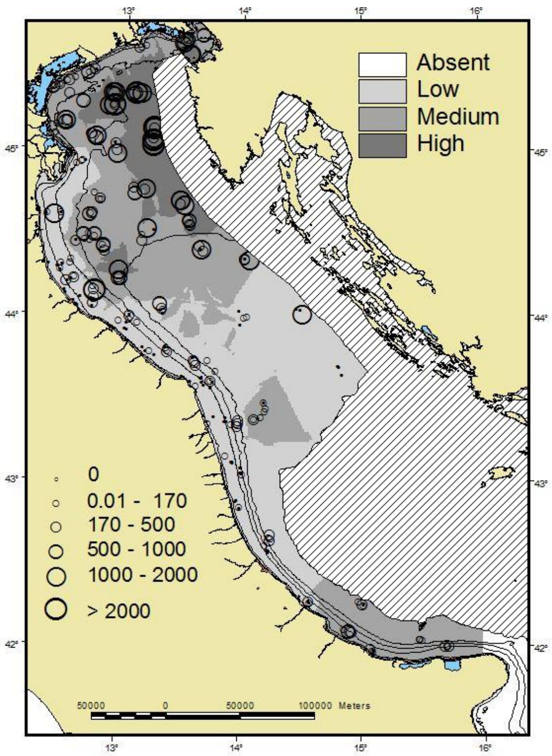

Figure 9: Maps distribution of cuttlefish in GSA 17 (bubbles: N km^{-2}), based on Solemon data.

4.1.2 Historical trends

The SoleMon trawl surveys provided data either on cuttlefish total abundance and biomass as well as on important biological events (recruitment, spawning). **Figure 10** shows the indices of cuttlefish obtained from 2005 to 2018 and **Figure *11*** show the annual LFDs.

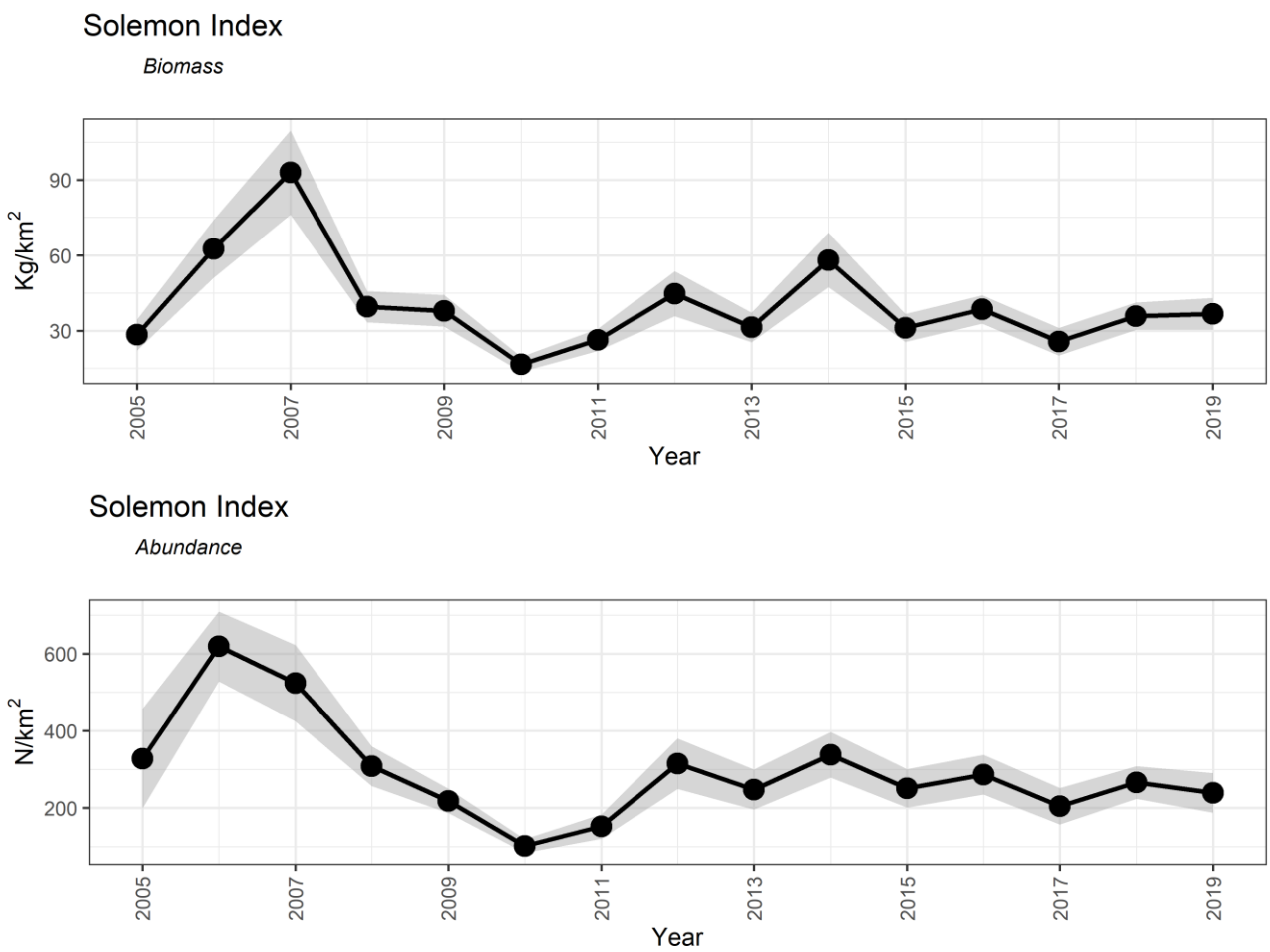

Figure 10: Density and Biomass indices (± s.d.) of cuttlefish obtained from SoleMon surveys.

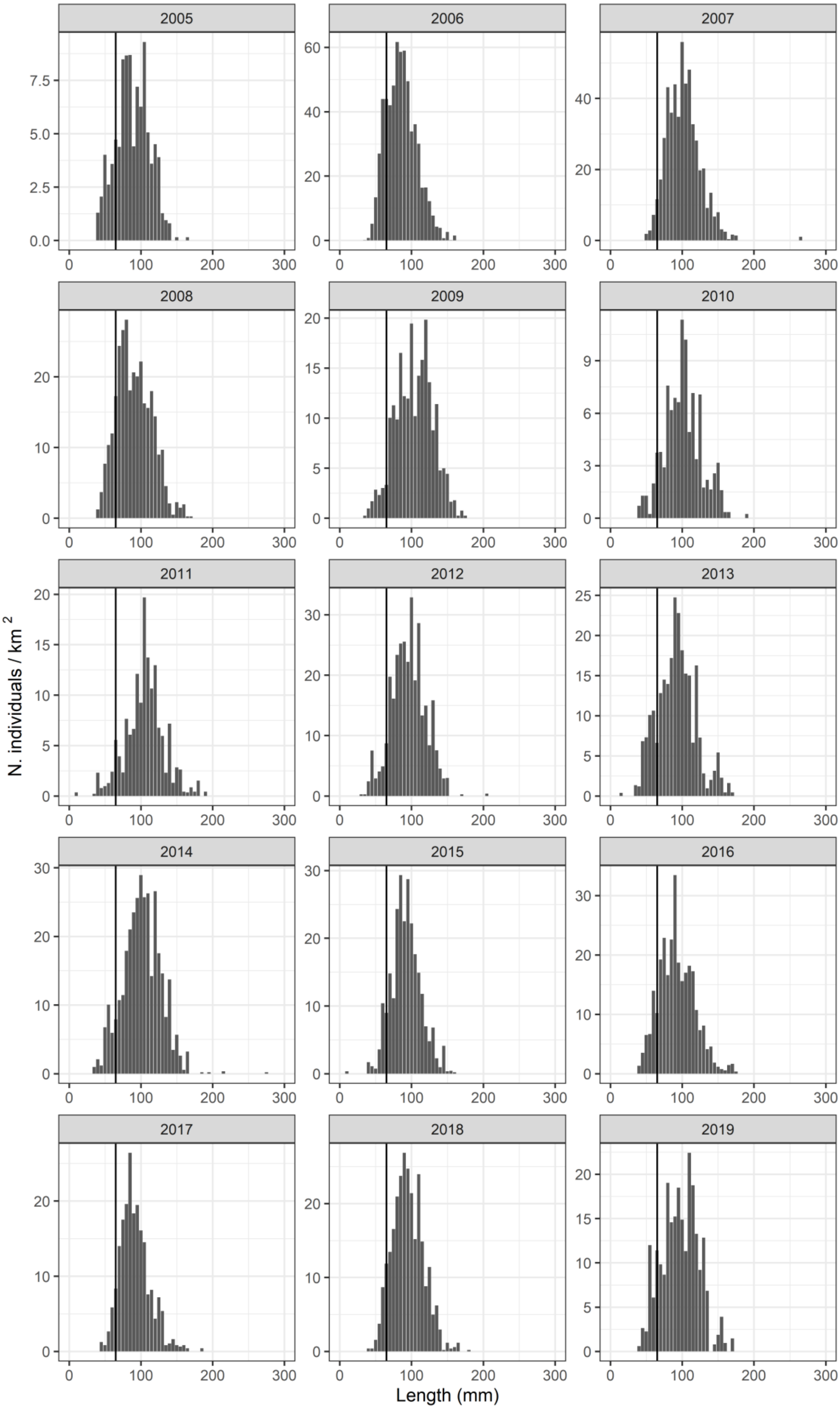

Figure 11 Stratified abundance indices by size, 2005-2019. Vertical line: size at first maturity

5 Ecological information

5.1 Protected species potentially affected by the fisheries

Rapido trawl fishery has a deleterious effect on benthic habitat (Pranovi et al. 2000). The list of species discarded during the fishing operation is presented in the table below.

Table 5.1-1 List of species/taxonomic groups and their mean biomass in rapido trawl fishery from Central Western Adriatic Sea

Taxa	Stratum 0-30 (kg km^{-2})	Stratum 30-60 (kg km^{-2})
Annelida		
Aphrodite aculeata	0.096	4.706
Glycera spp	0.001	0.006
Polychaeta	0.248	0.027
Cnidaria		
Alcyonum spp		0.112
Calliactis parasitica	0.002	0.033
Unidentified anemone	0.019	0.600
Unidentified colonial hydroid		0.065
Virgularia mirabilis	0.018	3.405
Crustacea		
Alpheus glaber	0.002	0.001
Corystes cassivelaunus	0.023	
Goneplax rhomboides	10.385	16.042
Inachus comunissimus	0.030	
Inachus phalangium	1.979	0.004
Inachus spp	0.531	0.002
Liocarcinus depurator	8.292	178.664
Liocarcinus vernalis	9.168	0.609
Lysmata seticaudata		0.019
Medorippe lanata	4.375	2.979
Melicertus kerathurus	0.208	0.213
Nephrops norvegicus	0.006	0.044
Pagurus excavatus	0.019	0.045
Pagurus spp	0.364	0.299
Parapenaeus longirostris		0.154
Parthenope angulifrons	0.755	
Pilumnus hirtellus	0.033	
Squilla mantis	5.197	0.397
Echinodermata		
Astropecten irregularis	28.562	8.210
Holothuroidea	0.135	1.771
Marthasterias glacialis	0.174	4.511
Ophiura ophiura	2.592	
Schizaster canaliferus	0.413	0.020
Spatangoida	0.033	
Trachythyone elongata	0.238	2.194
Trachythyone spp	0.022	0.368
Trachythyone tergestina	0.125	3.270
Mollusca		
Acanthocardia paucicostata	0.238	0.072
Acanthocardia tubercolata	0.307	0.146
Aequipecten opercularis	0.136	
Alloteuthis media	0.025	0.003
Antalis dentalis	0.047	
Antalis inaequicostata	0.639	0.001
Antalis spp	0.168	
Aporrhais pespelecani	299.666	6.160
Atrina pectinata	0.190	0.909
Bolinus brandaris	11.135	0.625
Calliostoma spp	0.008	0.310
Cassidaria echinophora		0.784
Chamelea gallina	0.183	
Chlamys varia	0.082	0.004
Corbula gibba	43.145	0.030

Flexopecten glaber glaber	1.389	0.007
Glossus humanus		0.710
Hexaplex trunculus	0.712	0.089
Illex coindetii	0.012	0.004
Mytilus galloprovincialis	2.774	0.907
Nassarius lima	0.068	0.010
Nassarius mutabilis	0.577	0.002
Nassarius reticulatus	0.748	0.001
Naticarius hebraea	0.025	
Naticarius stercusmuscarum	2.219	
Neverita josephinia	0.030	
Nucula nitidosa	0.002	0.004
Nucula nucleus	0.006	0.021
Nucula sulcata	0.003	0.203
Ostrea edulis	94.311	3.043
Pectinidae	0.112	0.060
Polinices nitida	0.001	
Scapharca demiri	30.051	0.009
Scapharca inaequivalvis	137.864	0.290
Scaphodopa	0.077	
Sepia elegans	0.026	0.122
Sepia officinalis	0.465	0.367
Solecurtus strigilatus	0.217	
Turritella communis	0.808	2.758
Unidentified nudibrancs	0.553	
Venerupis aurea	2.552	
Osteichthyes		
Arnoglossus laterna	0.820	1.101
Blennius ocellaris		0.152
Boops boops	0.291	0.033
Buglossidium luteum	0.150	0.110
Cepola macrophthalma		0.487
Chelidonichthys lucernus	3.727	1.214
Citharus linguatula	0.005	0.083
Diplodus annularis	0.130	
Engraulis encrasicolus	0.032	0.019
Eutrigla gurnardus	0.002	0.239
Gobius niger	1.114	0.675
Lesueurigobius friesii	0.005	0.048
Merluccius merluccius	0.129	0.256
Mullus barbatus barbatus	0.234	0.095
Pagellus erythrinus	0.150	0.104
Sardina pilchardus	0.039	0.046
Sardinella aurita	1.081	0.635
Scorpaena notata	0.005	0.239
Serranus hepatus	0.010	0.200
Solea solea	0.128	0.004
Spicara maena	0.058	0.046
Spicara smaris		0.017
Trachurus mediterraneus	0.051	0.007
Porifera		
Unidentified sponge	0.017	0.376
Tunicata		
Ascidiacea		0.189

[a] Commercially harvested groups are indicated in bold face.

