



# Stock Assessment Form

## Demersal species

**Reference year: 2022**

**Reporting year: 2023**

**Stock status:** ecologically unbalanced with low fishing mortality

**Advice and recommendations:** implement a recovery plan

**WG comments:** Ecological unbalance. The stock is in a low productivity status. Management should account for natural variability and ecological effects on the stock productivity.

**Assessment and advice summary:** The group validates the assessment for quantitative advice. The group considers the updated assessment based on the JABBA model as a realistic estimation for stock status. However, it is recognised that the low catches can be either due to a reduction of fishing pressure or to a low productivity regime. No explicit link between productivity and ecology/environment is considered in the model. Therefore, the model is considered not sufficiently robust to provide future fishing opportunity scenario by way of forecasts. Fishing mortality is estimated below  $F_{MSY}$  level with the biomass just above to the  $B_{lim}$  level. The group noted that the current assessment model is a valid method to track the biomass and fishing mortality trends but a different assessment method that accounts for life-cycle peculiarity and ecological drivers is needed to estimate how the stock can react to future management actions.

# Stock Assessment Form version 1.0

Uploader: *Enrico Nicola Armelloni*

## Stock assessment form

<b>1</b>	<b>Stock identification, biological and ecological information</b>	<b>3</b>
1.1	Stock distribution and stock unit	3
1.2	Biological aspects (reproduction, growth, environmental influence)	4
1.3	Diet	6
<b>2</b>	<b>Fisheries information</b>	<b>9</b>
2.1	Description of the fleet	9
2.2	Fishery performance	10
2.3	Historical trends	12
2.4	Management regulations	15
<b>3</b>	<b>Fisheries independent information</b>	<b>16</b>
3.1	Direct methods: trawl based abundance indices (SoleMon survey)	16
3.1.1	Biomass and density indices	18
3.1.2	Length Frequency Distribution	19
3.1.3	Spatial distribution of the resources	20
<b>4</b>	<b>Stock Assessment</b>	<b>22</b>
4.1	JABBA model	22
4.1.1	Input data, priors, and settings	22
4.1.2	Model results	24
4.1.3	Retrospective analysis	29
4.1.4	Sensitivity analysis	30
4.1.5	Reference points	32
4.2	Stock prediction	33
4.3	Summary of results	34
4.4	Assessment quality	35
	<b>Draft scientific advice</b>	<b>36</b>
<b>5</b>	<b>Acknowledgments</b>	<b>37</b>
<b>6</b>	<b>Literature cited</b>	<b>37</b>

Basic Identification Data

<b>Scientific name:</b>	<b>Common name:</b>	<b>ISCAAP Group:</b>
<i>Sepia officinalis</i>	Common cuttlefish	57
<b>1<sup>st</sup> Geographical sub-area:</b>	<b>2<sup>nd</sup> Geographical sub-area:</b>	<b>3<sup>rd</sup> Geographical sub-area:</b>
17		
<b>4<sup>th</sup> Geographical sub-area:</b>	<b>5<sup>th</sup> Geographical sub-area:</b>	<b>6<sup>th</sup> Geographical sub-area:</b>
<b>1<sup>st</sup> Country</b>	<b>2<sup>nd</sup> Country</b>	<b>3<sup>rd</sup> Country</b>
Italy	Croatia	Slovenia
<b>4<sup>th</sup> Country</b>	<b>5<sup>th</sup> Country</b>	<b>6<sup>th</sup> Country</b>
<b>Stock assessment method: (direct, indirect, combined, none)</b>		
Indirect: JABBA		
<b>Authors:</b>		
Armelloni E.N. <sup>1</sup> , Scanu M. <sup>1</sup> , Palermino A. <sup>1</sup> , Sabatini L. <sup>1</sup> , Scarcella G. <sup>1</sup>		
<b>Affiliation:</b>		
<sup>1</sup> Institute of Biological Resources and Marine Biotechnology, National Research Council, Italy		

## **1 Stock identification, biological and ecological information**

Common cuttlefish (*Sepia officinalis*, Linnaeus, 1758) is a bottom dwelling species that typically inhabits the continental shelf of temperate oceans. It is a valuable resource in the Adriatic Sea and one of the most studied and exploited cephalopods living in European waters (Lishchenko *et al.*, 2021). The following chapters provide a detailed and updated summary of the available knowledge for this species regarding distribution and biological characteristics.

### **1.1 Stock distribution and stock unit**

Common Cuttlefish is distributed throughout the continental shelf of the Adriatic Sea (AS) below 200 meters depth, especially on muddy and sandy bottoms covered with seaweed and phanerogams (Relini and Piccinetti, 1996). 200 m is considered to be the depth limit for this species, after which the shell does not longer support the water pressure (Guerra, 2006). The ontogenetic seasonal migrations characterizing the common cuttlefish lifecycle in the Adriatic Sea has been accurately described (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.

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. 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). 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)). The exploitation pattern was evaluated by analyzing the spatial distribution of trawlers in the basin (Armelloni *et al.*, 2021b; Coro *et al.*, 2022b). It results that vessel 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 GSA 17.

## 1.2 Biological aspects (reproduction, growth, environmental influence)

Common cuttlefish biological cycle and individual characteristics depends on ecological and environmental conditions, especially food availability and water temperatures (Bloor *et al.*, 2013). Regarding food availability, both quality and quantity are crucial aspects considering the high food intake required to sustain the high growth rate (Domingues *et al.*, 2004). Relation with temperature may vary depending on the life stage, but in general higher temperature enhances cephalopods metabolisms implying faster development (Forsythe, 2004) and spawning behavior modulation (Bloor *et al.*, 2013). The following paragraphs report a detailed summary of cuttlefish biological characteristics with special emphasis on the link with environmental and ecological aspects. Our aim is to provide a comprehensive information that can support the inclusion of the effects of the environment on the species distributions and on the recruitment success in support to cephalopod fisheries management (ICES, 2019).

### *Longevity and maximum size*

Common cuttlefish is a fast-growing species and a terminal spawner. Longevity of the common cuttlefish 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. 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). In the Adriatic Sea 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). No detailed study of growth parameters is available for the Adriatic Sea.

### *Reproductive behaviour*

Cuttlefish reproductive behavior and characteristics has been reported in seminal works (Boyle, 1983). The female produces clusters of eggs (diameter from 6mm to 8mm, (Mandic *et al.*, 1981)), individually enclosed in a tough 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 or artificial substrata (including fishing gears; (Bloor *et al.*, 2013). Cuttlefish, as most cephalopod species, has a flexible reproductive framework: generally females die soon after breeding (Le Goff and Daguzan, 1991), however some examples of intermittent spawning has been documented (Laptikhovsky *et al.*, 2003).

### *Maturity and spawning performance*

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. Spawning performance is linked to body condition, timing, and substrate availability. Body conditions of individuals influence eggs characteristics: a positive relation between adult dimension and eggs size it has been demonstrated in wild stocks (Laptikhovsky *et al.*, 2003)

and in captive conditions (Sykes *et al.*, 2006). Relation between adult diet and fecundity has been studied in captivity, suggesting that maternal nutrition status has a direct effect on hatchlings survivability (Sykes *et al.*, 2006). Considering that temperature increases metabolic rate and promotes food intakes, a potential sea warming can have a positive or negligible effect on body condition and therefore on spawning performance depending on the food availability (Forsythe, 2004). Spawning timing is influenced by water temperature, which determines the duration of the spawning season: ideal environmental conditions for spawning requires sufficiently warm temperature and preferably high salinity (Bloor *et al.*, 2013). In warm water, as in the Adriatic Sea, cuttlefish may spawn year-round. In fact, in the AS spawning events can occur throughout the year but there is a distinct peak in early spring potentially lasting until early summer (Vrgoč *et al.*, 2004). Potentially, an increase of the water temperature may extend the duration of the spawning peak or cause an anticipation. Preferred spawning substrata are plants and leaves, tubes of polychaetas and crabs, but also artificial substrata (Grati *et al.*, 2018). It has been observed that a reduction of essential habitats (such as seagrass meadows) might have a negative impact on the spawning success (Grati *et al.* 2018).

#### *Embryonic development*

Embryonic development is faster at higher temperatures (*e.g.*: Boletzky, 1987). Based on captive experiments, temperature increase is negatively related with yolk absorption efficiency, indicating that eggs reared at higher temperature produce smaller hatchlings with reduced yolk reserves (Vidal *et al.*, 2002). Smaller body size also implies a reduced predation capacity (Armelloni *et al.*, 2020), which coupled with shortage of food reserve may increase the natural mortality of hatchlings (size selective mortality; Steer *et al.*, 2003). Other conditions that may influence egg development are salinity, which if too low can inhibit embryo development, and storminess, that may detach eggs. Salinity in the coastal areas of the AS is driven by main circulation and by freshwater inputs, with flood events that may drastically reduce salinity at local scale (Cushman-Roisin *et al.*, 2001; Campanelli *et al.*, 2011). In the Adriatic Sea, water temperature in shallow coastal water rapidly increases in spring, moving from less than 15 to more than 20 in a short amount of time. The increase of temperature usually coincides with the end of the severe storms period and of the high river discharge. The relation with temperature is relevant, as the Adriatic Sea has been warming in recent years and climate projections predicts a further increase of 2° by 2050 (Parras-Berrocal *et al.*, 2020).

#### *Recruitment and sub-adults growth performance*

The recruitment and availability of cuttlefish it is also 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 (Doubleday *et al.*, 2016), and “passively”, being affected juveniles growth performance (Villanueva *et al.*, 2016). Cephalopod growth rate is exponential during early life stages and then slows down in adult stage (*e.g.*: Boyle, 1983). Growth performance during the first stages greatly influencing the potential body size of adults (Bloor *et al.*, 2013) and increases predatory abilities (Steer *et al.*, 2003). Growth during this stage is

dependent on temperature (Forsythe, 2004) and adequate food supply that can be a limiting factor (Domingues *et al.*, 2004). Regarding other environmental characteristics that can influence Juveniles and Adult cuttlefish survivability, acidification is suggested to have a negative effect on growth and cuttlebone development (Lishchenko *et al.*, 2021). Nevertheless, on the short-term horizon the effect of the water temperature is much higher than pH lowering. Considering high food requirements and sophisticated behavior to escape predation (O'Brien *et al.*, 2017), we consider the balance between temperature and food supply as major factors influencing cuttlefish stock biomass.

### **1.3 Diet**

The common cuttlefish is an opportunistic predator, which diet varies according to the animal size and the ecological characteristics of the environment. We provide here an estimation of cuttlefish diet based on a combination of data retrieved from bibliography. We targeted four studies providing detailed stomach contents and cuttlefish size or age information. Data for juveniles ( $\leq 65$ mm ML or Age 0) were gathered from a nursery area on the French coast of Atlantic Ocean (Blanc *et al.*, 1998); from northern Adriatic Sea (Bettoso *et al.*, 2016); and from an estuary on the Atlantic coast of Spain (Castro and Guerra, 1990). Data for adults (ML > 65 mm or Age > 0) were gathered from offshore French Atlantic coast (Pinczon Du Sel *et al.*, 2000); northern Adriatic Sea (Bettoso *et al.*, 2016); and from an estuary on the Atlantic coast of Spain (Castro and Guerra, 1990). Data were classified according to three Taxonomic ranks: 1) a combination of phylum and class resembling taxonomic codes adopted by the Solemon survey ; 2) order/infraorder rank; 3) family rank by matching the lowest available taxonomic rank with the Worms database (Holstein, 2018). Prey data were aggregated by taxonomy ranks and the occurrence value was averaged over the available sources of information. Figure 1 and Table 1.3-1 report the results of the bibliographic review, showing diet items contributing to 90% of cumulative importance in diet. The main prey item was Crustacean decapods (almost entirely crabs) for both Juveniles and adult cuttlefish. Amphipods are the second most important item for juveniles and are not part of the adult diet. Conversely, fish is a minor component of juvenile diet and become fundamental in adult stage (gobiids especially). Stomatopods crustaceans are also part of the diet and while increasing in importance during cuttlefish life they remain below 10% of contribution.

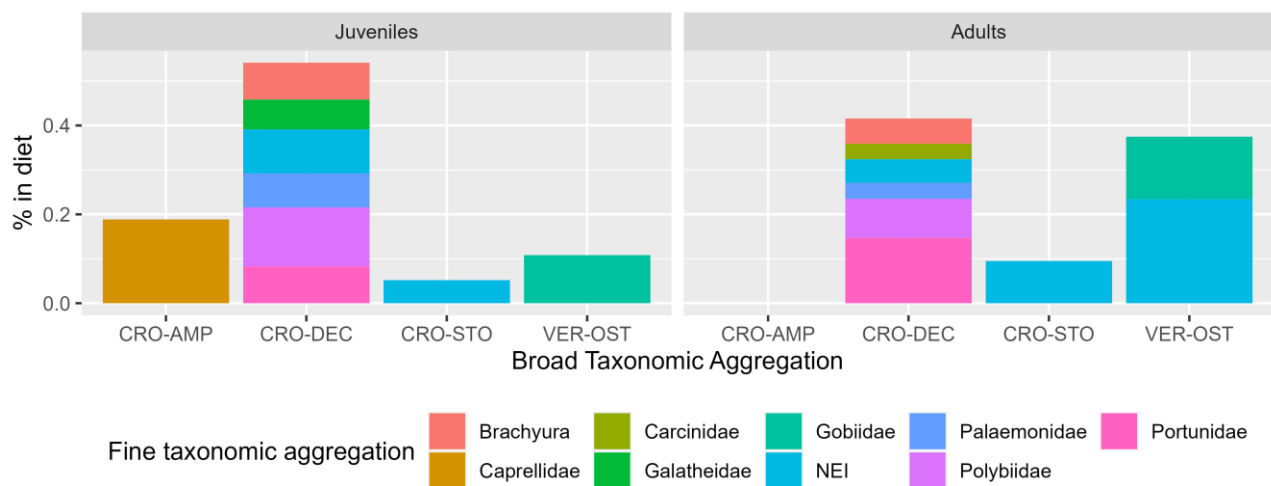


Figure 1: diet composition of common cuttlefish by life stage as estimated from literature review. CRO-AMP is Crustaceans-Amphipods; CRO-DEC is Crustaceans-Decapods; CRO-STO is Crustaceans-Stomatopods; VER-OST is Vertebrates-Osteichthyes. NEI is Not Either Identified.

