Stock Assessment Form Demersal species

Reference year:2019

Reporting year:2020

Stock Assessment Form version 1.0

Uploader: *Martina Scanu*

Stock assessment form

1 Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Squilla mantis	Spottail mantis shrimp	47
1st Geographical sub-area:	**2nd Geographical sub-area:**	**3rd Geographical sub-area:**
GSA_17		
4th Geographical sub-area:	**5th Geographical sub-area:**	**6th Geographical sub-area:**
1st Country	**2nd Country**	**3rd Country**
Italy	Slovenia	
4th Country	**5th Country**	**6th Country**
Stock assessment method: (direct, indirect, combined, none)		
Trawl survey, Stock Synthesis (SS3)		
Authors:		
[1*]Scanu M., [1*]Masnadi F., [1*]Armelloni E. N., [1]Polidori P.,[1]Pellini G., [1]Ferrà C., [1]Salvalaggio V., [1]Montagnini L., [1]Grati F., [1]Angelini S., [1]Santojanni A., [1]Domenichetti F., [1]Colella S., [1]Donato F., [1]Martinelli M., [2]Giovanardi O., [2]Raicevich S., [2]Sabatini L., [2]Franceschini G., [2]Fortibuoni T.,[3]Marceta B, [1]Fabi G., [4]Spedicato M.T., [4]Bitetto I., [4]Romagnoni G., [5]Ikika Z., [6]Kule M., [7]Milone N., [7]Arneri E., [8]Cardinale M.,[1]Scarcella G.		
Affiliation:		
[*] Univeristy of Bologna, Department of Biological, Geological and Environmental Sciences (BiGeA), Piazza di Porta S. Donato 1, Bologna, Italy** **[1]Institute of Biological Resources and Marine Biotechnology (IRBIM), National Research Council, Italy** **[2]Institute for Environmental Protection and Research, Italy** **[3]Fishery Research Institute of Slovenia, Slovenia** **[4]COISPA** **[5]Institute of Marine Biology, University of Montenegro** **[6]Ministry of Agriculture and Rural Development of Albania** **[7]FAO AdriaMed** **[8] Swedish University of Agricultural Sciences		

2 Stock identification and biological information

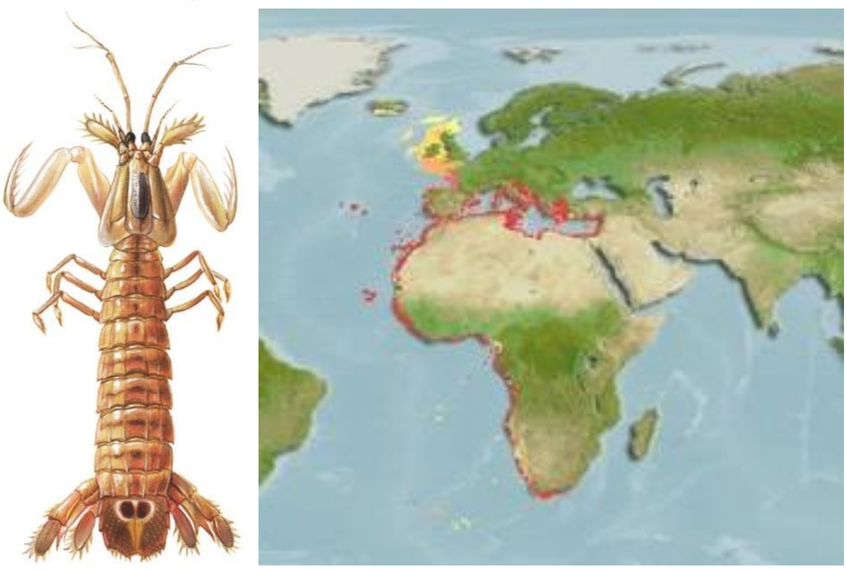

Figure 1 - *Squilla mantis* and its geographical distribution (from: https://mare.istc.cnr.it/fisheriesv2/species;jsessionid=BeseZSFHB3TT1BEGxoR_HEbbWAPOnPlpMB6ENsehDD6DzWX7BDp2!-906030247?lang=it&sn=34600, https://sealifebase.org/summary/Squilla-mantis.html)

2.1 Stock unit

The spot-tail mantis shrimp (*Squilla mantis)* is widespread in the Eastern Atlantic, from the Iberian Peninsula to Angola, including the Mediterranean Sea, but is absent from the Black Sea. It occupies the continental shelf to the maximum recorded depth of 367 m (Vasconcelos, 2017), but it usually digs burrows on soft bottoms to a depth of 100 m.

The highest densities of mantis shrimp in the Adriatic Sea are usually found on bottoms characterized by fine sand or sandy mud at depths of less than 50 m (Froglia *et al*., 1996). The species is more frequent in the Western side of the basin while it is quite rare in the Eastern side where the sediment features are not as suitable for their borrowing behavior (Scarcella, pers. comm.).

The burrows of *S. mantis,* in which it hides during the day (Froglia *et al*., 1996), are commonly U-shaped (fig. 2), large and distinctive with two circular openings, one bigger than the other, that sometimes are more than a metre apart (Atkinson *et al*., 1997).