6 Stock Assessment

6.1 C-MSY

6.1.1 Model assumptions

CMSY (Froese et al. 2017) 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, CPUE timeseries and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Probable ranges for the maximum intrinsic rate of population increase (r) and for unexploited population size or carrying capacity (k) are filtered with a Monte Carlo approach to detect 'viable' r-k pairs. 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.

The CMSY version referred in the present assessment (CMSY_2019_9f.R, available at http://oceanrep.geomar.de/33076/) is newer than the one used in Froese et al. (2017). 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+, associated with faster run times.

6.1.2 Priors selection

A prior can be seen as the numerical translation of the expert knowledge about a certain topic in the form of a mean and a standard deviation, and in Bayesian statistics the reliability of a result depends on the use of an appropriate prior distribution (Myers et al. 2002).

In the present work a particular emphasis was given to prior's selection. Here it is provided a summary of methodologies and sources of information used:

- Resilience: priors were obtained from the database SeaLifeBase (Palomares and Pauly).
- Exploitation (Initial): a summary of the status of the fishery in the Adriatic Sea is available from several sources. Basing on the reliability of the author, the trends provided in Marini et al. (2017) were taken as baseline to derive the exploitation status at the beginning of the timeseries, which was set as "Low depletion" in 1972, "Medium depletion" in 1992 and "High depletion" in 2004.
- Exploitation (Final): this prior was set equal to the output of another Bayesian model: AMSY (Froese et al. 2020). AMSY is a Bayesian Surplus production model, which can provide information on stock status (depletion) using CPUE data. Required input data for AMSY are (1) time-series of cpue, (timeseries 2005-2019 for Solemon Biomass trend) , (2) prior ranges for r (information from SeaLifeBase) and (3) relative stock size Bt/k in a given year (attempted

two sets of priors: 0.35-0.65 and 0.5-0.85, both in year 2007, which represent the largest spike of Solemon timeseries and also one of the highest spikes of the landings timeseries).

6.1.3 Input data and Parameters

Detail on reconstruction of dataset are given in paragraph 3.2. For the present assessment, the timeseries considered included years from 1974 to 2019. The addition of data prior to 1992 represent the main difference with previous assessment, where early years when landing data were less reliable were excluded (**Figure 12**). Biomass data were provided by SoleMon surveys, carried out in fall for the years 2005-2019 (**Figure 13**). Priors obtained with methodology explained in par. 6.1.2 are resumed in the table 6.1.3.1.

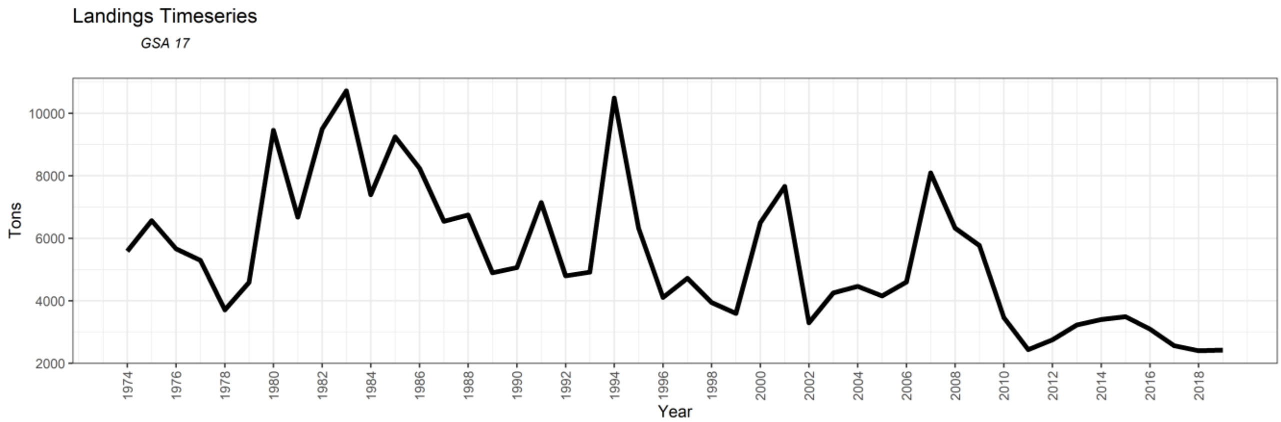

Figure 12: Landings data (tons) used in C-MSY model.

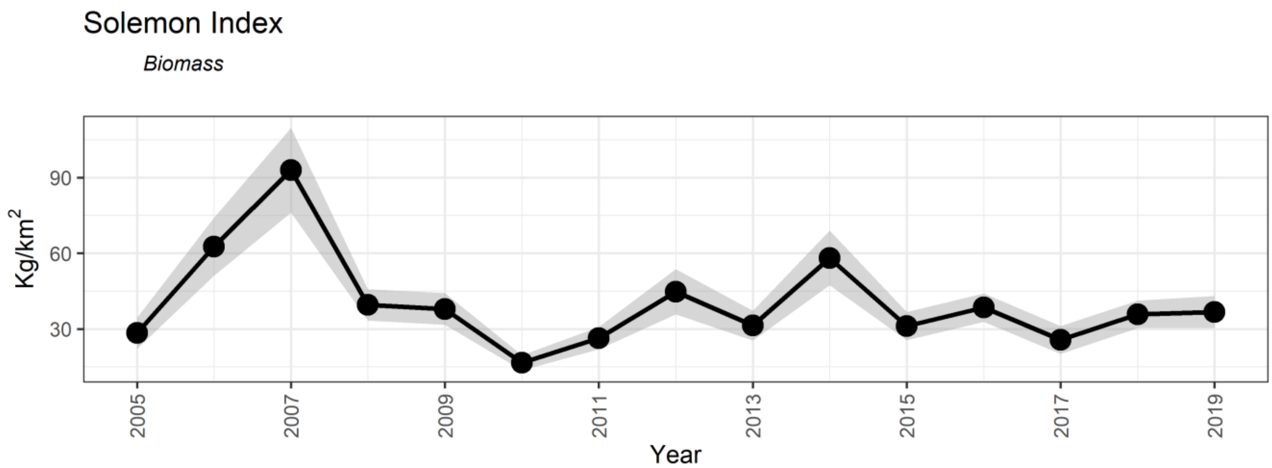

Figure 13: biomass index used in C-MSY model

Table 6.1.3-1 Model priors for the best run

Species	Min of year / Start year	Max of year / End year	Resilience	Stb.low	Stb.hi	Int.yr	Intb.low	Intb.hi	Endb.low	Endb.hi	btype
Common cuttlefish	1974	2018	0.37-0.84	0.6	0.9	2004	0.1	0.4	0.21	0.7	CPUE

6.1.4 Model results

In the following box is reported the screen output of the final run of CMSY for cuttlefish in GSA 17.

```
-------------------------------------
Species: Sepia officinalis , stock: Sepioff_longts
Sepia officinalis
Region: Mediterranean Sea , North Adriatic Sea
Catch data used from years 1974 - 2019 , abundance = CPUE
Prior initial relative biomass = 0.6 - 0.9 expert
Prior intermediate rel. biomass= 0.1 - 0.5 in year 2004 expert
Prior final relative biomass   = 0.21 - 0.7 expert
Prior range for r = 0.37 - 0.84 expert, , prior range for k = 30.4 - 91.1
Prior range of q = 0.00357 - 0.0107 , assumed effort creep 0.2 %

Results of CMSY analysis
------------------------
Altogether 536 viable trajectories for 437  r-k pairs were found
r   = 0.467 , 95% CL = 0.361 - 0.604 , k = 53.8 , 95% CL = 41.7 - 69.4
MSY = 6.17 , 95% CL = 5.48 - 7.05
Relative biomass in last year = 0.627 k, 2.5th perc = 0.324 , 97.5th perc = 0.698
Exploitation F/(r/2) in last year = 0.308 , 2.5th perc = 0.276 , 97.5th perc = 0.595

Results from Bayesian Schaefer model (BSM) using catch & CPUE
----------------------------------------------------------
q   = 0.00341 , lcl = 0.00247 , ucl = 0.00469
r   = 0.513 , 95% CL = 0.379 - 0.695 , k = 48.7 , 95% CL = 37.1 - 63.9 , r-k log correlation = -0.927
MSY = 6.24 , 95% CL = 5.57 - 7
Relative biomass in last year = 0.246 k, 2.5th perc = 0.18 , 97.5th perc = 0.457
Exploitation F/(r/2) in last year = 0.811 , 2.5th perc = 0.433 , 97.5th perc = 1.51

Results for Management (based on BSM analysis)
----------------------------------------------------------
Fmsy = 0.257 , 95% CL = 0.19 - 0.347 (if B > 1/2 Bmsy then Fmsy = 0.5 r)
Fmsy = 0.253 , 95% CL = 0.187 - 0.342 (r and Fmsy are linearly reduced if B < 1/2 Bmsy)
MSY  = 6.24 , 95% CL = 5.57 - 7
Bmsy = 24.3 , 95% CL = 18.5 - 31.9
Biomass in last year = 12 , 2.5th perc = 8.77 , 97.5 perc = 22.3
B/Bmsy in last year  = 0.492 , 2.5th perc = 0.36 , 97.5 perc = 0.915
Fishing mortality in last year = 0.204 , 2.5th perc = 0.11 , 97.5 perc = 0.278
Exploitation F/Fmsy  = 0.811 , 2.5th perc = 0.433 , 97.5 perc = 1.51
Comment: NA -------------------------------------------------------
```

The diagnostic panels are shown in **Figure 14**. The good overlap of the red (CMSY) and blue (BSM) crosses (panels B and C) support the coherence priors estimated by the BSM (based on Catches + CPUE) and by the CMSY model (Catch only model). In panel D the trajectories estimated by CMSY and BSM model diverge in the final years, with the CMSY model (catch-only) being more optimistic.

Figure 15 shows the comparison between priors and posterior understanding of the model. The posterior distribution for K was narrower in comparison to the priors, and resulting small prior to posterior variance ratio (PPVR) indicate that the input data was very informative about K. Regarding r the plot indicates a good agreement between the density distributions, however the larger PPVR value indicates that the data were not informative about r as they were about K. Prior for initial and intermediate depletion are also within the prior interval, while the prior for final depletion touch the lower boundary of the prior distribution.

Figure 16 shows additional information on model diagnostic, included in the last version of CMSY. The catch fit was acceptable, whereas the CPUE fit present some issues. In particular, the CPUE trend (Solemon survey biomass index) was so oscillatory that the most extremes values (in particular 2008 and 2010) were not properly caught, and the red panel indicates evidence for a non-random residual pattern (p>0.05).