Table 1.3-1: diet composition of common cuttlefish by life stage as estimated from literature review. CRO-AMP is Crustaceans-Amphipods; CRO-DEC is Crustaceans-Decapods; CRO-STO is Crustaceans-Stomatopods; VER-OST is Vertebrates-Osteichthyes. NEI is Not Either Identified.

Taxon. Lev 1	Taxon. Lev 2	Taxon. Lev 3	% in diet	Lifestage
CRO-ANF	Amphipods	Caprellidae	18.85	Juveniles
CRO-DEC	Crabs	Portunidae	8.27	
CRO-DEC	Crabs	Brachyura	8.30	
CRO-DEC	Crabs	Polybiidae	13.32	
CRO-DEC	Lobsters	Galatheidae	6.69	
CRO-DEC	NEI	NEI	9.93	
CRO-DEC	Shrimps	Palaemonidae	7.61	
CRO-STO	NEI	NEI	5.19	
VER-OST	Small demersal fishes	Gobiidae	10.81	
CRO-DEC	Crabs	Carcinidae	3.48	Adults
CRO-DEC	Crabs	Brachyura	5.67	
CRO-DEC	Crabs	Polybiidae	8.83	
CRO-DEC	Crabs	Portunidae	14.68	
CRO-DEC	NEI	NEI	5.33	
CRO-DEC	Shrimps	Palaemonidae	3.58	
CRO-STO	NEI	NEI	9.50	
VER-OST	NEI	NEI	23.43	
VER-OST	Small demersal fishes	Gobiidae	14.04	

Table 1.2-1.3-2: 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 1.2-2: Growth and length weight model parameters

		Sex				
		Units	female	male	Combined	Years
Growth model	$L_{\infty}$					
	K					
	$t_0$					
	Data source					
Length weight relationship	a				0.22041	
	b				2.773	
	M (scalar)					
	sex ratio (% females/total)					

## 2 Fisheries information

### 2.1 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 including specific pots; e.g. (Fabi et al., 2001; Armelloni et al., 2021a). Discards of this species is virtually absent (Sartor et al., 1998). Common cuttlefish is mostly targeted by the Italian fleet, which production represents nearly 95% of the entire production of GSA 17. The gears selectivity is related to the ontogenetic seasonal migrations. Figure 2 and Figure 3 reports a time series (2020-2023) of seasonal landings and length frequency distributions (only data for Italy) by fleet. The small-scale fishery (gillnets and pots, codes: GNS, FPO) mainly exploits sexually mature individuals in coastal waters during reproductive period (spring). Pots are equipped with plastic materials used to attract spawning females for eggs clusters deposition (Fabi et al., 2001; Grati et al., 2018). Eggs attached to fishing gear will have the potential to develop successfully only if fishermen adopt a correct behavior – i.e. by setting immediately at sea the gear. In the AS fishermen usually just haul their gears and clean them from eggs with destructive devices such as pressure cleaners (Grati et al., 2018). Considering that spawners are going to die soon, the mortality caused by artisanal fishery can be mostly considered a source of egg mortality. Trawlers (bottom otter trawlers and rapido trawlers, codes: OTB, TBB) are not selective for either recruits or spawners (Bettoso et al., 2016) and landings from those métiers prevail during autumn-winter. These gears exploit the adult stock when it is in offshore feeding grounds and potentially intercept recruits performing the offshore migration. Mortality caused by trawlers reduces the spawning stock potential.

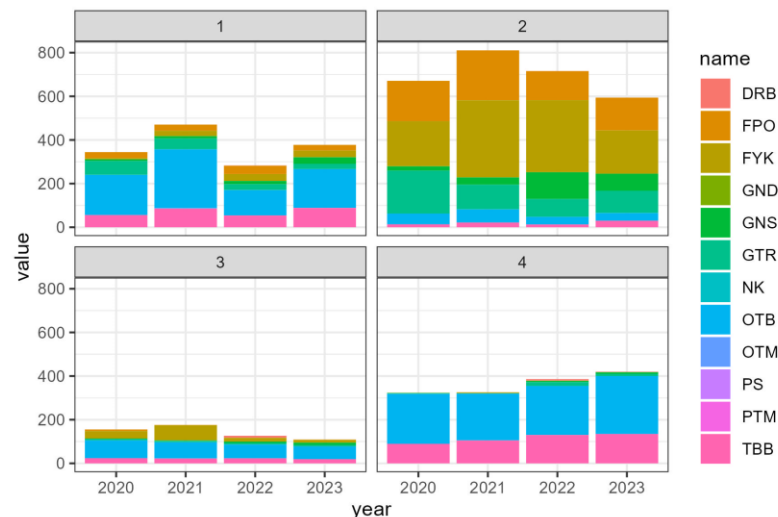


Figure 2: seasonal landings by gear. FPO = pots; GNS =gillnetters; OTB = bottom otter trawlers; TBB = bottom beam trawlers. Panels show quarters: Winter (1), Spring (2), Summer (3), Fall (4). Source: FDI 2024.

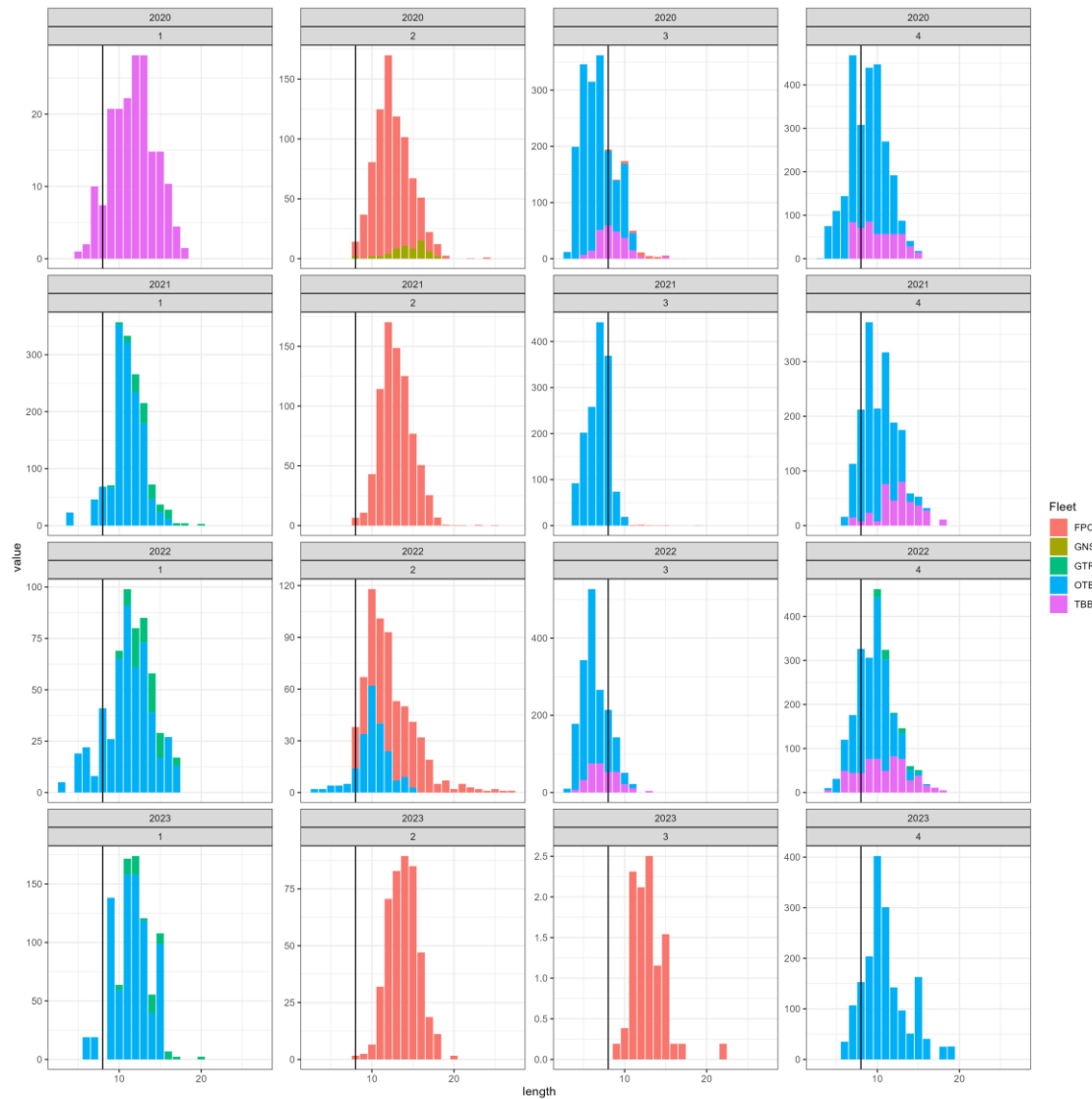


Figure 3: Seasonal length frequencies distributions of the Italian landings by gear in GSA 17, years 2020-2023. Source: FDI 2024 Italian data call. The vertical line indicates size at first maturity from females (7 cm). FPO = pots; GNS =gillnetters; OTB = bottom otter trawlers; TBB = bottom beam trawlers.

## 2.2 Fishery performance

The proportion of fishing effort deployed by the fleets targeting Common cuttlefish largely varied over time due to changes in regulation (see section Management regulations). Figure 4 provides information on the fishing days for trawlers and set gears. Trawlers (OTB and TBB) fishing capacity continuously declined since 2005. For small scale fishery, gillnets (GTR and GNS) have generally diminished their activity. Pots (FPO) fishing activity seems to have increased. Figure 5 provides an estimation of catches per unit of effort. Set gears spring CPUE (target season) peaked in 2007 and then dropped until 2012, resembling the biomass and overall trend pattern. In recent years it is observed a slight recover. CPUE of other seasons do not suggest any evident pattern. Trawlers autumn CPUE oscillated also resembling the overall biomass trajectory. The only interesting pattern is a slight change in the ratio winter/autumn CPUE over recent years.

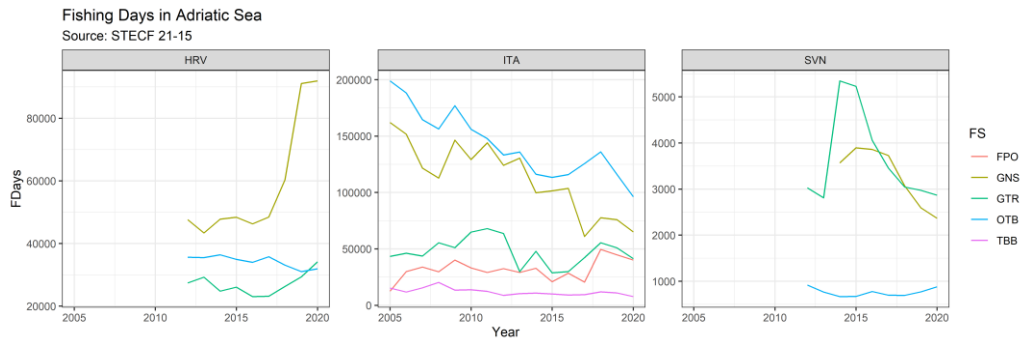


Figure 4 Fishing effort data from official European statistics by Fleet Segment (FS). FPO = pots; GNS =gillnetters; GTR: trammel nets; OTB = bottom otter trawlers; TBB = bottom beam trawlers.

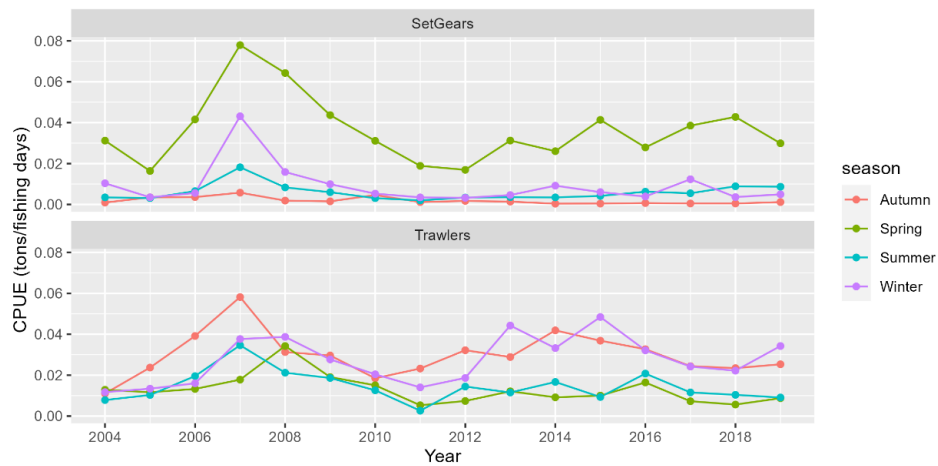


Figure 5: catches per unit effort of set gears and trawlers.