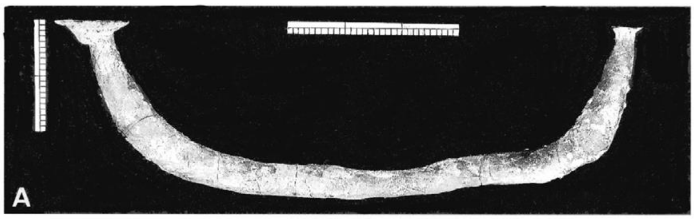

Figure 2 - Polyester resin cast of S. mantis burrow, side view. Horizontal scale bar lengths 30 cm, vertical scale bar lengths 20 cm (modified from: Froglia *et al*., 1996).

It is a strongly sedentary species and seasonal trends appearing in catch data are due more to its reproductive and burrowing behavior, and recruitment pattern, than to temporal changes in its distribution (Sartor *et al.,* 2004).

Pelagic larval stage lasts 2-3 months (Maynou *et al*., 2005; Piccinetti-Manfrin 1999). However, larval distribution is possibly constrained by local circulation patterns in inshore areas (Vila *et al*., 2013), where juveniles are most abundant (Abelló and Martín, 1993). All in all, the species has a potential for fine-scale spatial population structure; similarly with other species of the same family might exhibit local population structure (e.g. *Haptosquilla pulchella* in South-East Asia; Barber *et al*., 2002). Unfortunately, genetic studies to support the identification of different stocks in the Mediterranean are missing. However, considering its territorial behavior, it is reasonable to assume that the population inhabiting the Adriatic Sea is divided in 2 sub-populations characterized by a low rate of mixing and the sub-populations distributions loosely align with the two Adriatic GSAs (GFCM - WGSAD, 2012).

2.2 Growth and maturity

The growth of *S. mantis* in GSA17 has been studied by Froglia *et al.* (1996) using indirect method. The length frequency distributions for males and females recorded during experimental trawls carried in the central area of the GSA17 in 1994 and 1995 (Froglia *et al.,* 1996) showed similar size ranges for both sexes. The largest specimens (39 mm Carapace Length both for males and females) were collected in September. The new recruits, which larvae probably settled on the bottom in late summer and early autumn, first appeared in the trawl catches off Ancona in November with a Carapax Length (CL) of 5-13 mm equivalent to an average TL of 50 mm. This cohort reaches a size around 15 mm CL at the end of first year of life, by the next autumn it reaches sexual maturity. The results of the analyses indicate that the growth is quite similar for males and females. Both sexes reach around 18 mm CL at the end of the first year of life and around 32 mm CL at the end of the third of life. Do Chi (1975) was the first to investigate growth of S. mantis in the Western Mediterranean and, by applying the graphic method of Cassie (1954) to a series of size frequency distributions, he recognized the presence of three age classes. As he evidenced a single spawning season per year (Do Chi, 1975) they were considered year classes. Other Authors in the northern Adriatic (Ferrero *et al*., 1988) and in the Catalan Sea (Abellò & Sardà, 1989) arrived to similar conclusion from the analysis of size frequencies distributions obtained from commercial catches, and estimated in around 3 years the maximum life-span of *S. mantis* (Abellò & Sardà, 1989). In the GSA17 females reach maturity in their second year of life. Females with mature ovaries and active (white) cement glands are observed in late winter in the Central Adriatic (Piccinetti and Piccinetti Manfrin, 1970; Froglia *et al.,* 1996). Spent females, with still whitish glan, are usually observed from April to September, when the sex ratio (M/F) is strongly in favour of males (Piccinetti and Piccinetti Manfrin, 1971; Froglia *et al*., 1996). The mean size of mature females was around 29 mm CL, but according to a more recent work (Colella *et al*., 2016) the estimated CL at first maturity was 25.36±0.21 mm. These differences could be related to several environmental factors which characterize the different areas, such as the abundance and distribution of local populations, competition for space and availability of nourishment.

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

Somatic magnitude measured (CL)				Units	mm
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	Winter-early spring (Carbonara *et al.*, 2013)
Maximum size observed	39	39		**Recruitment season**	Autumn
Size at first maturity	25.5 (Colella *et al.*, 2016)			**Spawning area**	
Recruitment size to the fishery				**Nursery area**	

Table 2.2-2: Growth and length weight model parameters

				Sex			
		Units	**female**	**male**	**Combined**	**Years**
Growth model	**L_∞**	mm	41.88 (± 4.78)	41.18 (± 2.99)	41.53	1996
	K		0.448 (± 0.122)	0.532 (± 0.102)	0.49	1996
	t_0		0.038 (± 0.110)	-0.059 (± 0.154)	-0.0105	1996
	Data source	Froglia *et al*. (1996)				
Length weight relationship	**a**				0.00133	
	b				3.045	
	M * (scalar)	0	1	2	3	4+
		1.2	0.7	0.6	0.52	0.48
	sex ratio (% females/total)	50				

*Natural mortality as obtained from PRODBIOM method, using growth parameters in Table

3 Fisheries information

Although *S. mantis* ranks first among the crustaceans landed in the Adriatic ports of GSA17, it is not the target of a specialized fishery, but it is an important component of local multispecies trawl and gillnet fisheries. The main species caught in GSA17 associated with mantis shrimp are *Sepia officinalis, Trigla lucerna, Merluccius merluccius, Mullus barbatus and Eledone* spp.