Figure 17 shows the graphs meant to inform management. The catch trajectory compared to the MSY (left upper panel) show that the catches in recent years were far lower than the Maximum Sustainable Yeld. A possible explanation is related to the stock size trajectory: in 2010 the biomass fell below the 0.5 B/Bmsy, the threshold below which recruitment may be impaired (Froese et al. 2017). The reduction of exploitation level (left lower panel) from 2010 onward was not enough to permit the stock to recover. Even if the F current is below the Fmsy, the biomass is so low that the stock might need several years to rebuild.

Figure 18 represent the Kobe plot. The timeseries begun when the stock status was in a healthy condition. During the period considered, the effort level registered high pikes that resulted in a progressive erosion of the stock size. In recent years the F level was drastically reduced and fell below the Fmsy, however, the biomass did not increase at the same rate and remained quite below the Bmsy. As a consequence, in 2019 the stock trajectory is located in the yellow panel (with 68 % of probabilities).

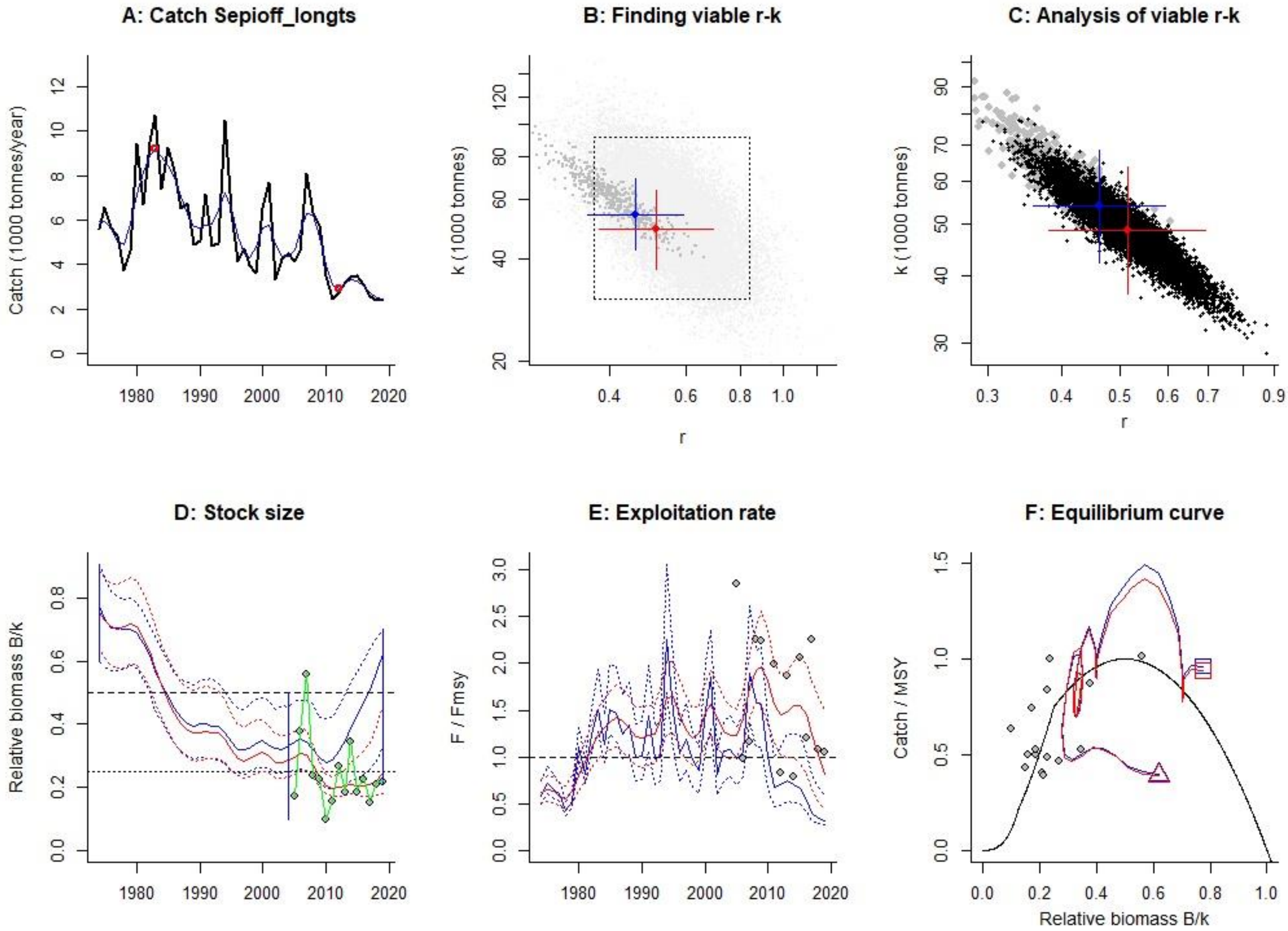

Figure 14: Diagnostics results of final C-MSY run. **Panel A** shows in black the time series of catches and in blue the three-years moving average with indication of highest and lowest catch, as used in the estimation of prior biomass by the default rules. **Panel B** shows the explored multivariate normal distribution of r-k in log 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 blue cross is the most likely r-k pair predicted by CMSY, and the red cross predicted by BSM. **Panel C** shows the most probable r-k pair and its approximate 95% confidence limits in blue. The black dots are possible r-k pairs found by the BSM model, with a red cross indicating the most probable r-k pair and its 95% confidence limits. **Panel D** shows the available abundance data in red, scaled to the BSM estimate of Bmsy = 0.5 k, and in blue the biomass trajectory estimated by CMSY. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. **Panel E** shows in red the harvest rate (catch/abundance) scaled to the r/2 estimate of BSM, and in blue the corresponding harvest rate from CMSY. **Panel F** shows the Schaefer equilibrium curve of catch/MSY relative to B/k, here indented at B/k < 0.25 to account for reduced recruitment at low stock sizes. The red dots are scaled by BSM estimates and the blue dots are scaled by CMSY estimates.

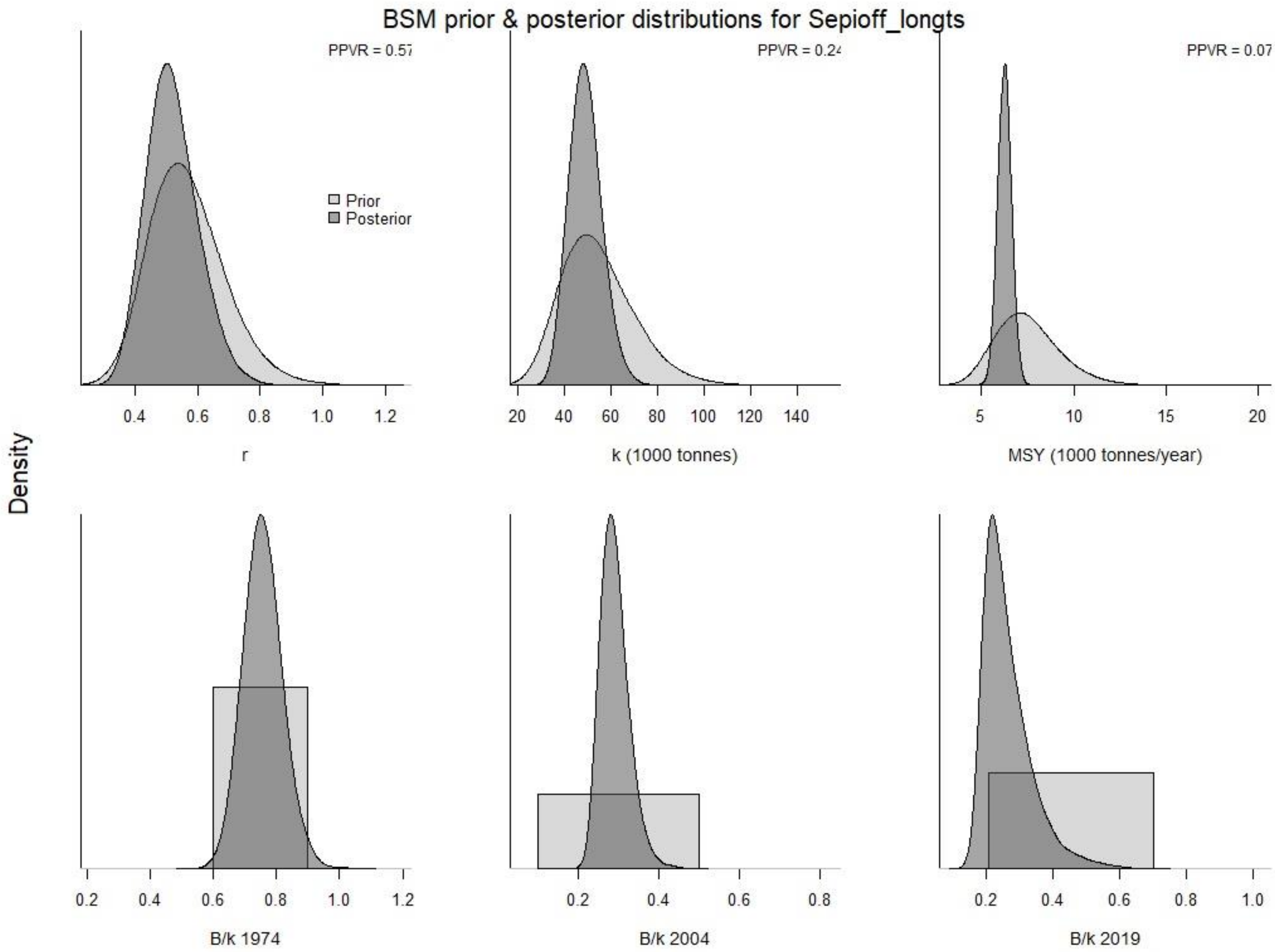

Figure 15: Marginal posterior distributions along with prior densities. The lower the prior-posterior variance ratio (PPVR), the more the posterior knowledge is improved relative to prior knowledge

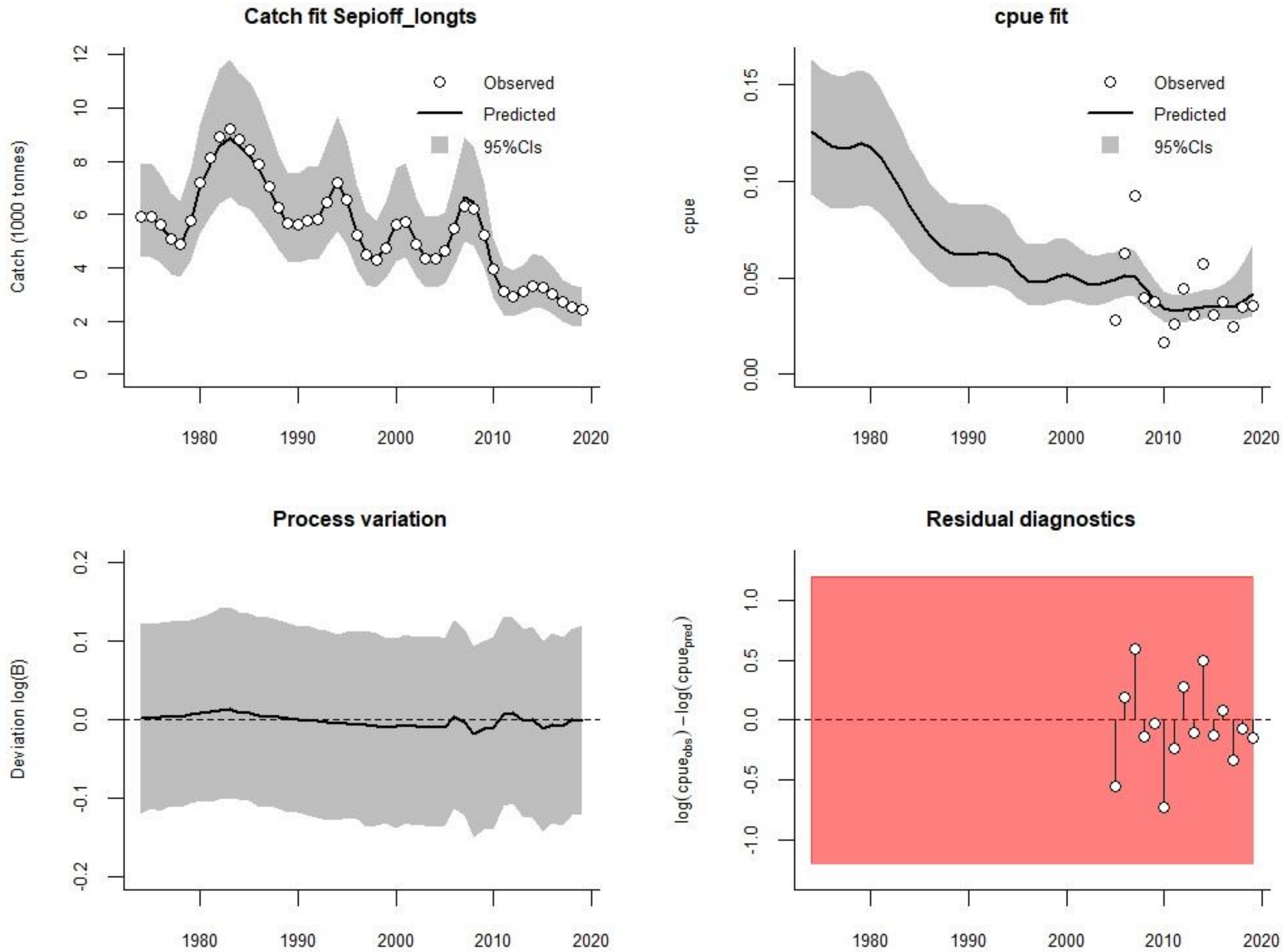

Figure 16: On the upper panels are compared the observed data to the trajectories estimated by the model for Catch (left) and CPUE (right). On the right lower panel are shown the residuals for the CPUE on a colored background, where red indicates some issues on the model fit. On the left lower panels is shown the variation of production given by the stochastic model in respect to the trajectory described by the Schaefer curve.