Table 2.2-1-1: Description of operational units exploiting the stock

	Country	GSA	Fleet Segment	Fishing Gear Class	Group of Target Species	Species
<b>Operational Unit 1</b>	ITA	17	E - Trawl (12-24 metres)	98 - Other Gear (rapido trawl)	33 - Demersal shelf species	
<b>Operational Unit 2</b>	ITA	17	E - Trawl (12-24 metres)	Otter trawl + other trawled gears	33 - Demersal shelf species	
<b>Operational Unit 3</b>	ITA	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets Traps + other	33 - Demersal shelf species	

<b>Operational Unit 4</b>	HRV	17	C - Minor gear with engine (6-12 metres) + E - Trawl (12-24 metres)	07 - Gillnets and Entangling Nets + Otter Trawl	33 - Demersal shelf species	
<b>Operational Unit 5</b>	SVN	17	C - Minor gear with engine (6-12 metres) + E - Trawl (12-24 metres)	07 - Gillnets and Entangling Nets + Otter Trawl	33 - Demersal shelf species	

Table 2.1-2: 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 (Fishing days)
<b>Operational Unit 1</b>		221				
<b>Operational Unit 2</b>		536				
<b>Operational Unit 3</b>		689				
<b>Operational Unit 4</b>		99				
<b>Operational Unit 5</b>		6.94				
<b>Total</b>		1500				

## 2.3 Historical trends

Landings dataset was reconstructed by exploring different data source and although it represents the best available knowledge 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). 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 2004-2023 data were available from the EU DCF (Data call FDI). For

the Croatian side, data from 1992 to 2011 were available from EUROSTAT database <sup>1</sup> and from 2012 to 2022 from (STECF, 2021). 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 2020 from STECF 2021. Data for Croatia and Slovenia for the period 1972-1991 were assumed to be equal to Yugoslavia data, available on FishStatJ. Table 2.3-1 reports the data agreed at data preparation meeting in 2024. The fishing of common cuttlefish started well before 1970's and in the early year of the time series catches are much higher than in the recent period

(

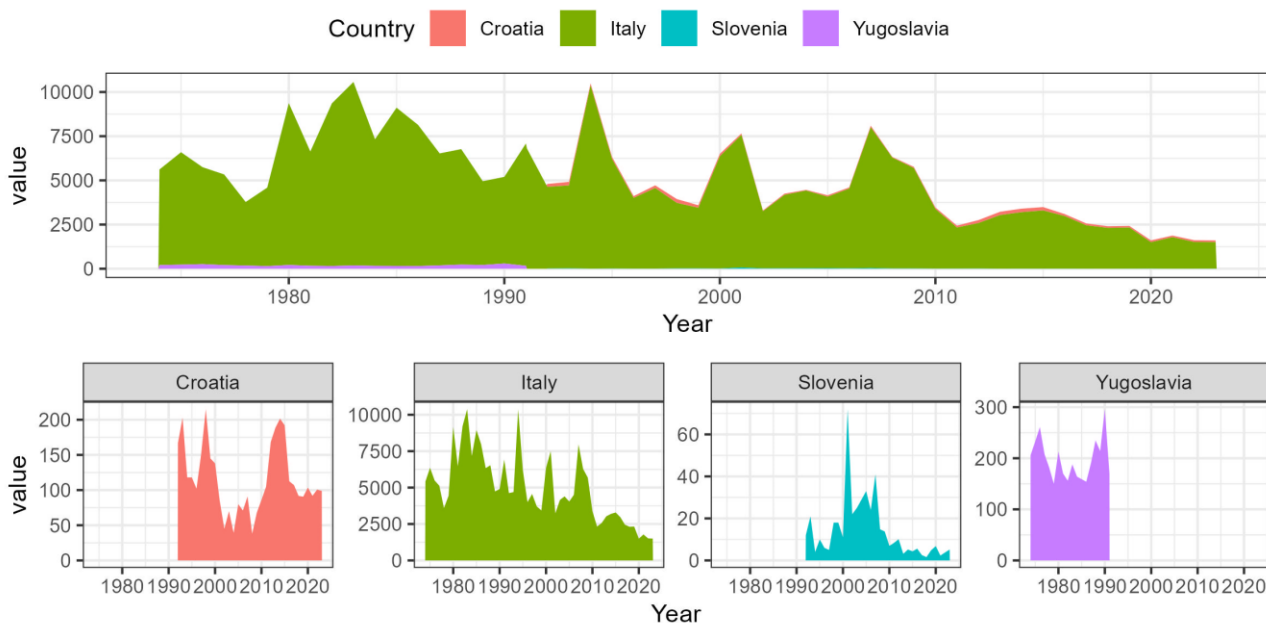


Figure 6). Captures trend is highly oscillatory according to a possible correlation between recruitment success and environmental characteristics already documented for a number of cephalopod species (Pierce *et al.*, 2008; Rodhouse *et al.*, 2014; ICES, 2019). Nonetheless, the trend is generally declining, and the high spikes observed in the past have been registered less frequently in recent years.

Table 2.3-1: Time series provided at GFCM data preparation meeting in 2023.

Year	Croatia	Slovenia	Yugoslavia	Italy	TOTAL
1974			206	5411	5617
1975			233	6361	6594
1976			261	5485	5746
1977			208	5129	5337
1978			182	3594	3776
1979			150	4441	4591
1980			213	9158	9371
1981			170	6466	6636
1982			156	9203	9359

<sup>1</sup> <https://ec.europa.eu/eurostat/web/fisheries/data/database>

Year	Croatia	Slovenia	Yugoslavia	Italy	TOTAL
1983			188	10382	10570
1984			164	7164	7328
1985			159	8955	9114
1986			154	7985	8139
1987			190	6337	6527
1988			235	6534	6769
1989			214	4739	4953
1990			296	4902	5198
1991			169	6917	7086
1992	167	12		4621	4800
1993	203	21		4692	4916
1994	118	4		10368	10490
1995	118	10		6193	6321
1996	102	6		4000	4108
1997	151	5		4563	4719
1998	215	18		3710	3943
1999	145	18		3431	3594
2000	138	11		6355	6504
2001	85	72		7500	7657
2002	45	22		3231	3299
2003	70	25		4155	4250
2004	39	29		4396	4464
2005	80	33		4043	4156
2006	71	24		4508	4603
2007	91	41		7964	8096
2008	38	15		6276	6329
2009	68	14		5683	5765
2010	86	7		3375	3468
2011	105	8		2324	2437
2012	168	10		2575	2754
2013	188	3		3033	3224
2014	202	5		3195	3401
2015	192	4		3293	3489
2016	113	6		2975	3093
2017	107	3		2453	2563
2018	92	2		2310	2404
2019	91	5		2326	2422
2020	104	7		1495	1605
2021	92	2		1784	1878
2022	101	4		1512	1617
2023	99	7		1500	1604

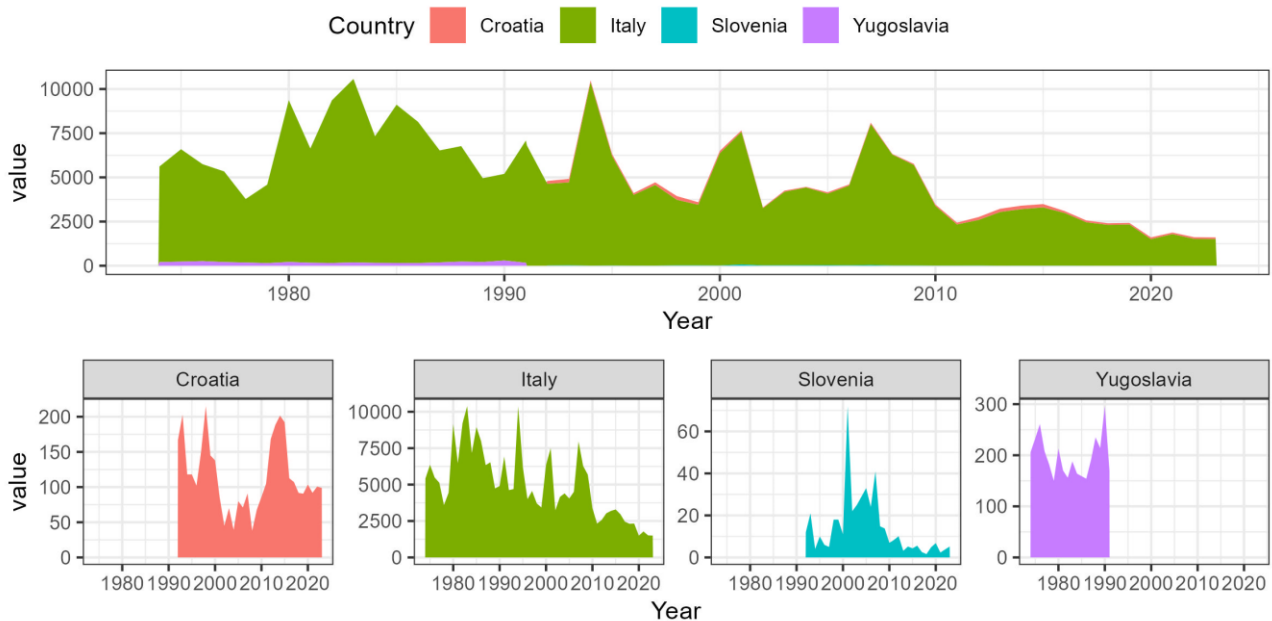


Figure 6: in the panels are shown annual landings by country, with colors referring to the data source.

## 2.4 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). Figure 7 provides a time series of implementation of main rules and events potentially impacting the fishing activity exerted on demersal resources in the Adriatic Sea. Regulations applied or influencing cuttlefish are:

- 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 Italy: minimum mesh size = 16 mm stretched; maximum length x vessel x day= 5000.
- Set net Croatia: minimum mesh size = 32 - 38 mm (middle layer) and 150 – 170 mm (outer layer); fishing season from 1/9 to 1/6; 800m of net allowed.

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

- Minimum of 45 days of absolute ban during summer, within 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 within 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.

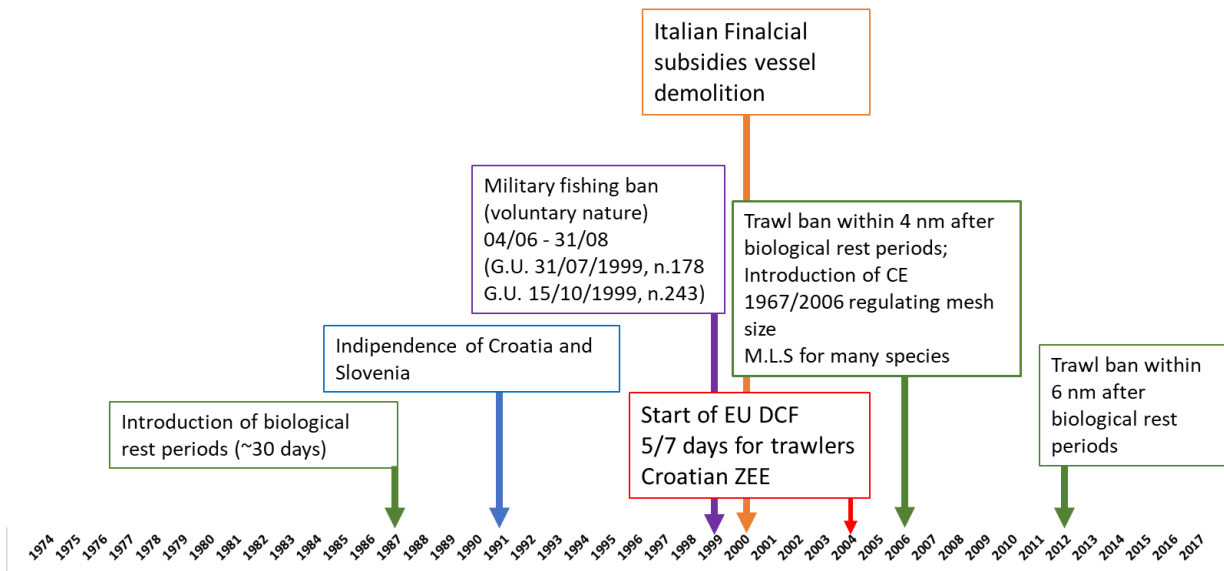


Figure 7: time series of management regulations and events that can affect fishing pattern and data collection in the Adriatic Sea.

### 3 Fisheries independent information

#### 3.1 Direct methods: trawl based abundance indices (SoleMon survey)

Solemon survey (Grati *et al.*, 2013) is a trawl fishing survey conducted with a modified beam trawl defined “Rapido” (Hall-Spencer, 1999), carried out in GSA 17 from 2005 onward in the 5-100 m depth waters of the GSA 17 (**Error! Reference source not found.**): one systematic “pre-surveys” (fall 2005) and the rest random surveys stratified on the basis of depth (5-30 m, 30-50 m, 50-100m). Hauls are carried out by day using 2-4 *rapido* trawls simultaneously (stretched codend mesh size = 46).

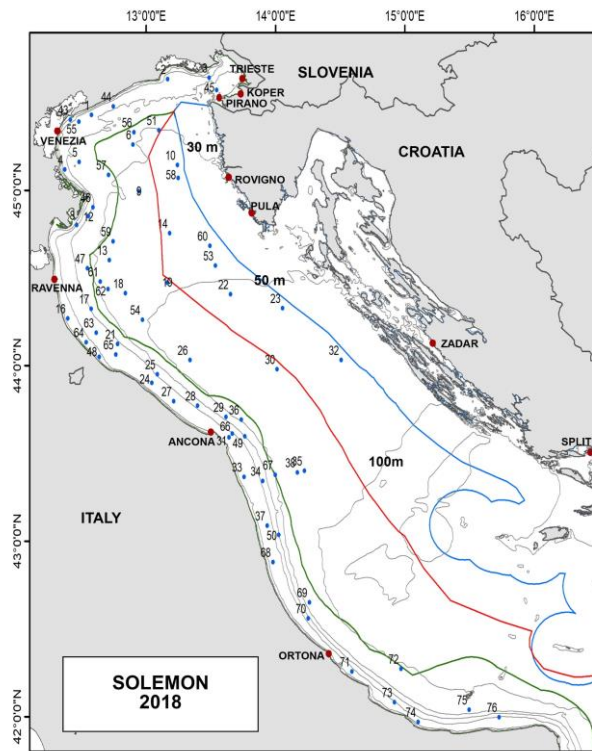



Figure 8: haul location for solemon survey in 2018.

Table 4.1-1 Number of hauls per year carried out by the Solemon survey in GSA 17

Depth strata	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total	62	67	63	68	68	68	68	64	66
Depth strata	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total	68	68	75	71	67	67	58	59	39
Depth strata	2023								
Total	68								

Table 4.1-2 Trawl survey basic information

Survey	SoleMon		Trawler/RV	Dallaporta
Sampling season	Fall			
Sampling design	Random stratified			
Sampler (gear used)	 <p>Rapido trawl</p>			
Codend mesh size as opening in mm	46			

Investigated depth range (m)	5-100
------------------------------	-------

Table 4.1-3 Trawl survey sampling area and number of hauls 2020. Note that hauls in HRV stratum have been removed from the analyses.

Stratum	Total surface (km <sup>2</sup> )	Trawlable surface (km <sup>2</sup> )	Swept area (km <sup>2</sup> )
1	11512		1.343
2	8410		0.55
3	22466		0.36
HRV	6000		0.09

### 3.1.1 Biomass and density indices

Abundance and biomass indexes from *rapido* trawl surveys are computed 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. The variation of the stratified mean is then expressed as the 95 % confidence interval. Solemon survey data and index calculation are handled through the TRUST software <sup>2</sup>.

In 2020, 2021 and 2022 due to issues as short time availability, sea weather conditions and COVID-19 pandemic, it was possible to survey a limited number of stations. The missing hauls were reconstructed through a model-based approach. The methodology used is detailed in the publication (Coro *et al.*, 2022a) along with data used to fit the submodules and available as open source R software on github ([https://github.com/CNRFisheries/Survey\\_gap](https://github.com/CNRFisheries/Survey_gap)). It is a three-component approach to estimate biomass at a location  $B_i = Wh_i * \frac{\alpha * Bs_i + \beta * Bt_i}{\alpha + \beta}$ . Wh is a weight based on ecological niche modelling (MaxEnt model, Phillips *et al.*, 2004); Bs derives from spatial kriging and advection-based model (DIVA model, (Beckers *et al.*, 2014)); Bt derives from Singular Spectrum Analysis model (Vautard *et al.*, 1992). The  $\alpha$  and  $\beta$  terms are weights that in the case of the present work were set as 1.