3.1 Description of the fleet

Squilla mantis is in GSA17 ranks first among the crustacean landed in the Adriatic ports even if it is not the target of a specialized fishery, but it is only an important component of local multispecies trawl and gill net fishery. Adriatic account around 80% of the Italian annual landings for this species. In Italian landings of GSA17 in 2018, 83% is represented by bottom trawl (2723 tons), 11% by gillnet (348 tons), 6% by rapido trawl (199 tons) and 1% by SSF pots and traps (29 tons).

The species is absent from the landings statistic of Croatia (FAO -FISHSTAT J – GFCM Database) and it accounted only for 1 tons in the Slovenian catches of 2017 (2016 DCF data). Considering this small amount of catches (they represent an average of 0.2% of total landings), Slovenian data have been summed with the Italian fleet using the same gear. Moreover, the species is not present in the list of shared stock of GFCM.

Catches show marked dial periodicity with significantly more animals caught at night (Froglia and Giannini,1989; Froglia and Gramitto, 1989). The burrowing behavior of *S. mantis* makes it vulnerable only when individuals are out of their burrows and this occurs mainly at night, between sunset and sunrise. Seasonal variations in catchability result from reduced out-of-burrow activity, because females rarely exit their burrow when they are incubating their egg mass in spring and early summer. Conversely, catches increase in winter, when mating takes place. At this time of the year maturing females become more vulnerable, as evidenced by the hourly catches and the changes in sex ratio obtained during our experimental trawling (Froglia *et al*., 1996). Catches increase further in late autumn with the arrival of new recruits.

Table 3.1-1: Mean percentage contribution to landings (2004-2018) of any fleet to each trimester of the year.

	1	2	3	4
OTB	19.85	16.60	15.79	47.76
GNS+GTR	8.48	16.32	56.42	18.78
TBB	17.14	18.58	22.99	41.14
FPO+FYK	9.45	10.82	64.34	10.88

Additionally, weather and sea conditions represent an important influence on the catchability of this species as catches increase after prolonged bad weather conditions probably because of disturbance of the burrow systems as a result of the high turbidity (Froglia *et al*., 1996).

Table 3.1-2: 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)	Otter trawl (OTB)	33 - Demersal shelf species	
Operational Unit 2	ITA	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets (GNS)	33 - Demersal shelf species	
Operational Unit 3	ITA	17	E - Trawl (12-24 metres)	98 - Other Gear (rapido trawl; TBB)	33 - Demersal shelf species	
Operational Unit 4	ITA	17	C- Minor gear with engine	Pots and traps	33 - Demersal shelf species	

Table 3.1-3: Catch, bycatch, discards and effort by operational unit in the reference year

Operational Units*	Fleet (n° of boats)	Catch (T or kg species assessed)	Other species caught (names)	Discards (species assessed)	Discards (other species caught)	Effort (units)
1 Italian OTB		1932	*Bolinus brandaris, Chelidonichthys lucernus, Sepia officinalis, Solea solea, Pecten jacobeus, Melicertus kerathurus*		*Aporrhais pespelecani, Ostrea edulis, Liocarcinus depurator, Anadara inaequivalvis, Anadara demiri*	
2 Italian GNS+GTR		363	*B. brandaris, C. lucernus, S. solea*		*A. pespelecan, O. edulis, Liocarcinus vernalis, Astropecten* irregularis	
3 Italian TBB		234	*B. brandaris, C. lucernus, Sepia officinalis, S. solea, Pecten jacobeus, Melicertus kerathurus*		*A. pespelecani, O. edulis, L. depurator, A. inaequivalvis, A. demiri*	
4 Italian FPO+FYK		34				
Total		2563				

3.2 Historical trends

S. mantis is an important commercial species in the Adriatic. It is caught in trammel nets, otter trawls and beam trawls (Froglia & Giannini, 1989). For this assessment landing data have been collected from different sources (Fig. 3): historical landings (1953-1969) have been obtained from Fortibuoni *et al*., (2018) and FishStatJ (1970-2003), while more recent information, updated at 2018, came from DCF-ITA.