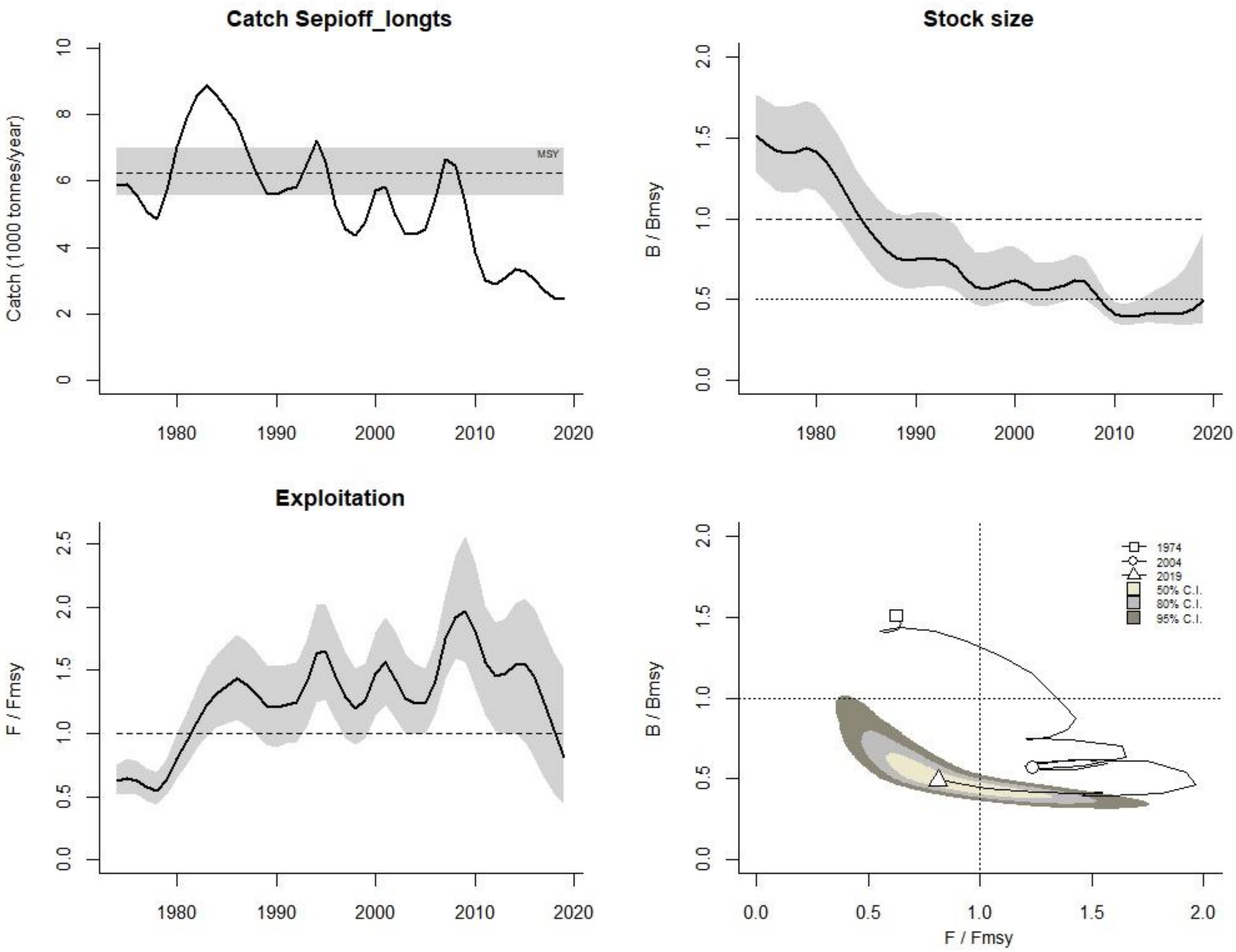

Figure 17: Results of final C-MSY run. The upper left panel shows catches relative to the BSM estimate of MSY, with indication of 95% confidence limits in grey. The upper right panel shows the development of relative total biomass (B/Bmsy), with the grey area indicating uncertainty. The lower left graph shows relative exploitation (F/Fmsy), with Fmsy corrected for reduced recruitment below 0.5 Bmsy. The lower-right shows a not colored version of the Kobe plot, with the trajectory of relative stock size (B/Bmsy) over relative exploitation (F/Fmsy).

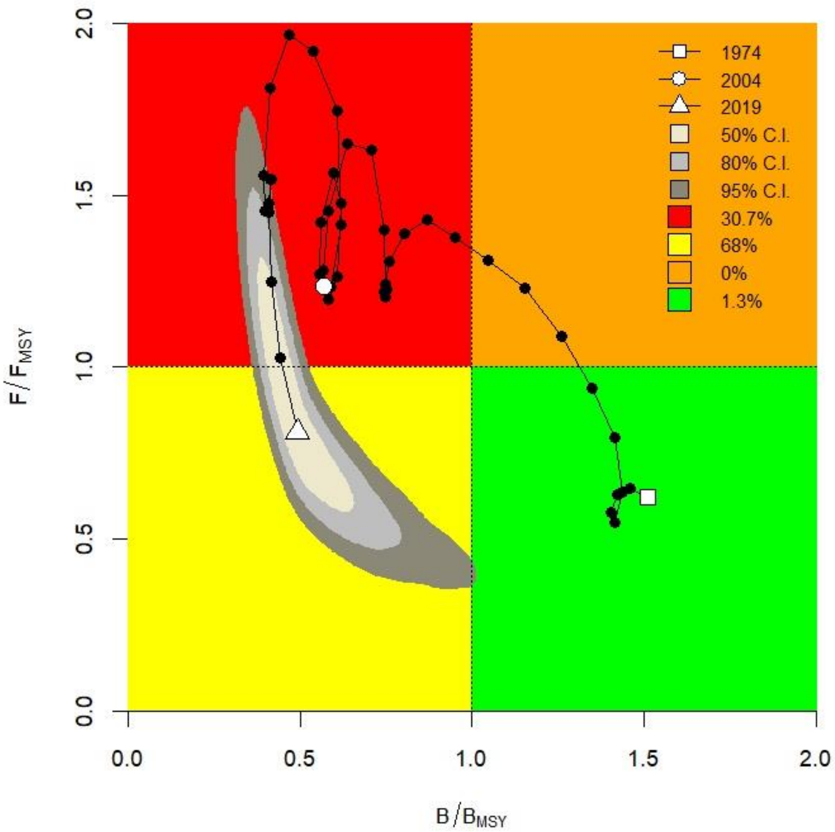

Figure 18: Kobe plot representing the time series of pressure (F/FMSY) on the Y-axis and of state of the Biomass (B/BMSY) on the X-axis. The brown area indicates healthy stock sizes that are about to be depleted by overfishing. The red area indicates ongoing overfishing while the stock is too small to produce maximum sustainable yields. The yellow area indicates reduced fishing pressure on stocks recovering from still too small biomass. The green area is the target area for management, indicating sustainable fishing pressure and healthy stock size capable of producing high yields close to MSY.

Table 6.1.4.1: summary of final results from C-MSY model

$F_{current}$ (2019)	0.204
Lower limit (95% c.i.)	0.11
Upper limit (95% c.i.)	0.28
F_{msy} (2019)	0.252
$F_{current}/F_{msy}$	0.81
Lower limit F_{curr}/F_{msy} (95% c.i.)	0.43
Upper limit F_{curr}/F_{msy} (95% c.i.)	1.51
Current Biomass (thousand tonnes)	11.98
B_{msy}(thousand tonnes)	24.341
Current Biomass / B_{msy}	0.49
L. limit Current Biomass/B_{msy}(95% c.i.)	0.36
U.limit Current Biomass/B_{msy}(95% c.i.)	0.91
MSY (thousand tonnes)	6.24
Catches 2019 (thousand tonnes)	2.43

State of exploitation: Exploitation highly oscillated during the whole timeseries. Until 2001 were observed high spikes alternated to years of exploitation at values close to Fmsy. Subsequently the F remained quite above the Fmsy for the period 2002-2016, with many up and downs. During the years 2016-2019 the F continuously declined and it was slightly below the Fmsy in 2019.

State of the biomass: biomass trend showed an almost monotonous decline in the early part of the timeseries, until 1988, then it oscillated without large spikes until 2007. In 2008 it was observed a steep decline which led the biomass to fall below 0.5 B/Bmsy in 2009. From 2012 onward, the biomass gradually increased and in 2019 it was approaching again 0.5 B/Bmsy. Nonetheless, the biomass is so low that the stock might need several years to rebuild.

6.1.5 Retrospective analysis, comparison between model runs, sensitivity analysis,

6.1.5.1: Retrospective analysis

The retrospective analysis (**Figure 19**) was conducted by removing up to three years of data. The model was stable by removing up to two years of data, while removing the third cause the trajectories to diverge. In particular, the model built on the 2016 as final year indicates an optimistic trajectory for the final part of the timeseries.

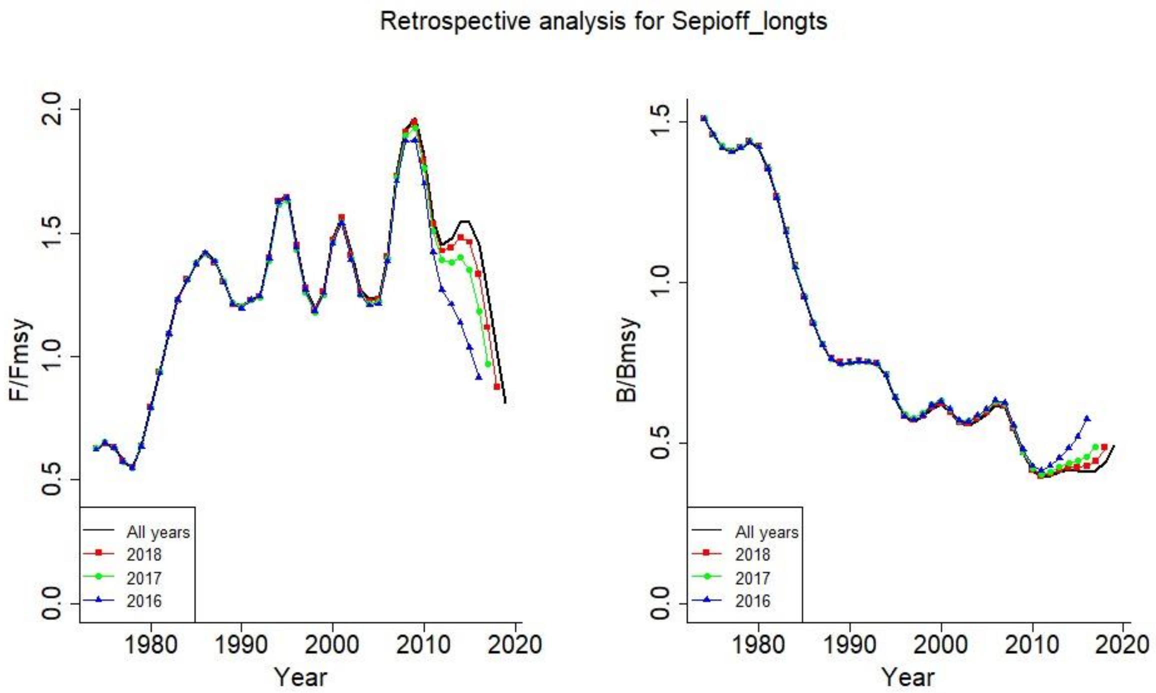

Figure 19: retrospective analysis of the best CMSY model

6.1.5.2 Sensitivity analysis

A sensitivity analysis was carried out by changing the priors for final depletion in CMSY model (Table 6.1.5.1) and by running a JABBA model (Winker et al. 2018) for comparison. First run (S1) base on AMSY model output coming from alternative runs. The second run (S2) was the JABBA model.