<sup>2</sup> <https://www.kosmosambiente.it/scientifictrawlsurveys/>

Biomass Index for Common cuttlefish in GSA 17

Solemon survey

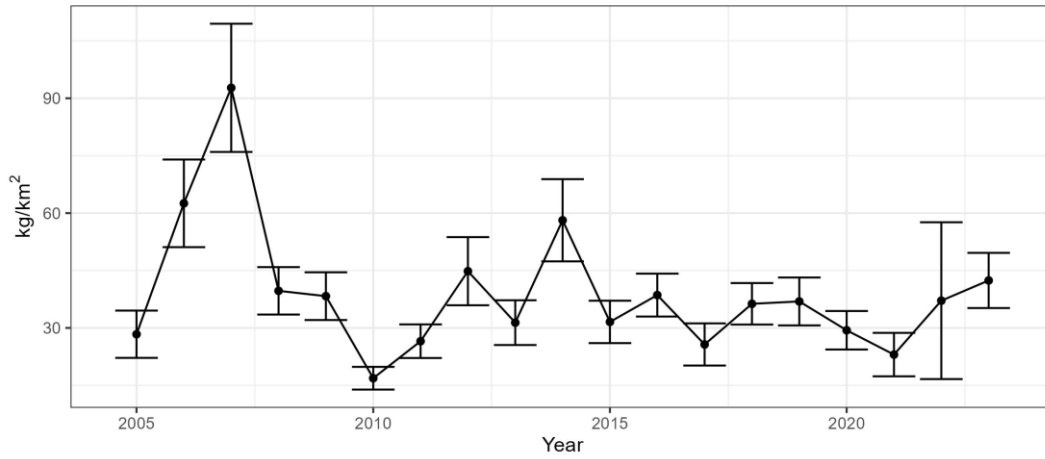


Figure 9: biomass index (kg/km<sup>2</sup>) estimated from solemon survey.

Table 4.1-4 Trawl survey biomass index

Years	Kg/km <sup>2</sup>	St Dev	CV
2005	28.35	6.18	0.22
2006	62.55	11.45	0.18
2007	92.73	16.81	0.18
2008	39.69	6.22	0.16
2009	38.3	6.26	0.16
2010	16.86	2.98	0.18
2011	26.53	4.41	0.17
2012	44.82	8.93	0.20
2013	31.38	5.87	0.19
2014	58.13	10.78	0.18
2015	31.57	5.56	0.18
2016	38.58	5.63	0.15
2017	25.68	5.53	0.21
2018	36.3	5.44	0.15
2019	36.92	6.28	0.17
2020	29.39	5.03	0.17
2021	23.03	5.68	0.25
2022	37.12	20.49	0.55
2023	42.4	7.21	0.17

3.1.2 Length Frequency Distribution

Length distributions represent an aggregation (sum) of all standardized length frequencies over the stations of each stratum. Aggregated length frequencies are then raised to stratum abundance and finally aggregated (sum) over the strata to the GSA. The method used to estimate data in 2020-2022 is not able to distinguish between age or length classes, so LFD in missing hauls was not estimated (Figure 10).

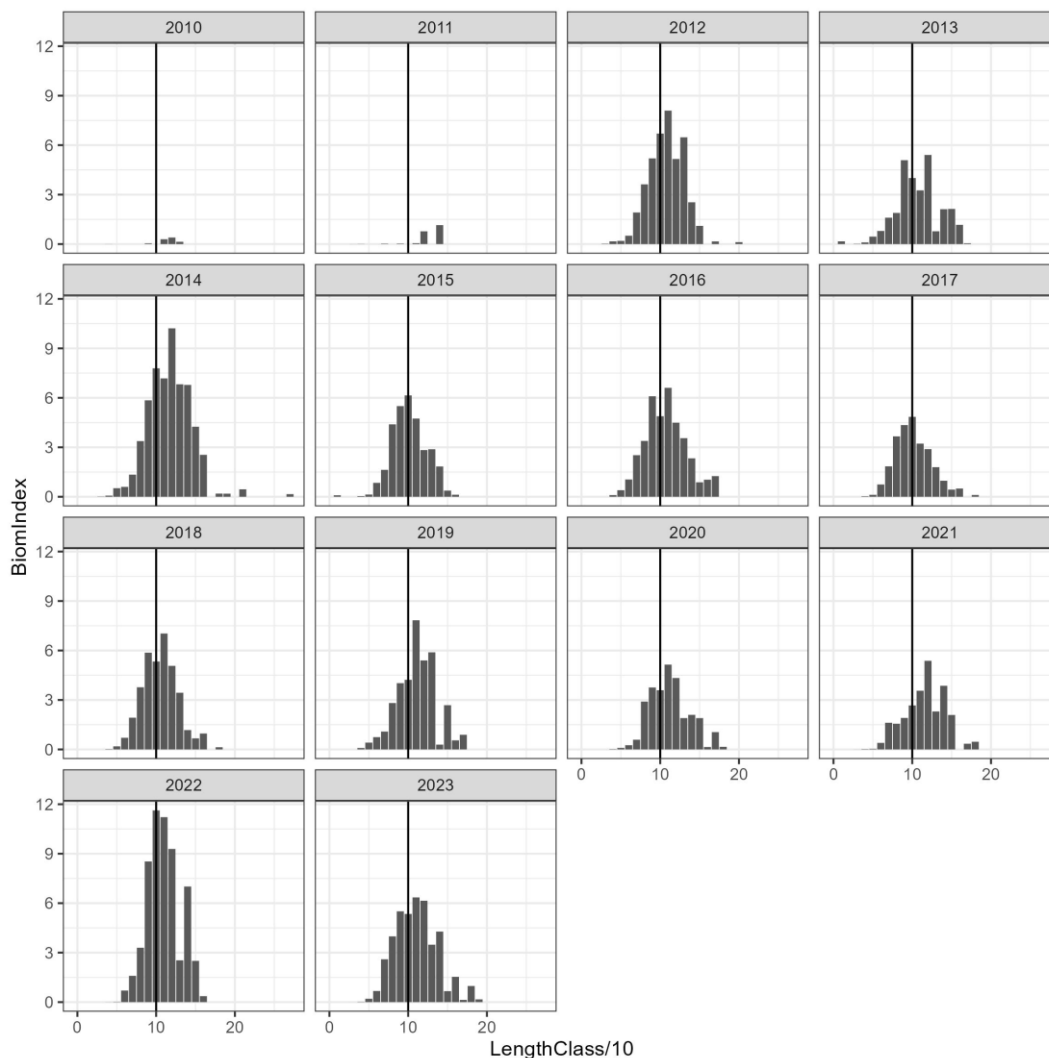


Figure 10 Stratified abundance indices by size, 2010-2023. Vertical line: size at first maturity.

### 3.1.3 Spatial distribution of the resources

According to data collected during SoleMon surveys, cuttlefish aggregates in the northern sector of GSA 17. The map reported here below based on observed data and spatial kriging.

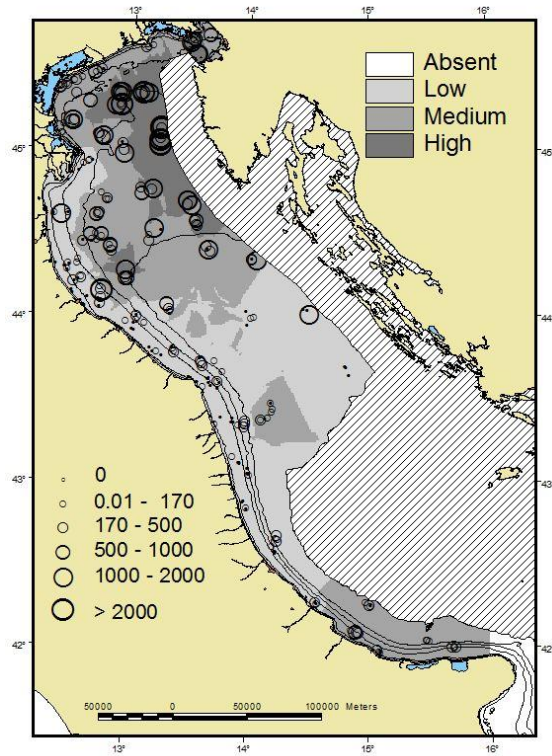


Figure 11: Maps distribution of cuttlefish in GSA 17 (bubbles:  $N \text{ km}^{-2}$ ), based on Solemon data.

## 4 Stock Assessment

### 4.1 JABBA model

Stock assessment of common cuttlefish is carried out with the state-space surplus production model “JABBA” (Winker *et al.*, 2018). JABBA is a flexible framework for biomass dynamic modelling used worldwide. JABBA features of particular interest for the case of common cuttlefish are the options to estimate process and observation variance components and the suite of inbuilt graphics and model diagnostic tools. Information required by JABBA model are time series of catch and biomass index as well as prior distribution for key stock parameters ( $r$ ,  $K$ ,  $q$ , depletion status).

#### 4.1.1 Input data, priors, and settings

The present assessment model has been fitted on data for years 1974-2023 (Table 4.1-1). Biomass Index data from SoleMon survey (2005-2023) were transformed in absolute biomass by multiplying the survey CPUE (kg/km<sup>2</sup>) by the area covered by the survey (42388 km<sup>2</sup>) and dividing kg by 1000 to obtain tons. Coefficient of Variation (CV) was used as source of error. The model estimates most of the key parameters (such as carrying capacity and initial depletion) from the available data using default prior distribution. A few informative and non-informative priors were nevertheless provided. Considering the length of the available time series, the overall good quality of the data and the fact that the survey is representative for our target stock (sampled area and catchability) we opted to use as little user-defined prior options as possible. We informed the model with following priors (Table 4.1-3): Resilience from the database SeaLifeBase (Palomares and Pauly, 2018); Survey Catchability ( $q$ ) applied to the total biomass timeseries provided (0.2-2 means that the absolute biomass provided to the model can be from 20% to 200% of the true value); Process variance ( $\text{igamma}$ ) with uninformative prior (0.001-0.001) approximately uniform on log-scale (Winker *et al.*, 2018). An additional setting provided to the JABBA model was the error associated with catch data ( $\text{catch.cv}$ ), set as 0.2 and asymmetric (more likely that observed catches are an underestimation of the real catches). The model was allowed to estimate additional observation variance ( $\text{sigma.est} = \text{TRUE}$ ).

Table 4.1-1: input data used in the reference run.

Year	Catches (ton)	Survey (ton)	CV survey	Year	Catches (ton)	Survey (ton)	CV survey
1974	5616.9			1999	3593.8		
1975	6594.0			2000	6503.6		
1976	5745.9			2001	7657.5		
1977	5337.0			2002	3298.5		
1978	3776.0			2003	4250.5		
1979	4591.0			2004	4464.1		
1980	9371.0			2005	4156.3	1201.7	0.22
1981	6636.0			2006	4602.5	2651.4	0.18
1982	9358.8			2007	8096.1	3930.6	0.18
1983	10570.4			2008	6329.1	1682.4	0.16
1984	7328.0			2009	5764.8	1623.5	0.16
1985	9113.6			2010	3468.0	714.7	0.18
1986	8138.5			2011	2437.1	1124.6	0.17
1987	6526.7			2012	2753.6	1899.8	0.20
1988	6769.1			2013	3224.5	1330.1	0.19
1989	4952.6			2014	3401.4	2464.0	0.18
1990	5198.1			2015	3489.5	1338.2	0.18
1991	7086.3			2016	3093.5	1635.3	0.15
1992	4800.3			2017	2563.0	1088.5	0.21
1993	4916.4			2018	2403.8	1538.7	0.15
1994	10490.1			2019	2421.9	1565.0	0.17
1995	6320.9			2020	1605.1	1245.8	0.17
1996	4108.3			2021	1877.8	976.2	0.25
1997	4718.6			2022	1616.5	1573.4	0.55
1998	3943.1			2023	1604.5	1797.3	0.17

Table 4.1-2: reference run settings.

	Initial Year	Final Year	SPM shape	Survey index	Sigma estimation
Value	1974	2023	Schaefer	Absolute biomass	TRUE

Table 4.1-3: priors used in the reference run.

	r	q	igamma	Catch.cv
Value ( $\mu, \sigma$ )	0.45, 0.5	0.2-2	0.001-0.001	0.2
Ditribution	lognormal	bounds	bounds	under

### 4.1.2 Model results

Figure 12 shows the fit of the input data. Catch data trend (on left) was well captured and a slight overestimation of predicted catches was observed in the left tail of the time series. Biomass index fitted reasonably well, nevertheless the estimation for the early years prior to survey data is associated with a large confidence interval.

Other diagnostics on biomass index fit are provided in Figure 13. The goodness-of-fit was 37.3% (a) and the log residual trend evidenced a slight underestimation of the biomass in the period 2005-2011. The Run Test is reported in panel (b), whereby green panels indicating no evidence for a non-random residual pattern ( $p > 0.05$ ). Annual process error deviation (d) on log biomass indicated some sign of systematic pattern. We report our impression on the pattern for the years when biomass index was available and therefore process could have been anchored to observations: the process deviation had a standing positive deviation in the period 2005-2012 followed by a prolonged negative deviation.

Figure 14 shows the trace plots of the MCMC analysis. Trace randomness (no evident trend and fair dispersion) indicates that the model explored the prior distribution efficiently, a good indicator that model was not stuck at local minima (or maxima). In overall, we consider this as an indicator of model convergence given the priors and the data. The only pattern observed is for  $q$ , in which the chains were repeatedly hitting the lower boundary.

In Figure 15 is shown the marginal posterior distributions along with prior densities. The broad prior distribution for  $K$  was the default provided by the JABBA model and has been highly informed by data (PPVR = 0.032). The posterior for  $r$  has also been highly informed by the data (PPVR = 0.079). Posterior distribution of  $\psi$  (initial depletion) overlapped with the broad default prior information. Posterior distribution for  $q$  was slightly skewed toward the left in analogy with what observed in the MCMC trace plot, indicating that the model posterior was close to the lower boundary of the prior distribution. The posterior for  $\sigma^2$  is also skewed and slightly bimodal.

Hindcasting cross-validation results (Figure 16) suggest that the model does not have great prediction skills, especially for the years 2018-2020, as judged by the MASE that is just above 1.