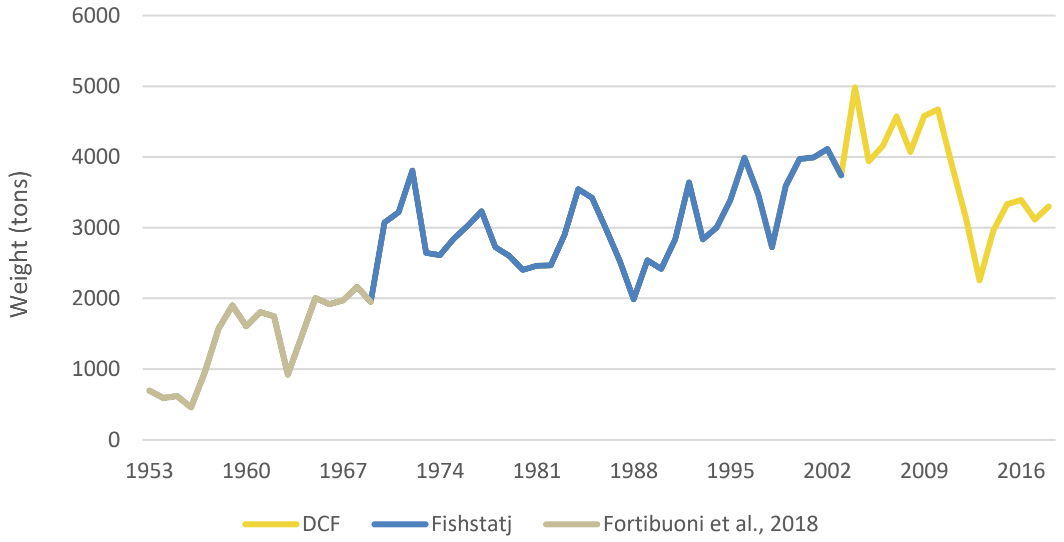

Figure 3 – Landings in GSA17 used for the assessment, from different data sources.

The overall trend in catches from '50s is a clear increase, although cyclical peaks and troughs every 3-4 years. A strong decrease results evident between 2010 and 2013. From 2014 to 2016 a new slight increase has been registered.

Looking at landings by fleet (Tab. 2.4-1 and Fig. 4), available since 2004, it is evident that the sudden drop landings in 2012-2013 is due to OTB and GNS activity, while the remaining fleet show a constant pattern. GNS contribution remains low in 2014-2019 period as well. This event might be connected to a general decrease in effort of GNS (nominal effort, gt per days and number of vessels) observed in 2013. Italian OTB on the other hand, show a decrease in landings starting in 2010 until 2013, and then rise again to more than 2,000 tons in the period 2014-2019.

Table 2.4-1: Annual total Italian landings (t) by fleets in the period 2005-2019 (from DCF-ITA). OTB: bottom otter trawling (including Slovenian), GNS+GTR: gillnets and trammel nets; TBB: modified beam trawl (rapido trawl); FPO+FYK: pots and traps.

Fleet	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
OTB	2826	2754	2995	2859	3167	3163	2399	1681	1684	2357	2481	2533	2458	2724	1932
GNS+GTR	868	899	945	844	887	982	1160	1155	221	341	444	520	443	348	363
TBB	208	323	438	309	490	440	251	283	240	184	262	195	176	199	234
FPO+FYK	36	183	196	61	36	88	70	27	109	73	148	144	36	29	34
TOTAL	**3938**	**4159**	**4574**	**4073**	**4580**	**4673**	**3879**	**3146**	**2254**	**2955**	**3335**	**3391**	**3113**	**3300**	**2563**

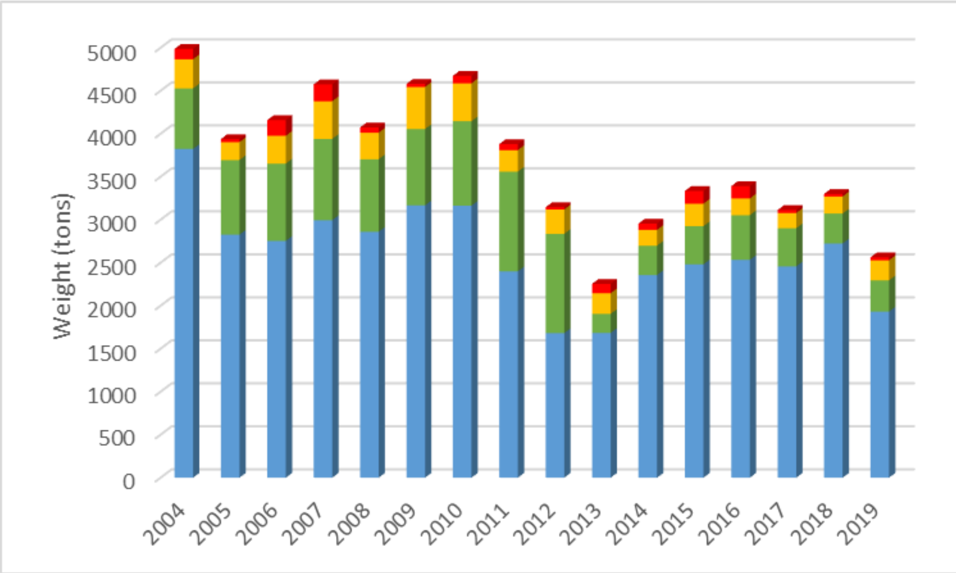

Figure 4 - Annual total landings in tons, in GSA17, by gear in the period 2004-2019. Blue=OTB: bottom otter trawling, Yellow=GNS+GTR: gillnets and trammel nets; Green=TBB: modified beam trawl (rapido trawl); Red=FPO+FYK: pots and traps.