Table 6.1.5.1: setting of sensitivity analysis runs

Run #	Model	B/k in 2007 used as AMSY prior	Final depletion priors in CMSY	Index data
S1	CMSY	0.35-0.65	0.16-0.53	Solemon biomass
S2	JABBA	NA	NA	Solemon biomass

Run S1: CMSY model with alternative priors for final depletion

The first run used as sensitivity analysis was built on CMSY model, by using the same priors used in the best model with the exception of the prior for the final depletion (table 6.1.5.1). The aim of this comparison was to test the sensitivity to the prior for final depletion, which diagnostics indicated a bad fit for the best model (the posterior knowledge was on the lower boundary of the prior's distribution).

Table 6.1.5.1: priors for S1 run

Species	Min of year / Start year	Max of year / End year	Resilience	Stb.low	Stb.hi	Int.yr	Intb.low	Intb.hi	Endb.low	Endb.hi	btype
Common cuttlefish	1974	2019	0.37-0.84	0.6	0.9	2004	0.1	0.4	0.16	0.53	CPUE

The diagnostic panels shown in ***Figure 21*** are consistent with those of the reference model. The good overlap of the red (CMSY) and blue (BSM) crosses (panels B and C) support the coherence priors estimated by the BSM (based on Catches + CPUE) and by the CMSY model (Catch only model). In panel D the trajectories estimated by CMSY and BSM model diverge in the final years, with the CMSY model (catch-only) being more optimistic.

Figure 22 shows the comparison between priors and posterior understanding of the model, which are also very consistent with the reference model: input data was very informative about K while not informative about r as they were about K. Prior for initial and intermediate depletion are also within the prior interval, while the prior for final depletion still touches the lower boundary of the prior distribution.

Figure 16 shows the additional information on model diagnostic, where the CPUE fit present some issues but less severe than in the reference model: the most extremes values (in particular 2008 and 2010) were not properly caught, however the green coloration of the panel excludes a non-random residual pattern ($p>0.05$).

Figure 23 represent the Kobe plot. The stock trajectory is largely comparable to the reference model: timeseries begun when the stock status was in a healthy condition, than the effort level registered high pikes that resulted in a progressive erosion of the stock size. In recent years the F level was drastically reduced, however in the last year the F remained just above the Fmsy (1.044). Similarly to the reference model, the biomass did not increase at the same rate and remained quite below the Bmsy. As a consequence, in 2019 the stock trajectory is located in the red panel (with 53.5 % of probabilities).

The retrospective analysis (***Figure 24***) was conducted by removing up to three years of data. The model was stable by removing up to two years of data, while removing the third cause the trajectories to diverge. In particular, the model built on the 2016 as final year indicates an optimistic trajectory for the final part of the timeseries.

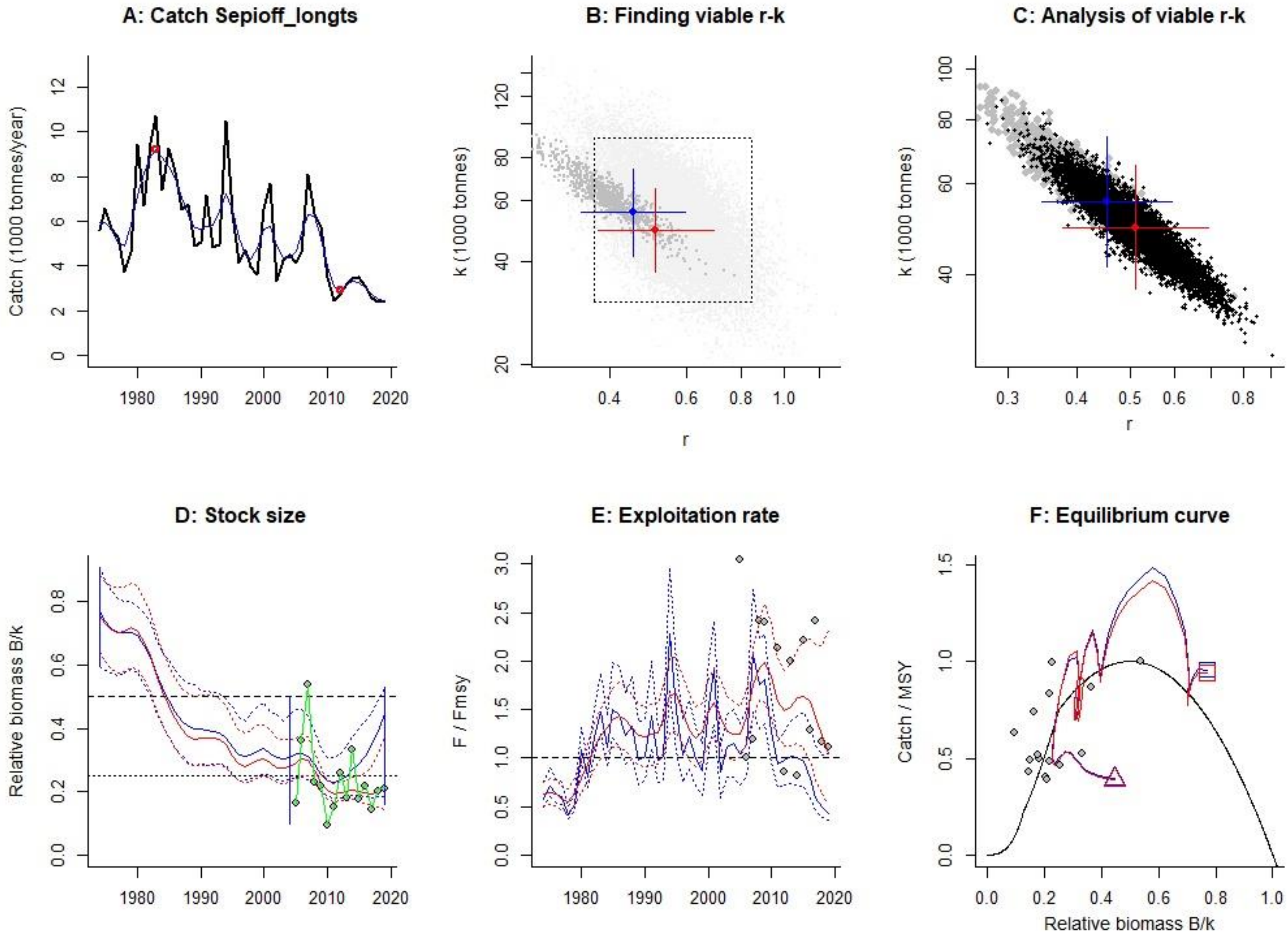

Figure 20: Diagnostics results of S1 C-MSY run. **Panel A** shows in black the time series of catches and in blue the three-years moving average with indication of highest and lowest catch, as used in the estimation of prior biomass by the default rules. **Panel B** shows the explored multivariate normal distribution of r-k in log 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 blue cross is the most likely r-k pair predicted by CMSY, and the red cross predicted by BSM. **Panel C** shows the most probable r-k pair and its approximate 95% confidence limits in blue. The black dots are possible r-k pairs found by the BSM model, with a red cross indicating the most probable r-k pair and its 95% confidence limits. **Panel D** shows the available abundance data in red, scaled to the BSM estimate of Bmsy = 0.5 k, and in blue the biomass trajectory estimated by CMSY. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. **Panel E** shows in red the harvest rate (catch/abundance) scaled to the r/2 estimate of BSM, and in blue the corresponding harvest rate from CMSY. **Panel F** shows the Schaefer equilibrium curve of catch/MSY relative to B/k, here indented at B/k < 0.25 to account for reduced recruitment at low stock sizes. The red dots are scaled by BSM estimates and the blue dots are scaled by CMSY estimates.

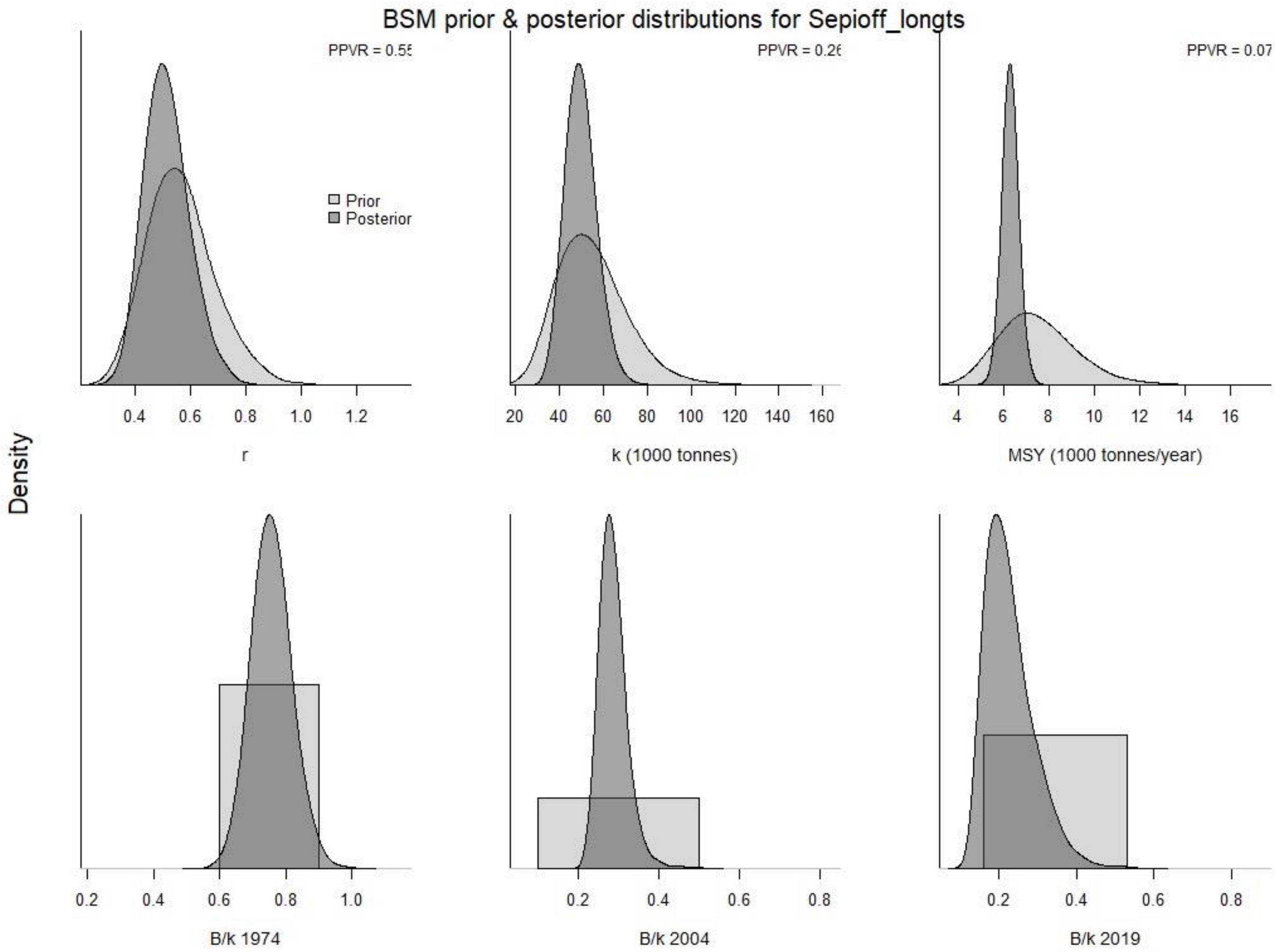

Figure 21: Marginal posterior distributions along with prior densities for the run S1. The lower the prior-posterior variance ratio (PPVR), the more the posterior knowledge is improved relative to prior knowledge