The Kobe biplots Figure 17 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 approached  $F_{msy}$  just for short periods and the biomass was continuously eroded. In recent years it was observed a steep reduction of the  $F$ , not followed by a visible recovery of the Biomass status.  $F$  went below  $F_{msy}$  in 2020 but returned over the reference point in 2021 and down again in 2022. The production curve version of the Kobe plot shows that the model estimated cuttlefish stock to produce a highly oscillatory surplus production given its biomass status, with

many years of low production interrupted by episodic spikes. The recent period (after 2009) remained below the expected surplus production.

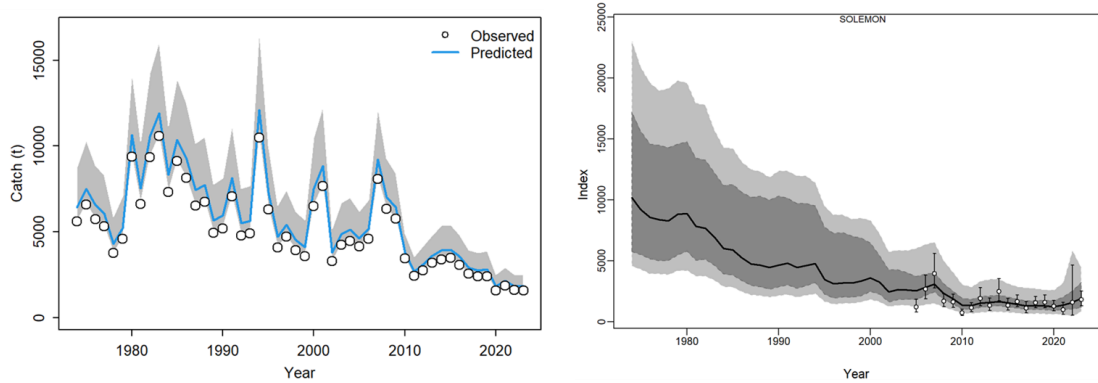


Figure 12: fit of catch and index data for the JABBA model. In the right panel it is shown the time-series of observed (circle) with error 95% CIs (error bars) and predicted (solid line) CPUE for the Bayesian state-space surplus production model JABBA. Dark shaded grey areas show 95% credibility intervals of the expected mean CPUE and light shaded grey areas denote the 95% posterior predictive distribution intervals.

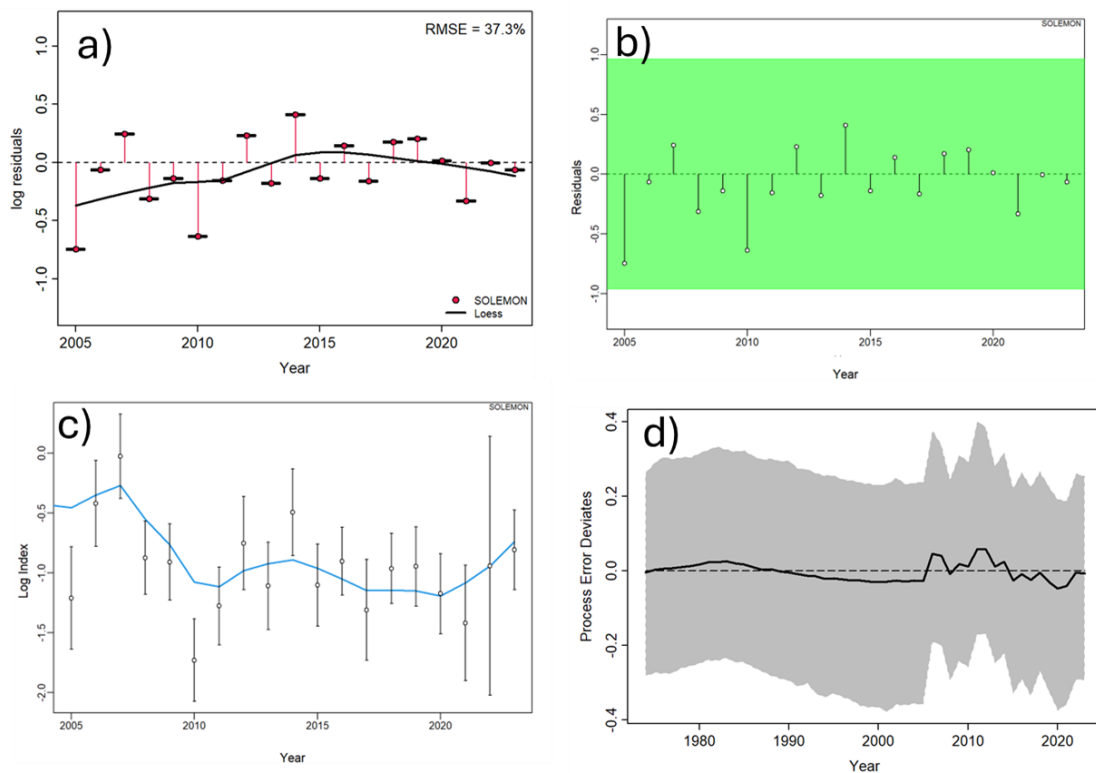


Figure 13: a) JABBA residual diagnostic plots, boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals; b) runs tests to quantitatively evaluate the randomness of the time series of CPUE. Green panels indicate no evidence of lack of randomness of time-series residuals ( $p > 0.05$ ) while red panels indicate the opposite; c) fit of the

estimated log-index to observed data  $d$ ) process error deviates (median: solid line) with shaded grey area indicating 95% credibility intervals.

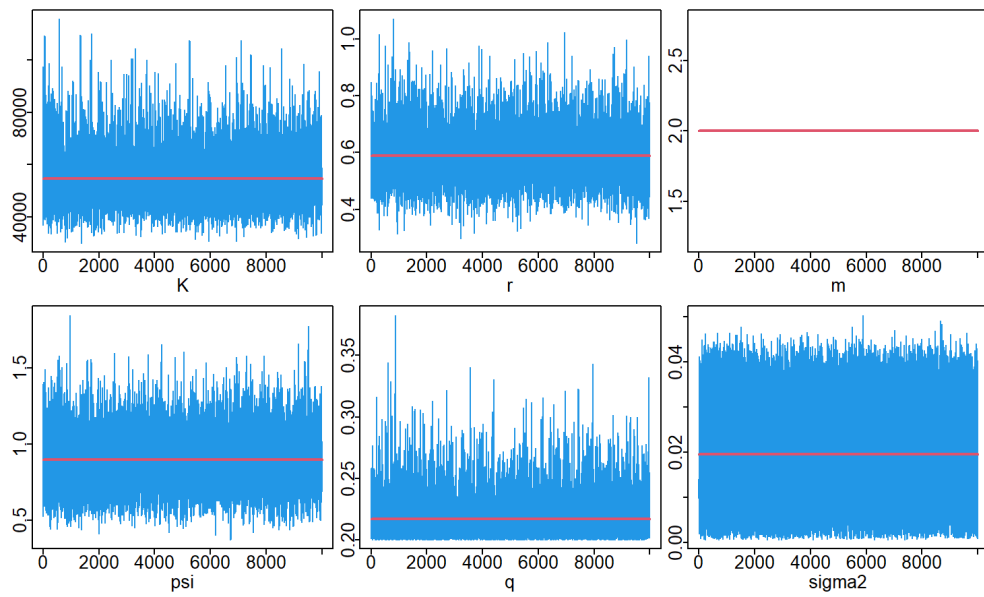


Figure 14: Monte Carlo Markov Chain (MCMC) trace plots for quantities estimated with the JABBA model.

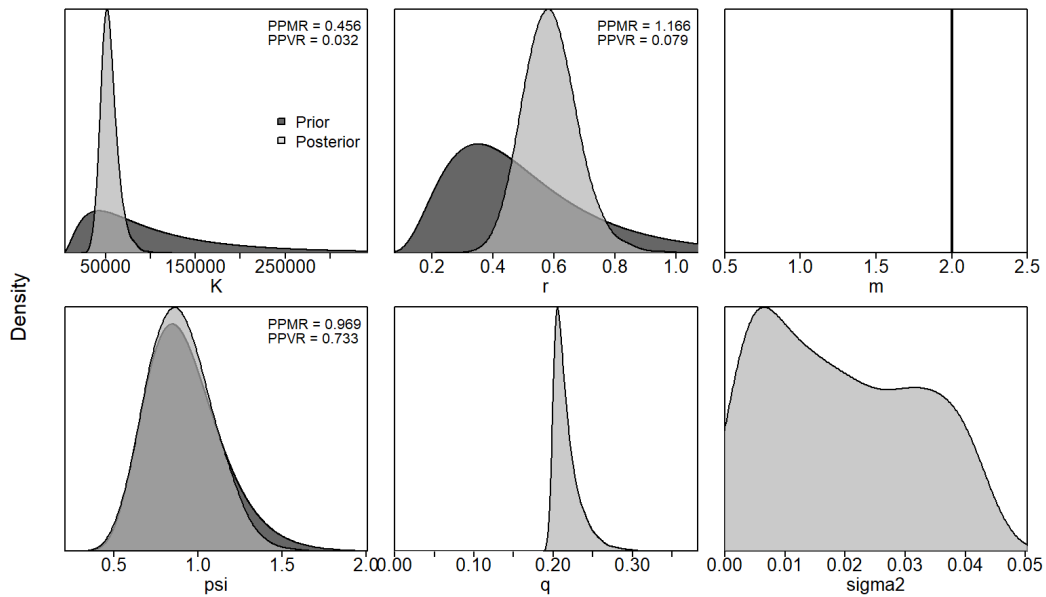


Figure 15: Marginal posterior distributions along with prior densities for the JABBA model. PPMR: Posterior to Prior Ratio of Medians; PPVR: Posterior to Prior Ratio of Variances.

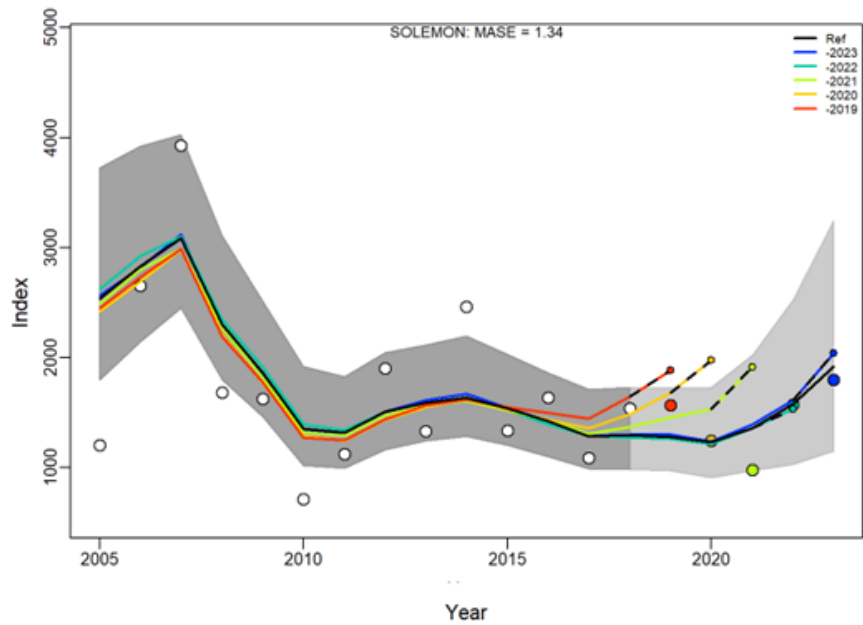


Figure 16: Hindcasting cross-validation results (HCxval) showing one-year-ahead forecasts of CPUE values, performed with 4 hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 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).

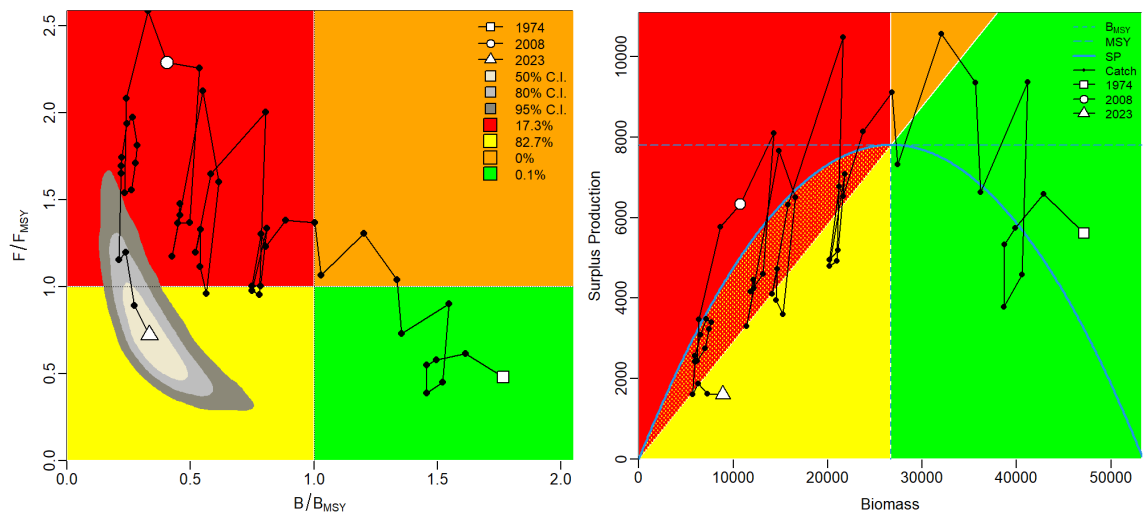


Figure 17: Kobe phase plot showing estimated trajectories (1974-2019) of  $B/B_{MSY}$  and  $F/F_{MSY}$  for the Bayesian state-space surplus production model for Common cuttlefish in GSA 17. Different grey shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend. Left panel is the standard Kobe plot image, right panel is an adaptation of the Kobe plot to the Schaefer production curve.

Table 4.1-4: estimates of the reference run for common cuttlefish in GSA 17.