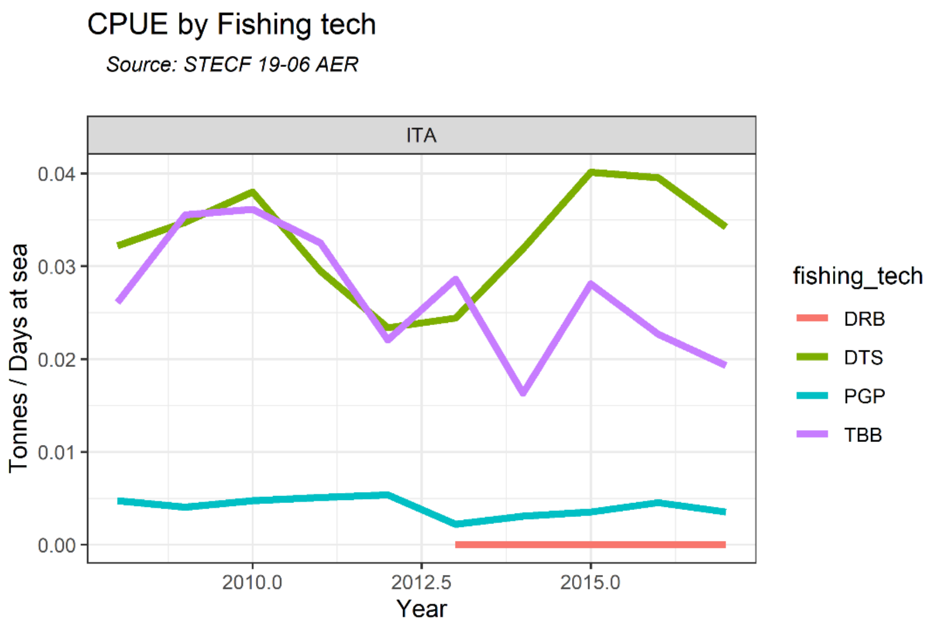

Figure 5 – CPUE by Fishing technique, from STECF (2019).

After exploring the Length Frequency Distribution (LFD) of the landings, it was agreed in discarding the 2007 (all) and 2008 (OTB) data, since a clear difference in the shape of the distribution is observed (Fig. 6). This was caused by the limited sampling period (LFD was sampled only in the 4th quarter of the year).

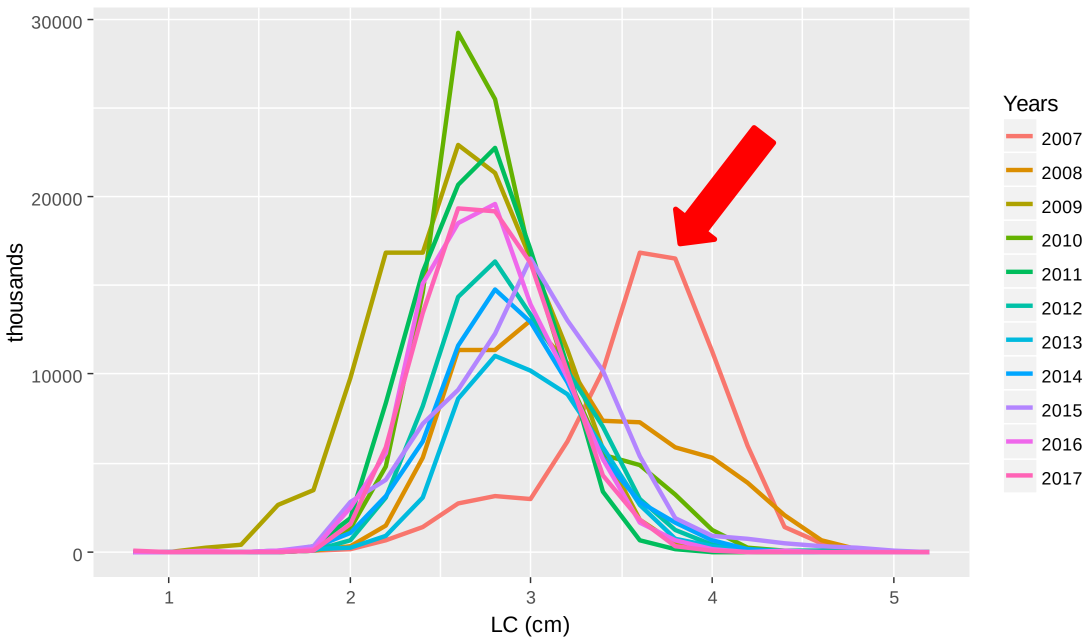

Figure 6 - Length Frequency Distribution of catches from 2007 to 2017, highlighting the 2007 issue.