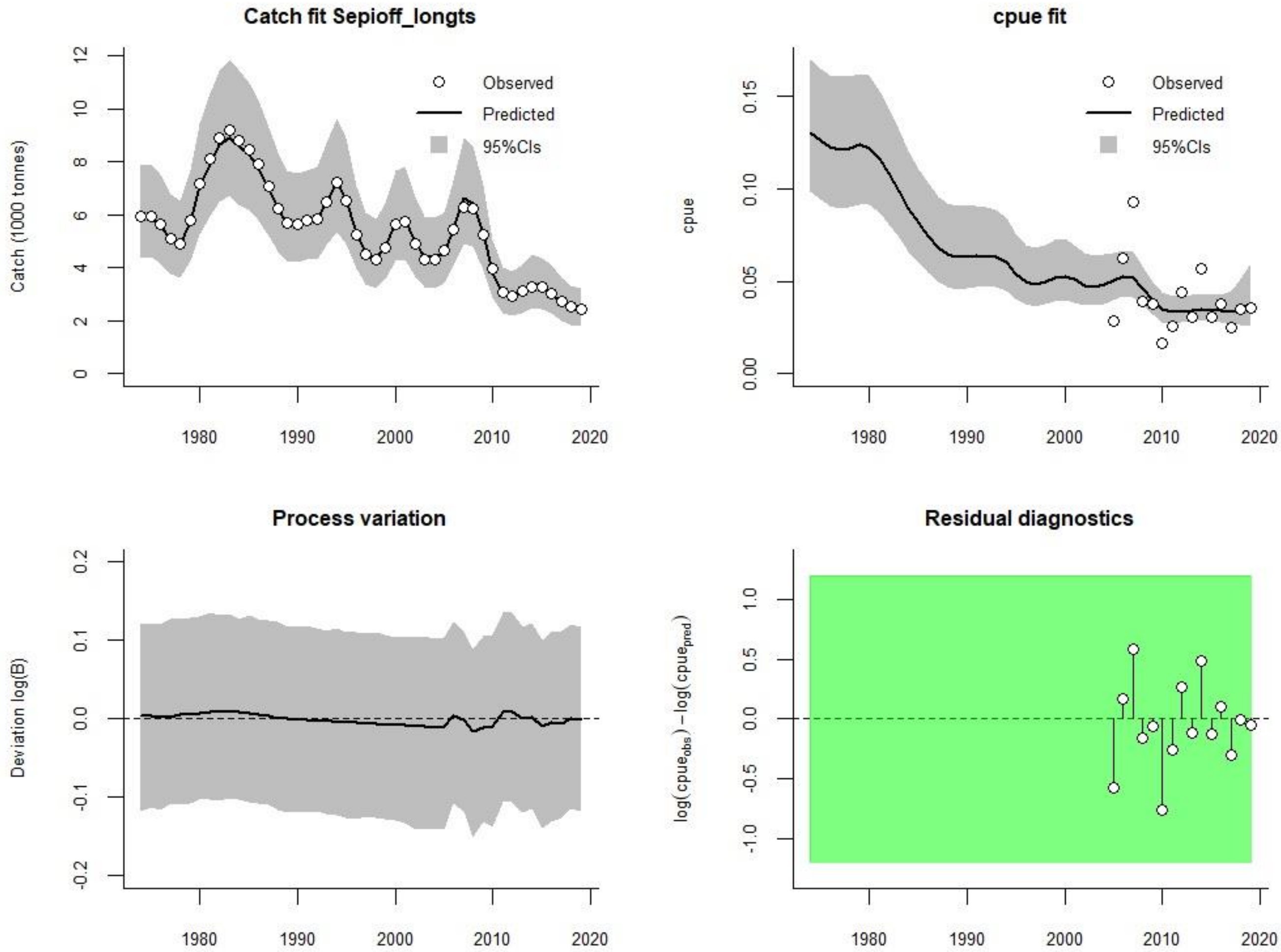

Figure 22: model fit for run S1. On the upper panels are compared the observed data to the trajectories estimated by the model for Catch (left) and CPUE (right). On the right lower panel are shown the residuals for the CPUE on a colored background, where red indicates some issues on the model fit. On the left lower panels is shown the variation of production given by the stochastic model in respect to the trajectory described by the Schaefer curve.

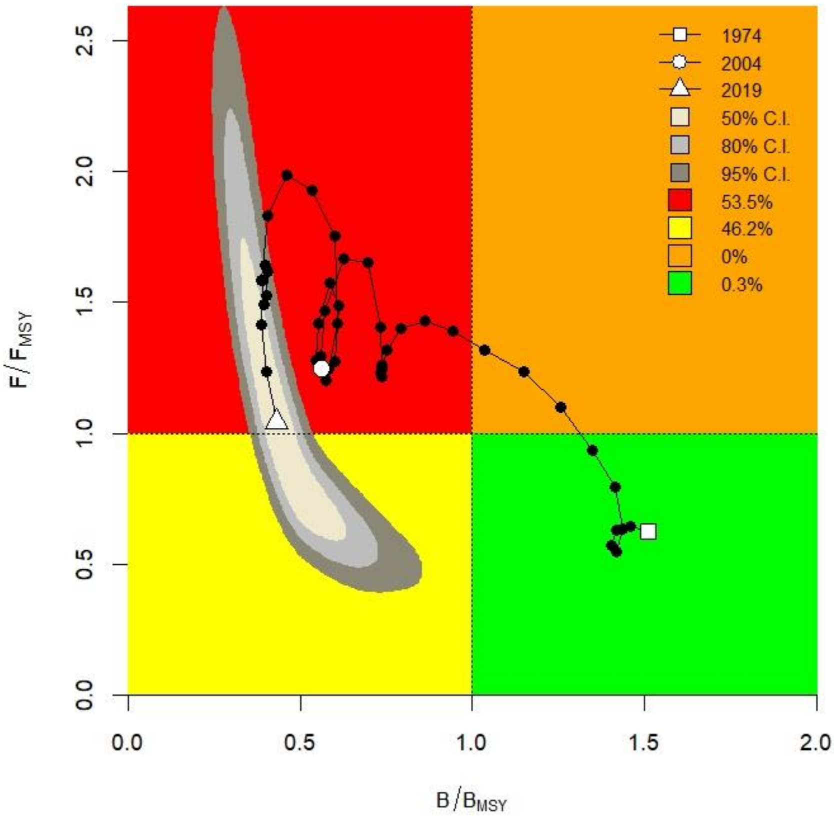

Figure 23: Kobe plot for run S1. Kobe plot representing the time series of pressure (F/FMSY) on the Y-axis and of state of the Biomass (B/BMSY) on the X-axis. The brown area indicates healthy stock sizes that are about to be depleted by overfishing. The red area indicates ongoing overfishing while the stock is too small to produce maximum sustainable yields. The yellow area indicates reduced fishing pressure on stocks recovering from still too small biomass. The green area is the target area for management, indicating sustainable fishing pressure and healthy stock size capable of producing high yields close to MSY.

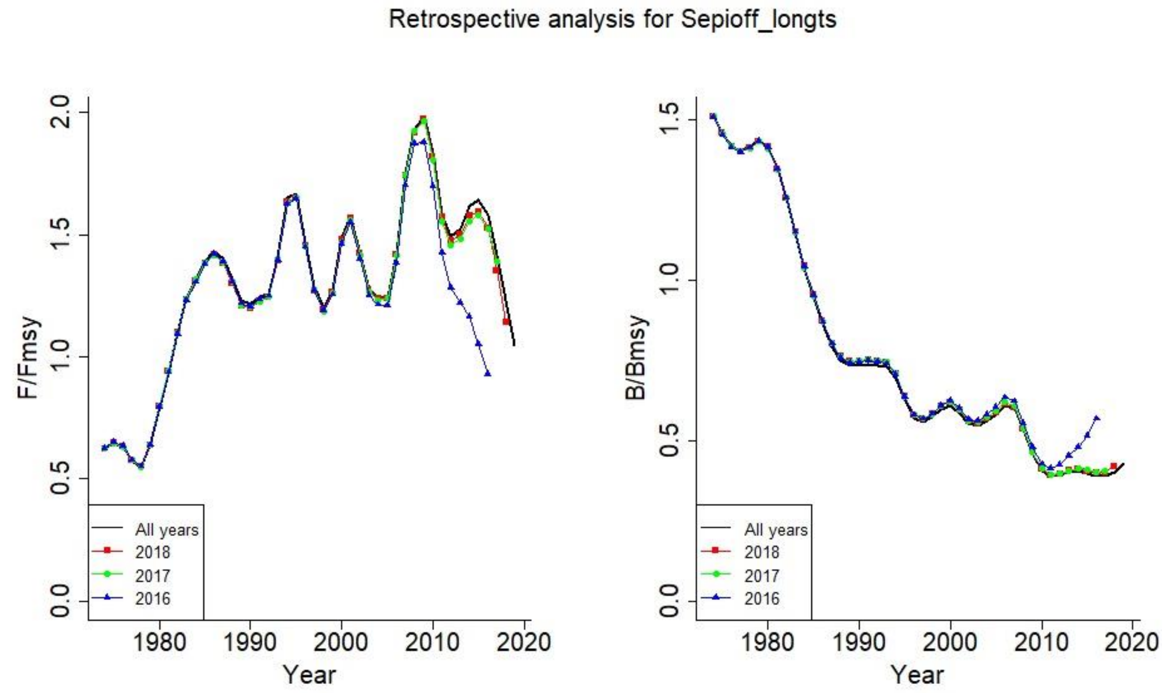

Figure 24: retrospective analysis for the run S1

Run S2: JABBA model

The second run used as sensitivity analysis was built on JABBA model. The aim of this comparison was to test the sensitivity to the prior for final depletion, which diagnostics indicated a bad fit for both the best model and for the S1 model (in both cases the posterior knowledge was on the lower boundary of the prior's distribution). Since JABBA model does not need a prior for the final depletion, it was considered appropriate to give additional information for the final advice. Parameters used to fit the model are showed in tables 6.1.5.2 and 6.1.5.3.

Table 6.1.5.2: JABBA model settings

	Initial Year	Final Year	SPM shape	Survey index
Value	1974	2019	Schaefer	Solemon Biomass (2005-2019)

Table 6.1.5.3: priors used in the JABBA model

	r	K	Psi (Initial depletion)	B (Depletion in intermediate year = 2004)	BmsyK	Fixed obs. error	Catch.cv	Additional obs. variance
Value (μ, σ)	0.5, 0.1	58000, 0.2	0.76, 0.2	0.26, 0.1	0.2	0.1	0.3	NO
Ditribution	lognormal	lognormal	lognormal	lognormal				

Figure 25 shows the fit of the input data. Catch data trend (on left) was well captured, in spite of the large CV used to account for data uncertainties. In analogy with the CMSY model, CPUE trend was generally well captured but with the exception of a few years in the first part of the time-series.

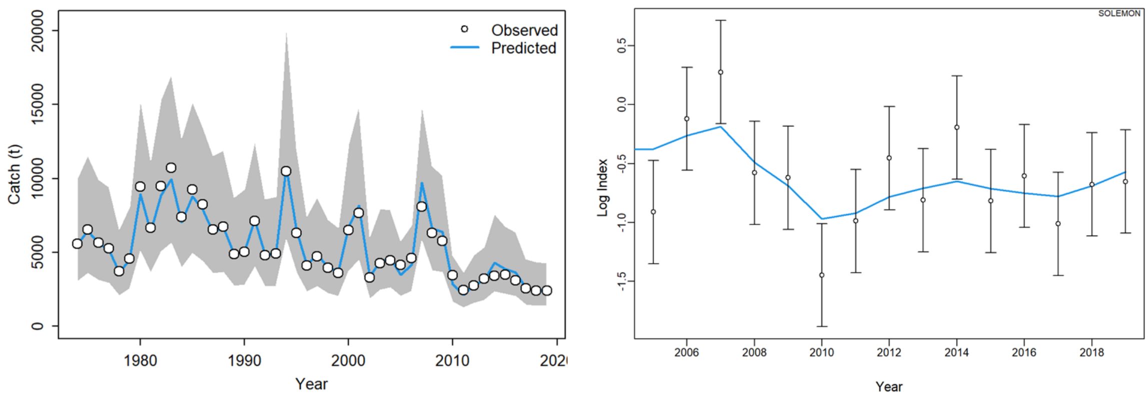

Figure 25: fit of catch and CPUE data for the JABBA model

The results of the log-residuals run test for each CPUE fit by year and model are provided in **Figure 26 b**, whereby red panels indicating evidence for a non-random residual pattern ($p>0.05$). The goodness-of-fit was 38.2% (**27c**) and the log residual trend evidenced a slight overestimation of the CPUE in the period 2012-2017. Annual process error deviation (**27d**) on log biomass indicated similar stochastic patterns, associated with relatively small process error estimates (< 0.05), which suggest no evidence of structural model misspecification causing conflicts with the predicted population dynamics.