Year	Biomass (l. ci)	Biomass (median)	Biomass (u. ci)	Catches (estimated)	F (l. ci)	F (median)	F (u. ci)
1974	28771	47146	74415	6441	0.140	0.239	0.313
1975	27329	42865	66034	7521	0.179	0.294	0.421
1976	25379	39838	62616	6568	0.169	0.276	0.387
1977	25129	38711	60989	6099	0.161	0.262	0.366
1978	25016	38654	60585	4306	0.113	0.185	0.261
1979	27241	40588	61873	5241	0.132	0.207	0.304
1980	28764	41196	62225	10639	0.263	0.392	0.614
1981	24655	36163	56306	7540	0.214	0.326	0.495
1982	25175	35667	55101	10568	0.303	0.443	0.704
1983	22703	32048	50600	11917	0.381	0.547	0.866
1984	18916	27418	45690	8322	0.310	0.462	0.670
1985	18691	26804	45883	10359	0.395	0.579	0.825
1986	16245	23717	42765	9284	0.400	0.589	0.801
1987	14456	21645	40877	7436	0.354	0.542	0.661
1988	13980	21186	40590	7732	0.375	0.575	0.681
1989	13011	20177	40052	5675	0.288	0.458	0.510
1990	13872	21091	41429	5960	0.289	0.451	0.511
1991	14595	21826	41118	8133	0.383	0.578	0.697
1992	13294	20195	38973	5507	0.279	0.438	0.493
1993	14321	20988	38866	5643	0.274	0.416	0.511
1994	15514	21654	38114	12104	0.579	0.788	1.126
1995	10820	15779	30700	7285	0.473	0.696	0.842
1996	9320	14130	28552	4718	0.344	0.528	0.587
1997	9699	14670	29182	5431	0.381	0.579	0.663
1998	9576	14521	28163	4539	0.319	0.493	0.565
1999	10410	15282	27520	4133	0.277	0.420	0.535
2000	11937	16607	26617	7518	0.464	0.653	1.011
2001	10730	14815	22588	8857	0.615	0.836	1.439
2002	7853	11414	17950	3795	0.340	0.509	0.766
2003	8670	12215	18211	4900	0.412	0.592	0.982
2004	8758	12143	17457	5133	0.432	0.611	1.094
2005	8666	11850	16318	4645	0.401	0.562	1.049
2006	10173	13156	17225	5165	0.400	0.533	1.059
2007	11537	14311	17927	9219	0.658	0.827	1.793
2008	8521	10729	13657	7043	0.669	0.850	1.876
2009	6875	8664	11048	6437	0.760	0.961	2.170
2010	4782	6355	8430	3804	0.613	0.811	1.694
2011	4664	6149	8129	2711	0.451	0.611	1.219
2012	5450	7009	9072	3119	0.454	0.607	1.210
2013	5841	7431	9447	3620	0.497	0.654	1.338
2014	6001	7652	9812	3922	0.524	0.696	1.372
2015	5584	7151	9072	3977	0.572	0.754	1.516
2016	5064	6539	8332	3577	0.560	0.746	1.466
2017	4587	5953	7674	2930	0.504	0.678	1.306

Year	Biomass (l. ci)	Biomass (median)	Biomass (u. ci)	Catches (estimated)	F (l. ci)	F (median)	F (u. ci)
2018	4550	5974	7752	2778	0.476	0.652	1.205
2019	4505	5930	7760	2824	0.488	0.669	1.208
2020	4189	5687	7653	1858	0.334	0.479	0.791
2021	4597	6306	8842	2150	0.347	0.501	0.795
2022	4976	7270	10823	1847	0.260	0.397	0.553
2023	5765	8905	13721	1837	0.211	0.342	0.421

### 4.1.3 Retrospective analysis

The results of a five-year retrospective analysis applied to scenarios is provided in Figure 18, 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 -0.20 and 0.22 (Hurtado-Ferro *et al.*, 2015). Although no Mohn value is outside the recommended boundaries, it emerges a tendency of the model to overestimate biomass and to underestimate F in the retrospective runs. Production curve estimation is also oscillating in the right tail.

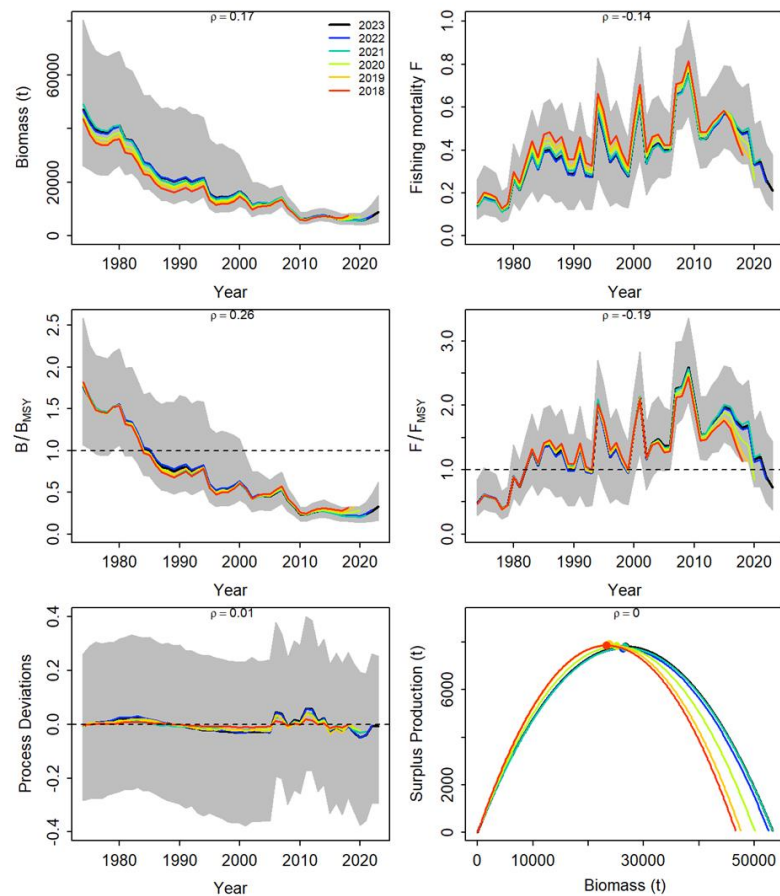


Figure 18: Retrospective analysis conducted by removing one year at a time sequentially ( $n=5$ ) and predicting the trends in biomass and fishing mortality (upper panels), biomass relative to BMSY ( $B/B_{MSY}$ ) and fishing mortality relative to FMSY ( $F/F_{MSY}$ ) (middle panels) and biomass relative to  $K$  ( $B/K$ ) and surplus production curve (bottom panels) from the Bayesian state-space surplus production model fits. Numbers in the above table indicate Mohn's rho values.

#### 4.1.4 Sensitivity analysis

A sensitivity analysis was carried out to test (1) the effect of the prior for the carrying capacity (k); (2) estimating the observation variance (sigma.est) and (3) the effect of catchability (q) lower boundary. A grid of 7 models was implemented, testing each combination of the levels of the sensitivity analysis. All data and other prior were the same as the reference run. Given the process and observation equations of the JABBA model (equations 9 and 11 from Winker et al., 2018), the sum of the process error and the observation error contributes together to explaining the difference between observed quantity (data) and the estimated quantity (the model). Process error distribution informs the deviation of the estimated biomass from the production function (eq. 9 and 10) while observation error is the deviation of the estimated biomass to the observed biomass (eq. 11). Process error and observation error posterior distributions are multiplicative components in the joint posterior distribution and are therefore inversely correlated: setting a strict prior to observation error likely cause a larger quantity of error associated to process (eq 12).

Table 4.1-5: settings of the sensitivity runs along with some performance metrics.

Scenario	K prior	Sigma.est	q. bound	MASE	B mohn	F mohn	Runtest
baseline		T	c(0.2,2)	1.34	0.17	-0.14	Passed
S1	c(30000,3)	T	c(0.2,2)	1.47	0.20	-0.16	Passed
S2		F	c(0.2,2)	1.28	0.10	-0.10	Passed
S3		T	c(0.1,2)	1.02	0.11	-0.10	Passed
S1_2	c(30000,3)	F	c(0.2,2)	1.31	0.10	-0.10	Passed
S1_3	c(30000,3)	T	c(0.1,2)	1.13	-0.10	0.11	Passed
S2_3		F	c(0.1,2)	1.04	0.04	-0.04	Passed
S1_2_3	c(30000,3)	F	c(0.1,2)	1.05	0.03	-0.04	Passed

The rationale of this sensitivity is to understand the model response to change in basic settings. Figure 19 report the prior vs posterior distribution of some of the sensitivity run, showing that the estimation of k is not sensitive to prior choice (S1) and that lowering the boundary for the catchability implies that the model estimates different productivity for the stock. Figure 20 reports a comparison between stock trajectories estimated by the model grid. It emerges that stock trajectories are coherent except for run 1\_3, however the production curve might differ. Considering that performance metrics did not suggest an evident improvement by changing model settings and that final estimations are similar, it was decided to maintain the settings unchanged from RefYear 2022.

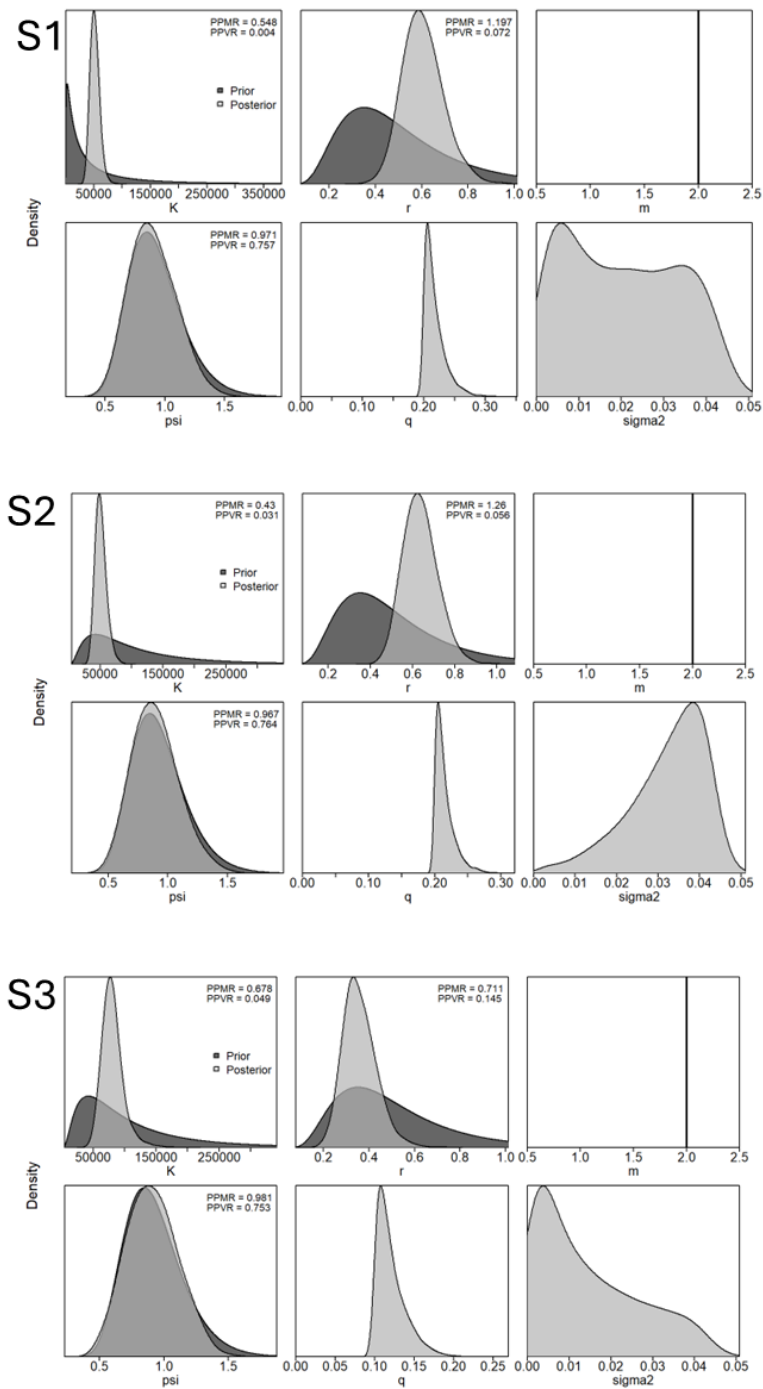


Figure 19: fit of catch and index data for the JABBA model. In the right panel it is shown the time-series of observed (circle) with error 95% CIs (error bars) and predicted (solid line) CPUE for the Bayesian state-space surplus production model JABBA. Dark shaded grey areas show 95% credibility intervals of the expected mean CPUE and light shaded grey areas denote the 95% posterior predictive distribution intervals.

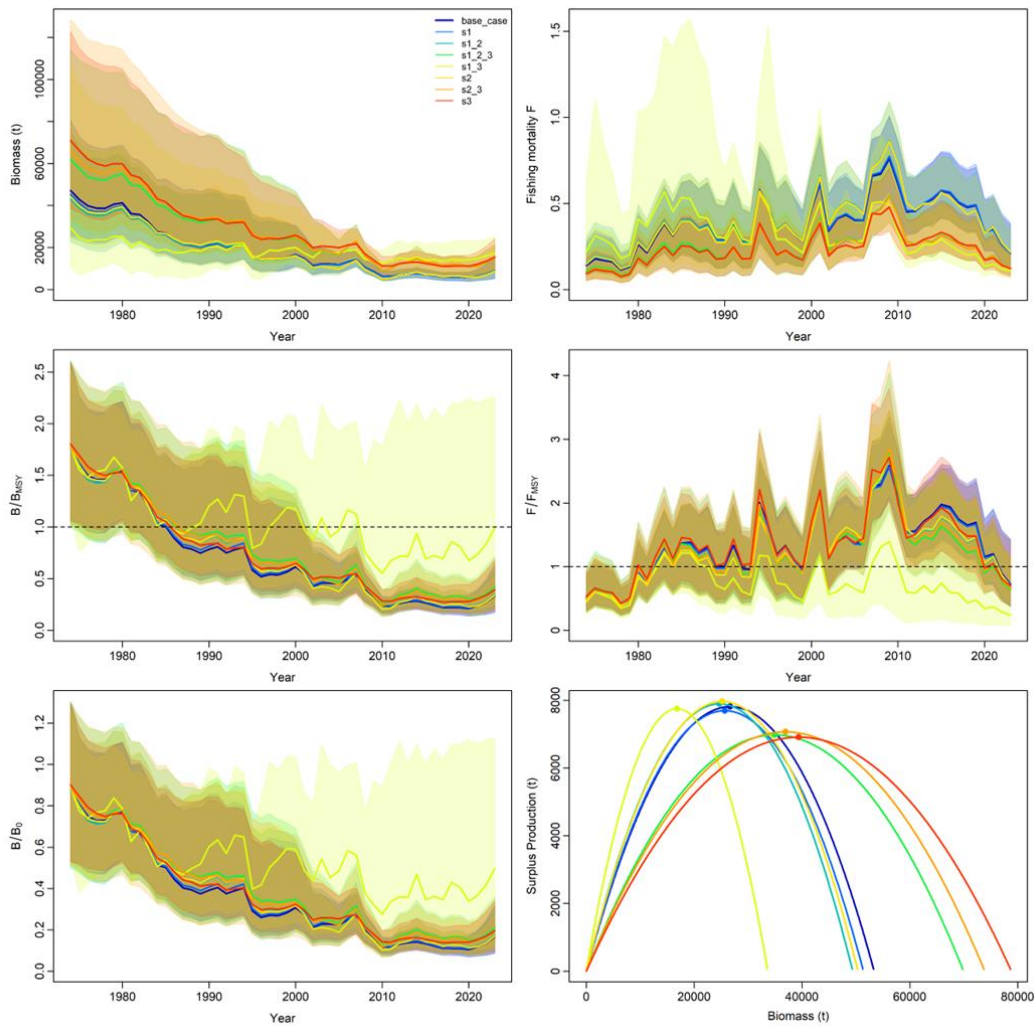


Figure 20: stock trajectories estimated by the sensitivity runs tested. Model definitions are provided in table 4.1-5.