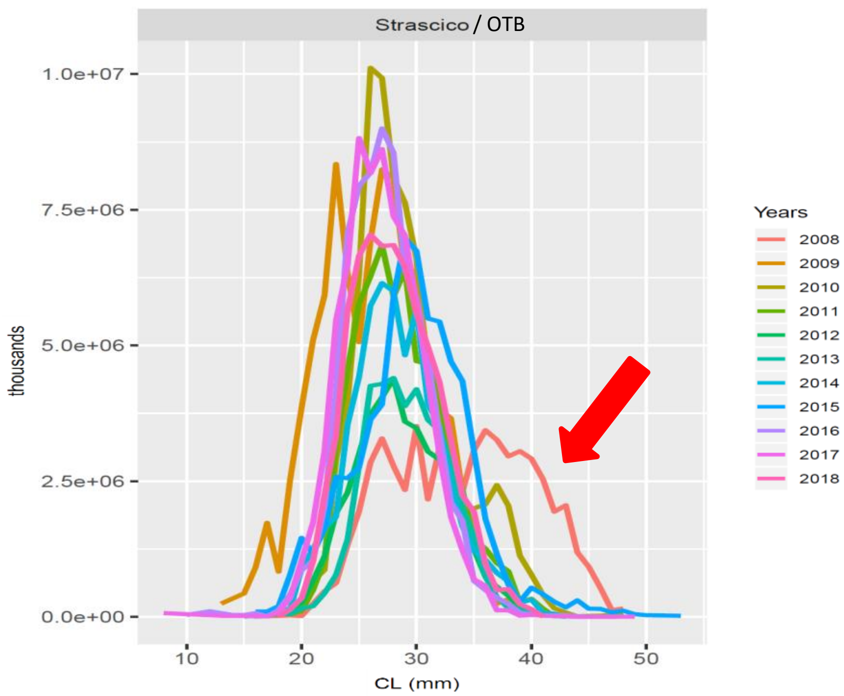

Figure 7 - Length Frequency Distribution of catches from 2008 to 2018, highlighting the 2008 issue.

Since the assessment have been performed using data quarterly based, have been possible to took a deeper look at these and do not use the ones that are considered reliable due to the low sampling effort. In fact, all LFDs showing sampling days lower than 3 have been discarded for statistical reasons.

3.3 Management regulations

In Italy and Slovenia the main rules in force are based on the applicable EU regulations (mainly EC regulation 1967/206):

- 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

Italy has also a national regulation:

- Fishing closure for trawling: 30-45 days in late summer (not every year the same days)
- Trawling activity banned up to 6 nautical miles 3 months after the summer closure.

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					
SSB				SSB40%=6542.84	
F				Fmsy=1.4	
Y					
CPUE					
Index of Biomass at sea					

4 Fisheries independent information

4.1 *SoleMon Survey*

4.1.1 Brief description of the direct method used

Fifteen *rapido* trawl fishing surveys were carried out in GSA17 from 2005 to 2018: two systematic "pre- suveys" (spring and fall 2005) and thirteen random surveys (spring and fall 2006, fall 2007-2017) 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 = 40.2 ± 0.83). The following number of hauls was reported per depth stratum (Tab. 3.1-1).

Tab. 3.1-1 Number of hauls per year and depth stratum in GSA 17, 2005-2018

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	41	41
30-50	12	20	19	18	18	18	18	18	18	18	18	18	16	15	15
50-120	15	8	11	10	10	10	10	10	10	10	10	10	10	12	12
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	68	68

Abundance and biomass indexes from *rapido* trawl surveys were computed using ATrIS software (Gramolini *et al*., 2005) which also allowed drawing GIS maps of the spatial distribution of the stock, spawing females and juveniles. Underestimation of small specimens in catches due to gear selectivity was corrected using the selective parameters given by Ferretti and Froglia (1975).

The abundance and biomass indices by GSA 17 were calculated through stratified means (Cochran, 1953; 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 (e.g. O'Brien *et al.*, 2004). 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.

Direct methods: trawl based abundance indices

Table 4.1-2: Trawl survey basic information

Survey	SoleMon	**Trawler/RV**	G. Dallaporta
Sampling season	Fall		
Sampling design	Random stratified		
Sampler (gear used)	Rapido trawl		
Cod –end mesh size as opening in mm	40		
Investigated depth range (m)	5-120		

Table 4.1-3: Trawl survey sampling area and number of hauls (2016 survey)

Stratum	**Total surface (km^2)**	**Trawlable surface (km^2)**	**Swept area (km^2)**	**Number of hauls**
0-30	11512		1.32	39
30-50	8410		0.55	18
50-100	22466		0.41	10
HRV	6000		0.09	7

Table 4.1-1: Trawl survey abundance and biomass results

	Years	N per km^2	SD	Kg per km^2	SD
	Spring 2005	209.26	78.79	6.47	2.25
	Fall 2005	546.13	213.29	17.01	5.87
	Spring 2006	134.58	45.29	3.92	1.15
	Fall 2006	317.47	85.2	8.69	2.07
	2007	98.08	34.85	3.33	1.19
	2008	302.40	88.50	9.61	3.00
	2009	511.48	106.25	14.65	2.84
	2010	568.50	88.61	18.66	2.93
	2011	525.62	78.39	17.74	2.58
	2012	425.75	70.88	14.29	2.47
	2013	607.34	121.31	16.56	3.23
	2014	682.81	137.67	21.75	4.10
	2015	974.97	174.06	28.67	4.55
	2016	628.64	108.69	17.54	3.01
	2017	520.54	94.52	14.83	2.64
	2018	566.29	105.39	15.80	2.69
	2019	826.85	140.88	25.75	4.26