In ***Figure 27*** is shown the marginal posterior distributions along with prior densities. The posterior distribution for K was narrower in comparison to the priors, and resulting small prior to posterior variance ratio (PPVR) indicate that the input data was very informative about K. The small prior to posterior median ratio (PPMR) for r indicated a good agreement and overlapped well between the density distributions, however the PPVR value close to one indicates that the data were not very informative about r. The marginal posteriors for initial depletion (φ) indicated both PPMR and PPVR close to 1, which suggests that the marginal posteriors were largely informed by the priors.

The results of a four-year retrospective analysis applied to scenarios is provided in ***Figure 28***, and show a negligible retrospective pattern for both models. The estimated Mohn's rho are provided within each figure and fell within the acceptable range of -0.22 and 0.33 (Hurtado-Ferro et al. 2015) and confirm the absence of an undesirable retrospective pattern. Nevertheless, it is evidenced a slight departure of runs with -3 and -4 years, in analogy to what observed in the CMSY models' retrospectives.

Hindcasting cross-validation results (***Figure 29***) suggest that the model have good prediction skills as judged by the MASE of 0.89, which indicates that future projections are consistent with reality of model-based scientific advice.

The Kobe biplots ***Figure 30*** show the typical anti-clockwise pattern with the stock status moving from underexploited through a period of unsustainable fishing beginning to the overexploited phase at the end of the '80s. In the following years the exploitation oscillated and returned below the Fmsy just for short periods and the biomass was continuously eroded. In the recent years it was observed a steep reduction of the F, followed by a modest recover of the B. Current stock status is in the yellow quadrant of the Kobe biplot (B2019<BMSY and F2019<FMSY) with almost 70% probability.

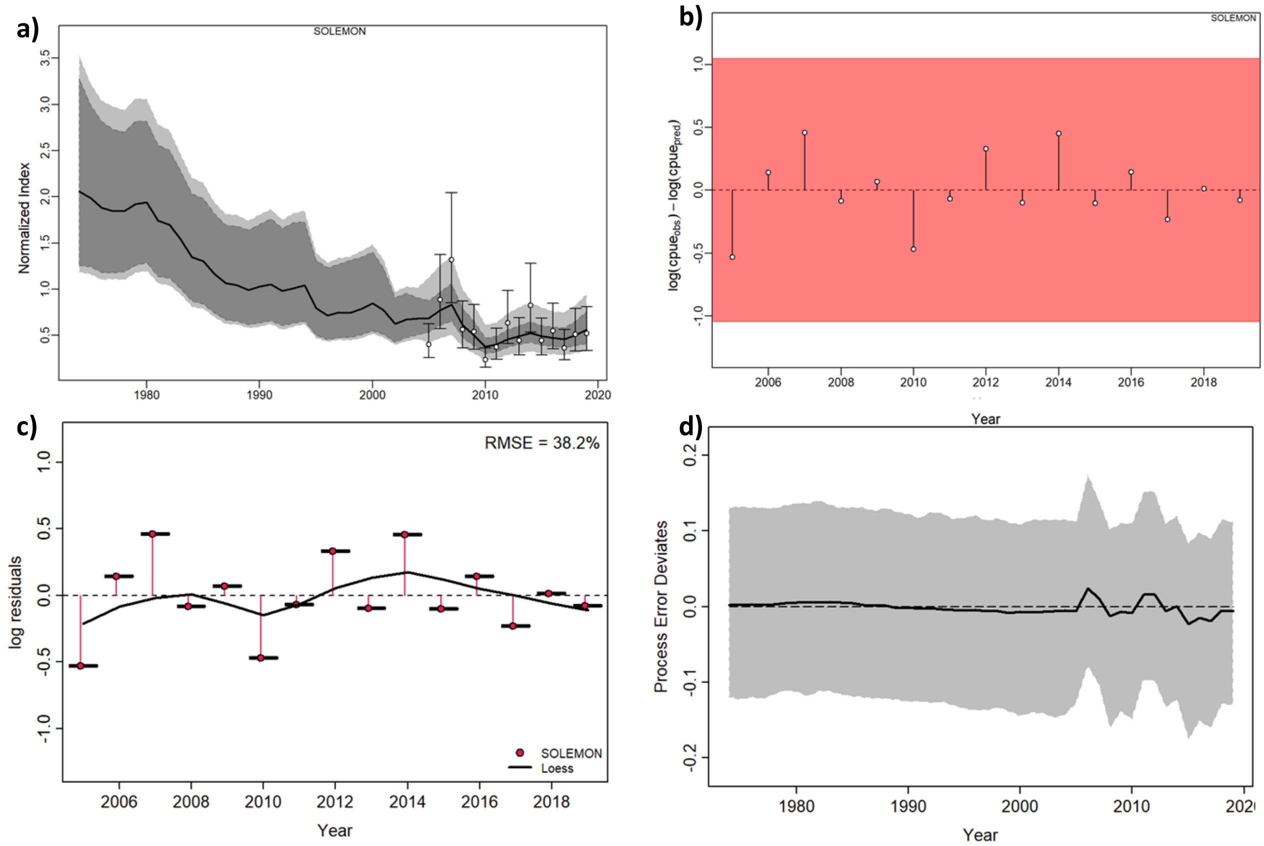

Figure 26: a) Time-series of observed (circle) with error 95% CIs (error bars) and predicted (solid line) CPUE for the Bayesian state-space surplus production model JABBA. Dark shaded grey areas show 95% credibility intervals of the expected mean CPUE and light shaded grey areas denote the 95% posterior predictive distribution intervals*; b) r*uns tests to quantitatively evaluate the randomness of the time series of CPUE. Green panels indicate no evidence of lack of randomness of time-series residuals (p>0.05) while red panels indicate the opposite*; c)* JABBA residual diagnostic plots*, b*oxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals*; d) p*rocess error deviates (median: solid line) with shaded grey area indicating 95% credibility intervals.

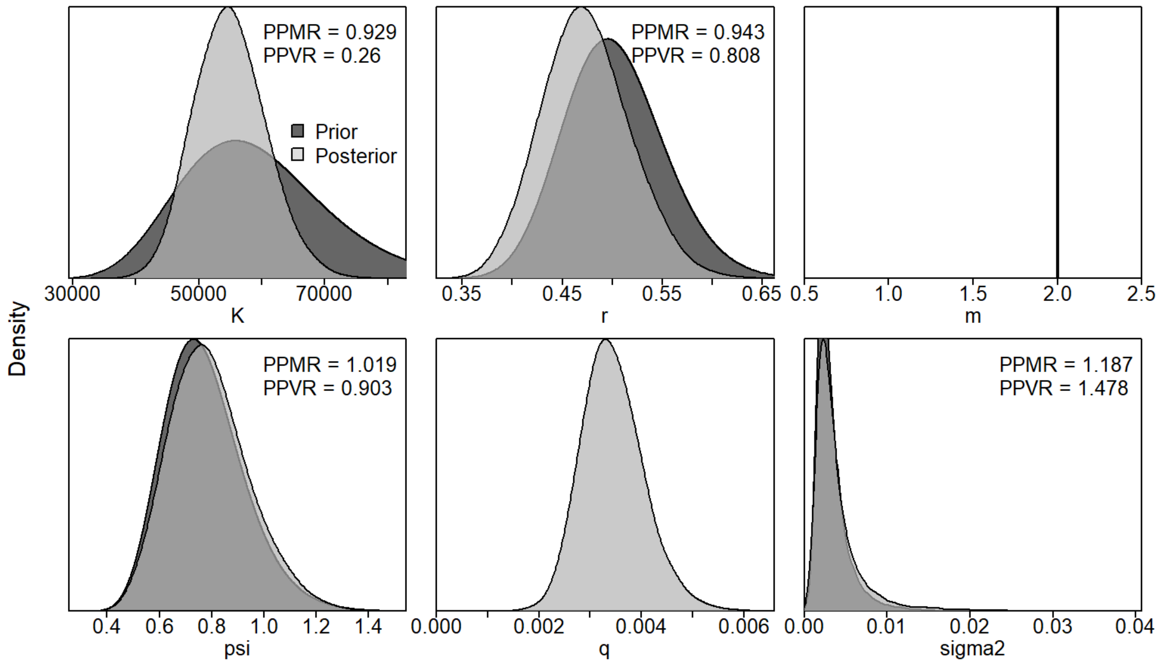

Figure 27: Marginal posterior distributions along with prior densities for the JABBA model. PPRM: Posterior to Prior Ratio of Medians; PPRV: Posterior to Prior Ratio of Variances.

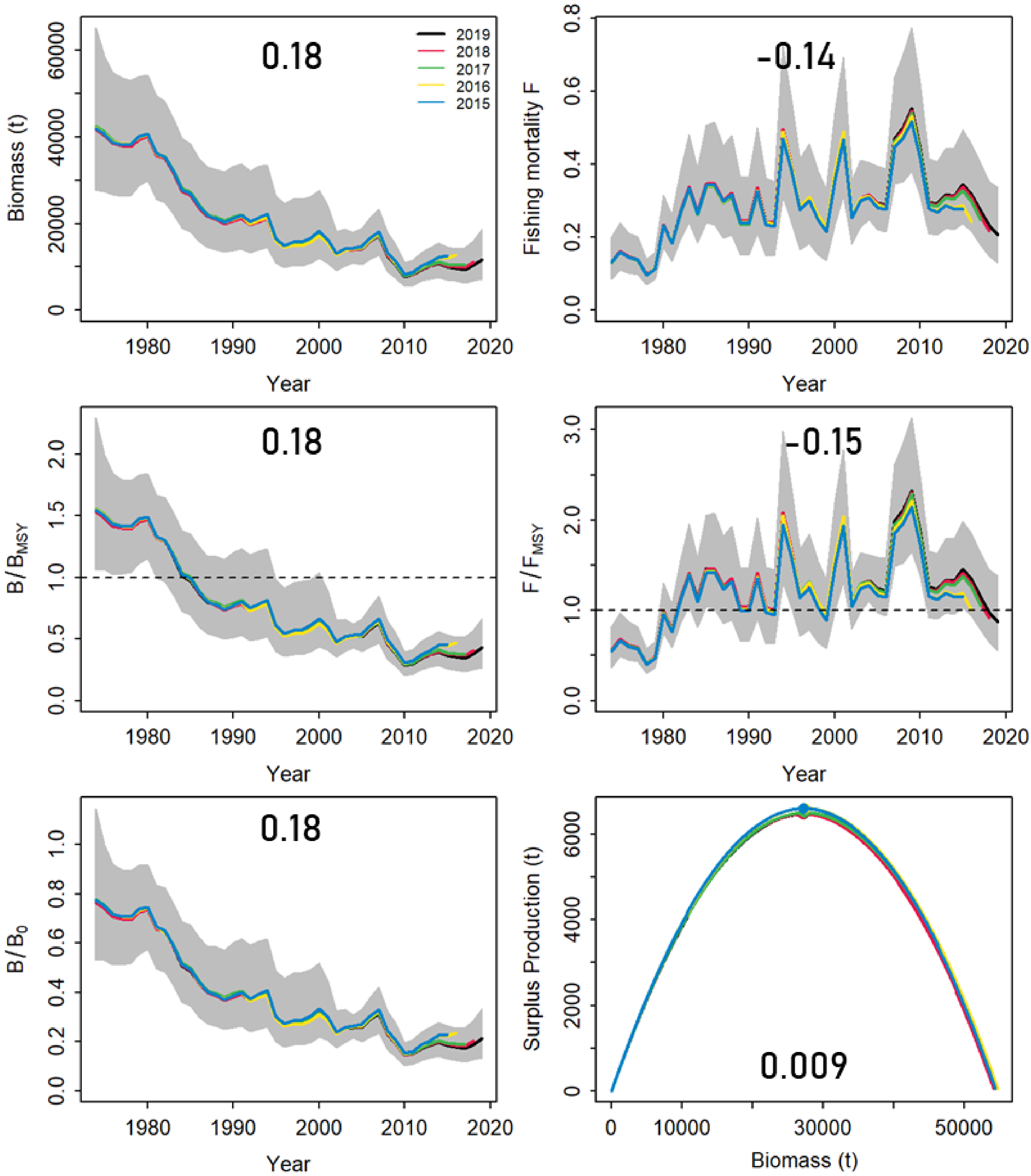

Figure 28: Retrospective analysis conducted by removing one year at a time sequentially (n=4) and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to BMSY (B/BMSY) and fishing mortality relative to FMSY (F/FMSY) (middle panels) and biomass relative to K (B/K) and surplus production curve (bottom panels) from the Bayesian state-space surplus production model fits. Bold numbers indicate Mohn's rho values.