### 4.1.5 Reference points

The JABBA model provides estimations for biomass and fishing mortality at MSY. Additional precautionary biomass reference points provided are Blim and Bthr. Blim is provided as 0.25 Bmsy and Bthr is 0.5 Bmsy. Table 4.1-6 reports the reference points estimated and Figure 21 reports stock trajectories along with the reference points. The stock biomass is currently at Blim.

Table 4.1-6: reference points estimated in the present stock assessment.

Label	Value
Ftgt (Fmsy)	0.291
Btgt (Bmsy)	26647
Bthr	13323
Blim	7994

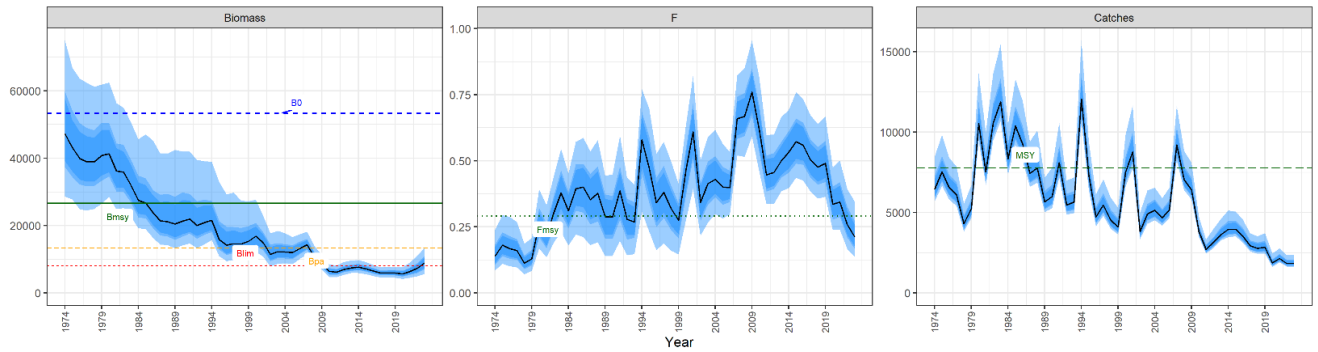


Figure 21: stock trajectories and reference points.

## 4.2 Stock prediction

Short term forecast has been calculated with the forecast option from the JABBA package (`fw_jabba`). Forecast scenario were applied imposing intermediate year of fishing at  $F_{current}$  and afterward imposing constant  $F$  scenario as fractions of  $F_{msy}$ . Forecasts suggest closing the fishery allows the stock recovering to 0.95  $B_{msy}$  by 2026 and that increasing  $F$  to 1.5  $MSY$  would anyway allow the biomass to slowly recover toward  $B_{msy}$ . Considering the potential ecological imbalance of cuttlefish stock and the process deviation observed in the JABBA model (not accounted here, forecasts does not assume departure from mean process estimate) we suggest that these projections are overly optimistic. We do not recommend applying any increase of the fishing mortality for common cuttlefish. Further work is needed to provide a modeling framework able to deal with environmental and ecological influence on cuttlefish stock productivity to provide reasonable catch forecasts.

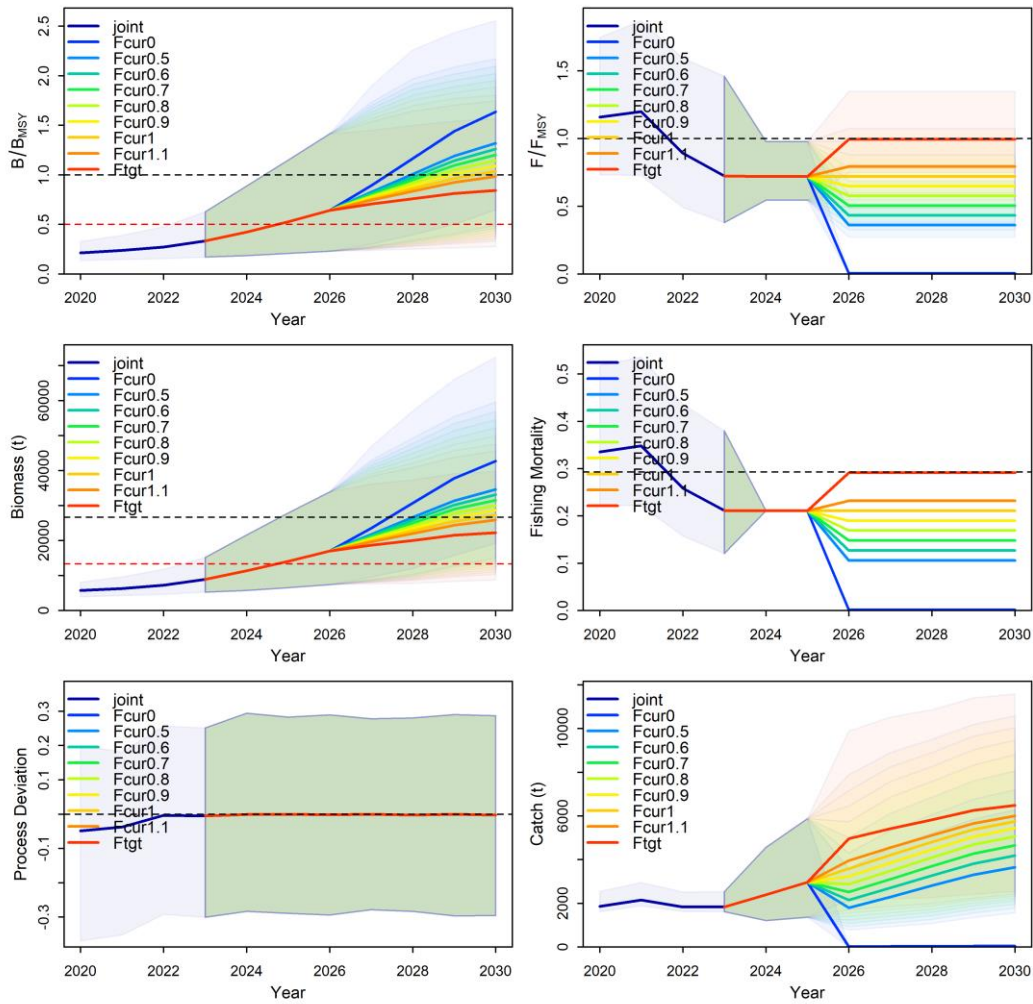


Figure 22: catches produced by short term scenario forecasts.

### 4.3 Summary of results

GSA	Species	Reference Year	Method	Current Levels	Reference Points	Quantitative Status	% F reduction*
17	<i>Sepia officinalis</i>	2023	JABBA	Fc= 0.211, Bc= 8905	Fmsy = 0.291, Bmsy = 26647, Bpa = 13323, Blim = 7994	F/Target = 0.73 B/Btarget = 0.33 B/Bthreshold = 0.67 B/Blimit = 1.11	--

**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 2002-2021, excluding year 2020. During the years 2016-2021 the F declined, and it was below the Fmsy in 2022. The decrease in F is not reflected in an improvement in biomass status.

**State of the biomass:** biomass trend showed an almost monotonous decline in the early part of the time series, until 1995, then it oscillated without large spikes until 2007. In 2008 it was observed a steep decline

which led the biomass to remain around Blim from 2010. In 2010s the biomass did not show sign of recovering and in 2023 is still close to Blim. The stock is on the left tail of the production function (Figure 23) and years of surplus production above the median expectation have not been recorded for more than a decade. The stock can potentially be in a low productivity status due to ecological or environmental reasons.

**Stock status:** ecologically unbalanced with a low fishing mortality.

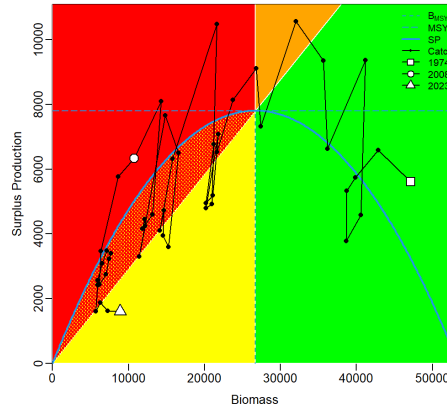


Figure 23: trajectory of the surplus production function from the reference run of the JABBA model.

Table 6.1.4.1: summary of final results from JABBA model.

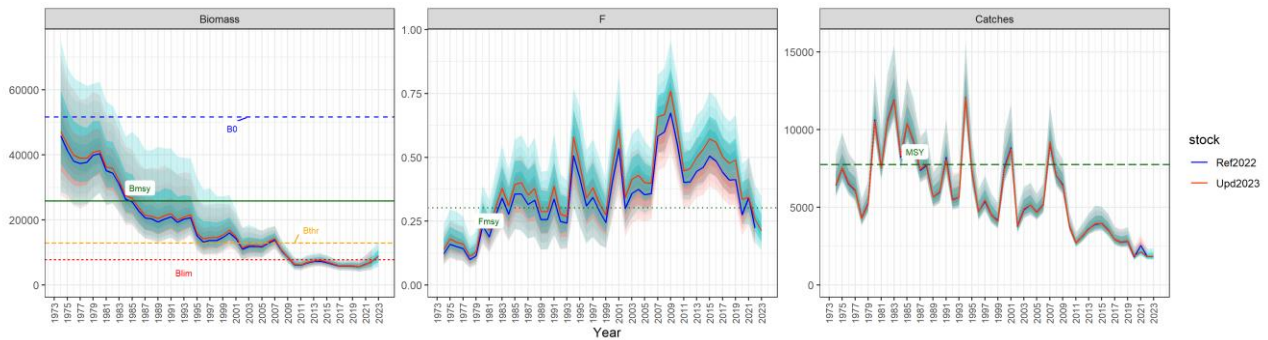


Figure 24: trajectory of the surplus production function from the reference run of the JABBA model.

Table 6.1.4.1: summary of final results from JABBA model

#### 4.4 Assessment quality

The quality of the input data used in the stock assessment model can be considered reasonably good. The catch data used has been carefully revised in recent years and can be considered the best available source of information, although some criticism was raised in the dedicated section of this report. The survey is representative of the species distribution and captures the target species well. No major violation to the survey protocol has been reported, except for the low sampling coverage in the years 2020-2020. Nevertheless, the biomass index in the missing sampling station has been reconstructed with a state-of-the-art model-based approach that shows good overall predictive power. The stock assessment has been

developed by fitting data with a modern surplus production model. No major failures to model diagnostics have been observed, except for a small retrospective pattern and a low predictive ability with a systematic overestimation of the biomass index. Nevertheless, there are issues regarding model plausibility. SPM assumes a fixed stock productivity and a stable state ecosystem. These assumptions can be violated by fluctuations of the stock productivity due to environmental and/or ecological reasons. The JABBA implementation allows model departures from production curve by accounting for observation and process error. This strategy might improve the ability of the model to cope with changing stock productivity but does not solve the problem of correctly allocating the biomass deterioration and the surplus oscillation to natural or fishery related reasons. Therefore, estimated Biomass can be accurate, but the reference point associated might not be. Since the environmental parameters might interact with fishery exploitation in determining cephalopods population dynamics (Pierce et al., 2008; ICES, 2019), it can be of great help to understand the link between environmental data and stock status in future assessments in order to obtain more robust results and estimation of advice related quantities.

## Draft scientific advice

The scientific advices in the following table are based on the JABB 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 (2017-2022)	Stock Status
<b>Fishing mortality</b>	Fishing mortality	Fmsy: 0.291	Fcurr: 0.211	F/Ftarget = 0.73,	D	S
<b>Stock abundance</b>	Biomass	Bmsy: 26.647	Bcurr: 8.905	B/Btarget = 0.33, B/Bthreshold = 0.67, B/Blimit = 1.11	I	IO
<b>Recruitment</b>					C	
<b>Final Diagnosis</b>		Ecologically unbalanced with a low fishing mortality.				
<b>Advice and recommendations</b>		Implement a recovery plan				

## 5 Acknowledgments

The research effort needed to implement this stock assessment and to provide detailed biological information has been done by the author (Armelloni E. A.) in the context of the Ph.D. Program “Innovative Technologies and Sustainable Use of Mediterranean Sea Fishery and Biological Resources – FishMed”.