4.1.2 Spatial distribution of the resources

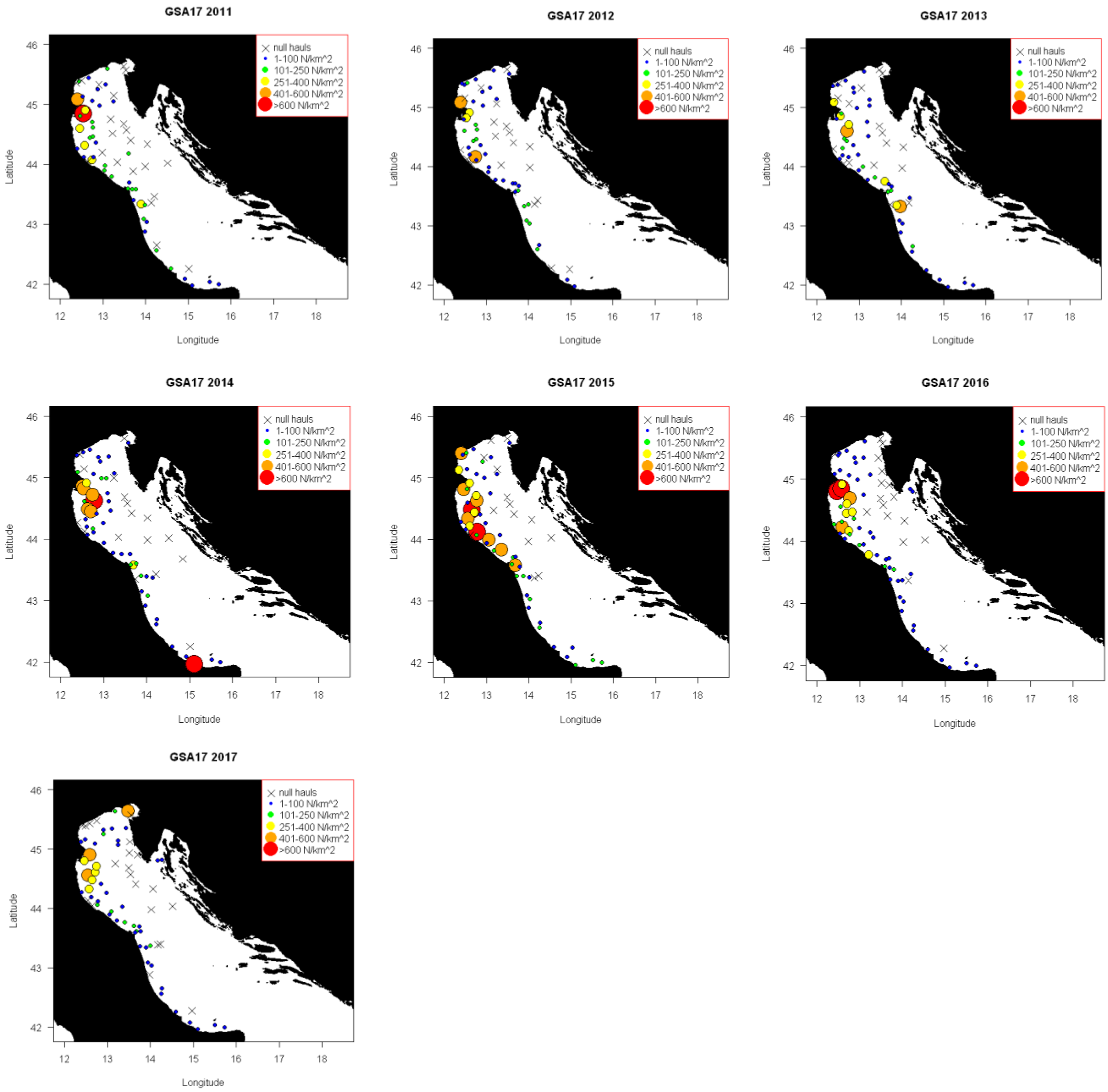

Figure 8 – Maps of spatial distribution of Squilla mantis by year in GSA 17 from SoleMon survey.

4.1.3 Historical trends

The SoleMon trawl surveys provided trend in abundance for *S. mantis.*

The trends in abundance index show a clear decrease of the stock in 2007 followed by an increase in the rest of the time series, with a peak in 2015 (Fig. 9).

Figure 10 displays the abundance indices by size obtained in GSA 17 from 2012 to 2019 during fall survey. The mean CL in the survey season is 25.5 mm.