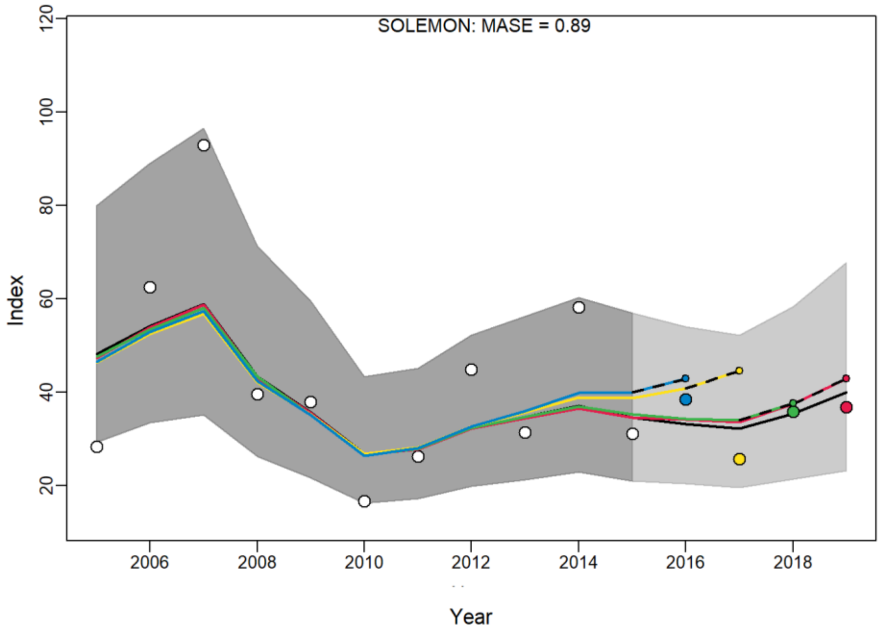

Figure 29: Hindcasting cross-validation results (HCxval) showing one-year-ahead forecasts of CPUE values, performed with 4 hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 95% confidence interval. The model reference year refers to the end points of each one-year-ahead forecast and the corresponding observation (i.e. year of peel + 1).

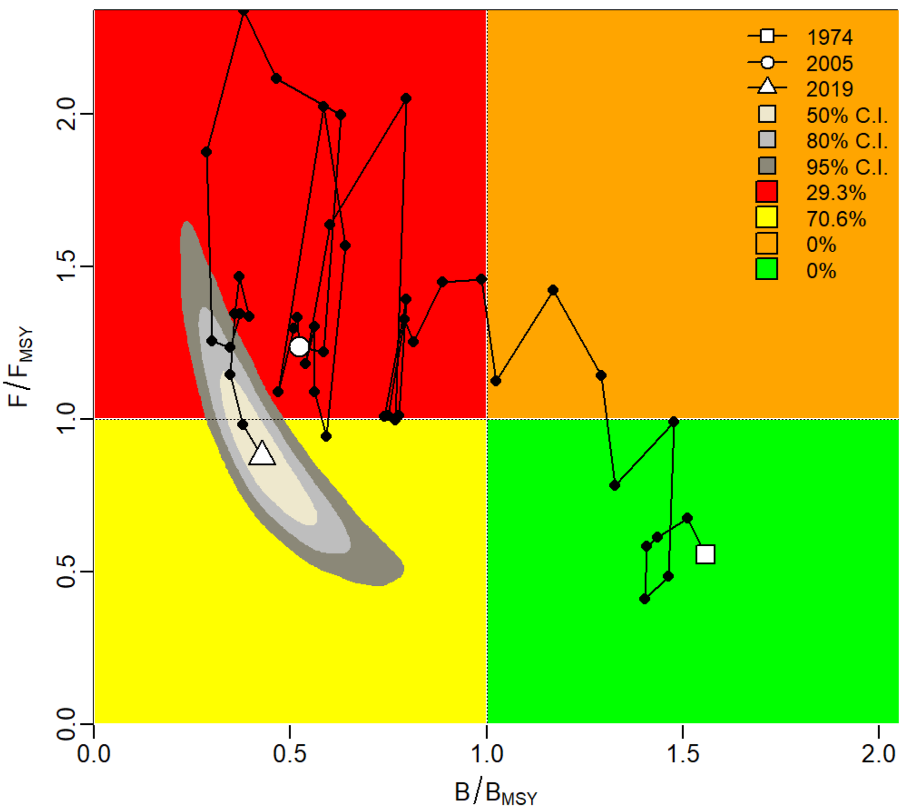

Figure 30: Kobe phase plot showing estimated trajectories (1974-2019) of B/BMSY and F/FMSY for the Bayesian state-space surplus production model for Common cuttlefish in GSA 17. Different grey shaded areas

denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend.

6.1.5.3 Comparison between model runs

The sensitivity analyses showed in 6.1.5.2 was conducted to test the effect of the final depletion prior on the model. The alternative prior tested for the CMSY model (medium-to-high depletion; 0.16-0.53) caused a slight improvement of the model diagnostics, in particular regarding the residuals run test. Nevertheless, the comparison of the priors and posteriors distribution did not show large differences with the reference model and the distribution of the posteriors for the final depletion remained on the lower boundaries of the prior's range. Stock trajectories were very similar between the two models (***Figure 31***, ***Figure 32***), indicating B largely below Bmsy. The value for the F/Fmsy on the final year was relatively close to Fmsy in both models, however in the case of the reference model was just below the Fmsy. The comparison between model's diagnostic was judged not robust enough to select a best model, since there were indications that the final prior selection had a significant influence on the model result. To obtain alternative indications on the stock trajectories we fitted catch and CPUE data to a JABBA model, which did not require priors for final depletion.

Interestingly, some of the diagnostic of the JABBA model gave similar results to the CMSY model. In particular, the CPUE index was not perfectly fitted in the first part of the time series and the residuals run test failed. Posteriors distribution well overlapped the prior's specifications and, similarly to CMSY, the values for *r* were largely informed by the priors. The advanced diagnostic tools implemented in the JABBA model permitted to exclude severe model misspecification which can lead to degradation of results: in the retrospective analysis all Mohn's Rho value were within the reference thresholds (Hurtado-Ferro et al. 2015) and the MASE statistic in the HCxval was below 1.

Considering the sensitivity analysis we resumed the steps which led us to the selection of the best model: (1) the diagnostic of the S1 CMSY run shown a slight improvement in term of residuals but did not cause an improvement in term of coherence between BSM and CMSY models; (2) the posterior distribution of the S1 and reference CMSY models remained on the lower boundaries of the prior's range evidencing the influence of prior choice on final result; (3) the advanced diagnostic support the robustness of the JABBA model; (4) results of the JABBA model are better aligned with the reference CMSY run.

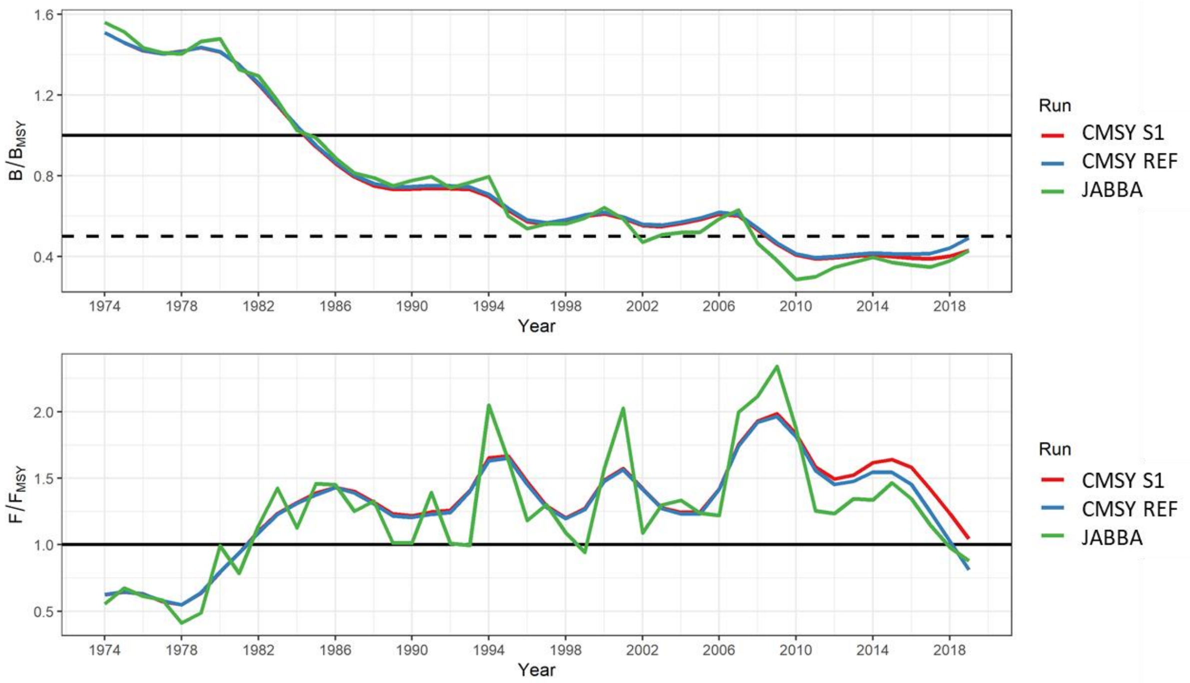

Figure 31: comparison of the B/Bmsy and of the F/Fmsy trajectories as estimated by the CMSY reference model presented in 6.1.4 (CMSY REF, blue lines) and by the models used as sensitivity analysis in 6.1.5.2 (CMSY S1, red line; JABBA model, green line).

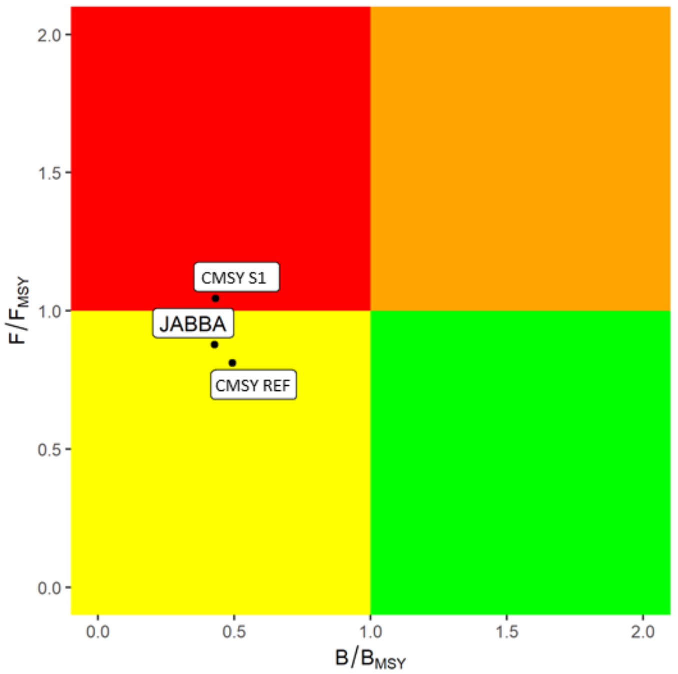

Figure 32: Kobe phase plot showing the final year value of B/BMSY and F/FMSY for the Bayesian state-space surplus production model for the model tested for Common cuttlefish in GSA 17: CMSY model presented in 6.1.4 (CMSY REF), CMSY model presented in 6.1.5.2 (CMSY S1) and JABBA model (JABBA).

6.1.6 *Assessment quality*

The result given in the advice are coherent with the output of the sensitivity analysis, where all candidate models provide reasonably robust fits to the data as judged by the presented model diagnostics, but current stock status estimates were fairly sensitive to variations in the prior for final depletion. The consistency in current status estimates between the JABBA model and the reference CMSY model (***Figure 31***) provide a degree of confidence in selecting the CMSY reference run as base for the updated assessment of the stock status of GSA17 common cuttlefish.

Exploitation trajectories are generally in line with results obtained in other exploited stocks within the area, confirming the plausibility of the values obtained.

Nonetheless, the environmental parameters might greatly interact with fishery exploitation in determining cephalopods population dynamics (Pierce et al. 2008; ICES 2019), calling for the implementation of environmental data in future assessments in order to obtain more robust results.

7 Stock predictions

No information available.

Draft scientific advice

The scientific advices in the following table are based on the BSM analysis using CMSY model results and on the Biomass index from Solemon survey.

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 (2016-2019)	Stock Status
Fishing mortality	Fishing mortality	Fmsy: 0.252	Fcurr: 0.204		D	S
Stock abundance	Biomass	Bmsy: 24.341	Bcurr: 11.98		I	O
Recruitment					C	
Final Diagnosis		**Reduce fishing mortality; implement recovery plan**				

8 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)*

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