## 6 Literature cited

- Armelloni, E. N., Lago-Rouco, M. J., Bartolomé, A., Felipe, B. C., Almansa, E., and Perales-Raya, C. 2020. Exploring the embryonic development of upper beak in *Octopus vulgaris* Cuvier, 1797: New findings and implications for age estimation. *Fisheries Research*, 221: 105375. Elsevier.
- Armelloni, E. N., Scanu, M., Masnadi, F., Coro, G., Angelini, S., and Scarcella, G. 2021a. Data Poor Approach for the Assessment of the Main Target Species of Rapido Trawl Fishery in Adriatic Sea. *Frontiers in Marine Science*, 8. [www.frontiersin.org](http://www.frontiersin.org) (Accessed 6 August 2021).
- Armelloni, E. N., Tasseti, A. N., Ferrà, C., Galdelli, A., Scanu, M., Mancini, A., Fabi, G., *et al.* 2021b. AIS data, a mine of information on trawling fleet mobility in the Mediterranean Sea. *Marine Policy*, 129: 104571.
- Beckers, J. M., Barth, A., Troupin, C., and Alvera-Azcárate, A. 2014. Approximate and efficient methods to assess error fields in spatial gridding with data interpolating variational analysis (DIVA). *Journal of Atmospheric and Oceanic Technology*, 31: 515–530. American Meteorological Society.
- Belcari, P., Sartor, P., Sanchez, P., Demestre, M., Tsangridis, A., Leondarakis, P., Lefkaditou, E., *et al.* 2002. Exploitation patterns of the cuttlefish, *Sepia officinalis* (Cephalopoda, Sepiidae), in the Mediterranean Sea. *Bulletin of Marine Science*, 71: 187–196.
- Bettoso, N., Borme, D., Faresi, L., Aleffi, I., Orlando-Bonaca, M., and Lipej, L. 2016. New insights on the biological parameters of the exploited cuttlefish *Sepia officinalis* L. (Mollusca: Cephalopoda) in the northern Adriatic Sea in relation to the main fishing gears employed. *Mediterranean Marine Science*, 17: 152–162.
- Blanc, A., Pinczon Du Sel, G., and Daguzan, J. 1998. Habitat and diet of early stages of *Sepia officinalis* L. (Cephalopoda) in Morbihan Basy, France. *J. Moll. Stud.*, 64: 263–274.
- Bloor, I. S. M., Attrill, M. J., and Jackson, E. L. 2013. A Review of the Factors Influencing Spawning, Early Life Stage Survival and Recruitment Variability in the Common Cuttlefish (*Sepia officinalis*). *Advances in Marine Biology*, 65: 1–65. Academic Press.
- Boletzky, S. V. 1987. Embryonic phase (cephalopods). *In Cephalopod Life Cycles*. Volume 2. Comparative Studies.
- Boletzky, S. von, and Villanueva, R. 2014. Cephalopod Biology. *In Cephalopod Culture*, pp. 3–16. Springer Netherlands, Dordrecht. [http://link.springer.com/10.1007/978-94-017-8648-5\\_1](http://link.springer.com/10.1007/978-94-017-8648-5_1) (Accessed 2 December 2017).
- Boyle, P. 1983. Cephalopod life cycles: comparative reviews. Academic Press. 210 pp.
- Campanelli, A., Grilli, F., Paschini, E., and Marini, M. 2011. The influence of an exceptional Po River flood on the physical and chemical oceanographic properties of the Adriatic Sea. *Dynamics of Atmospheres and Oceans*, 52: 284–297. Elsevier.
- Castro, B., and Guerra, A. 1990. The diet of *Sepia officinalis* (Linnaeus, 1758) and *Sepia elegans* (D’Orbigny, 1835)(Cephalopoda, Sepioidea) from the Ria de Vigo (NW Spain). *SCI. MAR.*, 54: 375–388.
- Cochran, W. G., Mosteller, F., and Tukey, J. W. 1954. Principles of Sampling. *Journal of the American Statistical Association*.
- Coro, G., Bove, P., Armelloni, E. N., Masnadi, F., Scanu, M., and Scarcella, G. 2022a. Filling Gaps in Trawl Surveys at Sea through Spatiotemporal and Environmental Modelling. *Frontiers in Marine Science*, 9. <https://www.frontiersin.org/articles/10.3389/fmars.2022.919339> (Accessed 29 June 2023).
- Coro, G., Tasseti, A. N., Armelloni, E. N., Pulcinella, J., Ferrà, C., Sprovieri, M., Trincardi, F., *et al.* 2022b. COVID-19 lockdowns reveal the resilience of Adriatic Sea fisheries to forced fishing effort reduction. *Scientific Reports*, 12: 1052. Nature Publishing Group.

- Cushman-Roisin, B., Gacic, M., Poulain, P.-M., and Artegiani, A. 2001. Physical Oceanography of the Adriatic Sea.
- Domingues, P., Sykes, A., Sommerfield, A., Almansa, E., Lorenzo, A., and Andrade, J. P. 2004. Growth and survival of cuttlefish (*Sepia officinalis*) of different ages fed crustaceans and fish. Effects of frozen and live prey. *Aquaculture*, 229: 239–254.
- Doubleday, Z. A., Prowse, T. A. A., Arkhipkin, A., Pierce, G. J., Semmens, J., Steer, M., Leporati, S. C., *et al.* 2016. Global proliferation of cephalopods. *Current Biology*, 26: R406–R407.
- Fabi, G., Grati, F., Lucchetti, A., and Scarcella, G. 2001. Osservazioni preliminari sulle catture di *Sepia officinalis* con tre attrezzi da posta in medio Adriatico. *Biologia marina mediterranea*, 8: 660–664.
- FAO. 2017. FishstatJ: Software for fishery statistical time series. <http://www.fao.org/fishery/statistics/software/fishstatj/en> (Accessed 23 December 2019).
- Forsythe, J. W. 2004. Accounting for the effect of temperature on squid growth in nature: from hypothesis to practice. *Marine and Freshwater Research*, 55: 331–339. CSIRO PUBLISHING.
- Fortibuoni, T., Libralato, S., Arneri, E., Giovanardi, O., Solidoro, C., and Raicevich, S. 2018. Erratum: Fish and fishery historical data since the 19th century in the Adriatic Sea, Mediterranean. *Scientific Data*, 5: 180144.
- Garoia, F., Guarniero, I., Ramšak, A., Ungaro, N., Landi, M., Piccinetti, C., Mannini, P., *et al.* 2004. Microsatellite DNA variation reveals high gene flow and panmictic populations in the Adriatic shared stocks of the European squid and cuttlefish (Cephalopoda). <https://www.nature.com/articles/6800489> (Accessed 29 November 2018).
- Grati, F., Scarcella, G., Polidori, P., Domenichetti, F., Bolognini, L., Gramolini, R., Vasapollo, C., *et al.* 2013. Multi-annual investigation of the spatial distributions of juvenile and adult sole (*Solea solea* L.) in the Adriatic Sea (northern Mediterranean). *Journal of Sea Research*, 84: 122–132. Elsevier.
- Grati, F., Fabi, G., Scarcella, G., Guicciardi, S., Penna, P., Scanu, M., Leoni, S., *et al.* 2018. Artificial spawning substrates and participatory research to foster cuttlefish stock recovery: A pilot study in the Adriatic Sea. *PLoS ONE*, 13: e0205877.
- Guerra, A. 2006. Ecology of *Sepia officinalis*. *Vie et milieu*, 56: 97–107.
- Hall-Spencer, J. 1999. The impact of Rapido trawling for scallops, *Pecten jacobaeus*(L.), on the benthos of the Gulf of Venice. *ICES Journal of Marine Science*, 56: 111–124.
- Holstein, J. 2018. `_worms: Retriving Aphia Information from World Register of Marine Species_`. R package. <https://CRAN.R-project.org/package=worms> (Accessed 10 April 2023).
- Hurtado-Ferro, F., Szuwalski, C. S., Valero, J. L., Anderson, S. C., Cunningham, C. J., Johnson, K. F., Licandeo, R., *et al.* 2015. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. *ICES Journal of Marine Science*, 72: 99–110. Oxford University Press.
- ICES. 2019. Interim Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 5–8 June 2018, Pasaia, San Sebastian, Spain. *ICES CM 2018/EPDSG*: 194.
- Jones, J. B., and Lishchenko, F. V. 2019. Non-genetic tools for cephalopod stock identification. *In* Interim Report of the Working Group on Cephalopod Fisheries and Life History (WGCEPH), 5–8 June 2018, Pasaia, San Sebastian, Spain., p. Annex III. <https://www.researchgate.net/publication/329239231> (Accessed 10 January 2020).
- Laptikhovskiy, V., Salman, A., Önsoy, B., and Katagan, T. 2003. Fecundity of the common cuttlefish, *Sepia officinalis* L. (Cephalopoda, Sepiidae): A new look at an old problem. *Scientia Marina*, 67: 279–284.
- Le Goff, R., and Daguzan, J. 1991. Growth and life cycles of the cuttlefish *Sepia officinalis* L. (Mollusca: Cephalopoda) in South Brittany (France). *Bulletin of Marine Science*, 49: 341–348. University of Miami - Rosenstiel School of Marine and Atmospheric Science.
- Lishchenko, F., Perales-Raya, C., Barrett, C., Oesterwind, D., Power, A. M., Larivain, A., Laptikhovskiy, V., *et al.* 2021. A review of recent studies on the life history and ecology of European cephalopods with emphasis on species with the greatest commercial fishery and culture potential. *Fisheries Research*, 236: 105847. Elsevier B.V.
- Mandic, S., Stjepcevic, J., Medit, Y. K.-Rapp. *Comm. int. M.*, and 1981, U. 1981. Mouvements migratoires de quelques espèces de céphalopodes économiquement importantes dans l’Adriatique méridionale. *Rapp. Comm. int. Mer Medit*, 27.5: 213–216.

- Mangold, K. 1983. Food, feeding behaviour and growth in some Cephalopods. *Mem.natn.Mus.Vict.*, 44: 81–93.
- Mannini, P., and Massa, F. 2000. Brief overview of Adriatic fisheries landing trends (1972-97). *In* Report of First Meeting of the Adriamed Coordination Committee. FAO-MiPAF Scientific Cooperation to Support responsible Fisheries in the Adriatic sea. GCP/RER/010/ITA/TD-01, pp. 31–49.
- Nixon, M., and Mangold, K. 1998. The early life of *Sepia officinalis*, and the contrast with that of *Octopus vulgaris* (Cephalopoda). *Journal of Zoology*, 245: S0952836998008048.
- O'Brien, C. E., Mezrai, N., Darmaillacq, A. S., and Dickel, L. 2017. Behavioral development in embryonic and early juvenile cuttlefish (*Sepia officinalis*). *Developmental Psychobiology*, 59.
- Palomares, M., and Pauly, D. 2018. SeaLifeBase. Version (02/2018).
- Parras-Berrocal, I. M., Vazquez, R., Cabos, W., Sein, D., Mañanes, R., Perez-Sanz, J., and Izquierdo, A. 2020. The climate change signal in the Mediterranean Sea in a regionally coupled atmosphere–ocean model. *Ocean Science*, 16: 743–765.
- Phillips, S. J., Dudík, M., and Schapire, R. E. 2004. A maximum entropy approach to species distribution modeling. *In* Proceedings, Twenty-First International Conference on Machine Learning, ICML 2004, pp. 655–662. ACM Press, New York, New York, USA.  
<http://portal.acm.org/citation.cfm?doid=1015330.1015412> (Accessed 2 May 2022).
- Piccinetti Manfrin, G., and Giovanardi, O. 1984. Données sur la biologie de *Sepia officinalis* L. dans l'Adriatique obtenues lors des expéditions Pipeta. *FAO, Fish. Rep.*, 290: 135–138.
- Pierce, G. J., Valavanis, V. D., Guerra, A., Jereb, P., Orsi-Relini, L., Bellido, J. M., Katara, I., *et al.* 2008. A review of cephalopod-environment interactions in European Seas. *In* *Hydrobiologia*, pp. 49–70. Springer Netherlands.
- Pierce, G. J., Allcock, L., Bruno, I., Jereb, P., Lefkaditou, E., Malham, S., Moreno, A., *et al.* 2010. Cephalopod biology and fisheries in Europe. ICES Cooperative Research Report No. 303: 175.
- Pinczon Du Sel, G., Blanc, A., and Daguzan, J. 2000. The diet of the cuttlefish *Sepia officinalis* L. (mollusca: cephalopoda) during its life cycle in the Northern Bay of Biscay (France). *Aquat. Sci.*, 61: 67–178.
- Relini, G., and Piccinetti, C. 1996. Ten years of trawl surveys in Italian seas (1985-1995). *In* *FAO Rapport sur les Peches (FAO)*. <http://agris.fao.org/agris-search/search.do?recordID=XF9663403> (Accessed 29 November 2018).
- Rodhouse, P. G. K., Pierce, G. J., Nichols, O. C., Sauer, W. H. H., Arkhipkin, A. I., Laptikhovskiy, V. V., Lipiński, M. R., *et al.* 2014. Environmental effects on cephalopod population dynamics: Implications for management of fisheries. *In* *Advances in Marine Biology*, pp. 99–233.
- Sartor, P., Belcari, P., Carbonell, A., Gonzalez, M., Quetglas, A., and Sánchez, P. 1998. The importance of cephalopods to trawl fisheries in the western Mediterranean. *South African Journal of Marine Science*: 67–72.
- Saville, A. 1977. Survey methods of appraising fishery resources. *In* *Fao Fisheries Technical Paper No 171*. FAO.
- STECF. 2021. Scientific, Technical and Economic Committee for Fisheries (STECF) – Fisheries Dependent - Information – FDI (STECF-21-12). Publications Office of the European Union, Luxembourg, 2021.
- Steer, M., Pecl, G., and Moltschanivskyj, N. 2003. Are bigger calamary *Sepioteuthis australis* hatchlings more likely to survive? A study based on statolith dimensions. *Marine Ecology Progress Series*, 261: 175–182.
- Sykes, A. V., Domingues, P. M., and Andrade, J. P. 2006. Effects of Using Live Grass Shrimp (*Palaemonetes varians*) as the only Source of Food for the Culture of Cuttlefish, *Sepia officinalis* (Linnaeus, 1758). *Aquaculture International*, 14: 551–568.
- Vautard, R., Yiou, P., and Ghil, M. 1992. Singular-spectrum analysis: A toolkit for short, noisy chaotic signals. *Physica D: Nonlinear Phenomena*, 58: 95–126. North-Holland.
- Vidal, E. A. G., DiMarco, F. P., Wormuth, J. H., and Lee, P. G. 2002. Influence of temperature and food availability on survival, growth and yolk utilization in hatchling squid. *In* *Bulletin of Marine Science*.
- Villanueva, R., Vidal, E. A. G., Fernández-Álvarez, F., and Nabhitabhata, J. 2016. Early mode of life and hatchling size in cephalopod molluscs: Influence on the species distributional ranges. *PLoS ONE*, 11: 1–27.
- Vrgoč, N., Arneri, E., Jukić-Peladić, S., and Šifner, S. 2004. Review of current knowledge on shared demersal stocks of the Adriatic Sea. *In* *AdriaMed Technical Documents*, vol 12, p. 91.

Winker, H., Carvalho, F., and Kapur, M. 2018. JABBA: Just Another Bayesian Biomass Assessment. *Fisheries Research*, 204: 275–288. Elsevier.