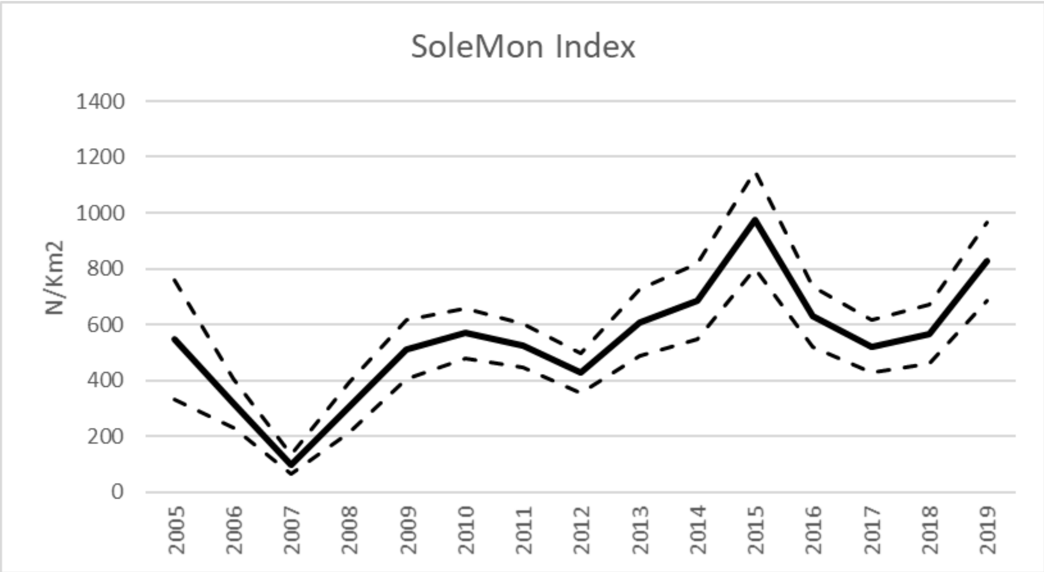

Figure 98 - Index of abundance from SOLEMON survey from 2005 to 2018.

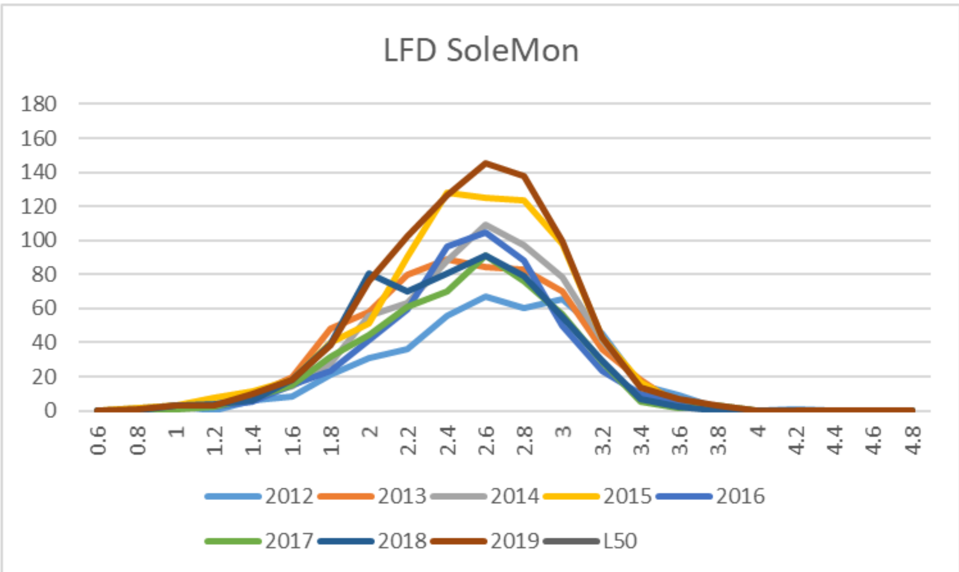

Figure 10 - Stratified abundance indices by size from SOLEMON survey, 2012-2019.

5 Stock Assessment

In this section, there will be one subsection for each different model used and also different model assumptions runs should be documented when all are presented as alternative assessment options.

5.1 SS3 model

The fundamental idea of the stock assessment here presented is to use the integrated approach of SS3 model (last version SS3.3) to model the size structure data available for the mantis shrimp.

5.1.1 Model assumptions

Stock Synthesis (SS) is an age- and size-structured assessment model in the class of models termed integrated analysis models. SS has a population sub-model that simulates a stock's growth, maturity, fecundity, recruitment, movement, and mortality processes, an observation sub-model estimates expected values for various types of data, a statistical sub-model characterizes the data's goodness of fit and obtains best-fitting parameters with associated variance, and a forecast sub-model projects needed management quantities. SS outputs the quantities, with confidence intervals, needed to implement risk-averse fishery control rules. The model is coded in C++ with parameter estimation enabled by automatic differentiation (www.admb-project.org). Windows, Linux, and iOS versions are available. Output processing and associated tools are in R, and a graphical interface is in QT. SS is available from NOAA's VLAB. The rich feature set in SS allows it to be configured for a wide range of situations. SS has become the basis for a large fraction of U.S. assessments and many other assessments around the world.

Differently from VPA based approaches (e.g. by XSA) SCAA calculates abundance forward in time and allows for errors in the catch at age matrices. Selectivity has been generated as length-specific by fleet, with the ability to capture the major effect of length-specific survivorship. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data.

In the present assessment, the variance is not shown for fishing mortality results, because the model outputs provide F values (called continuous F) within a year as standardized into selection coefficients by dividing each F value by the maximum value observed for any age class in the year (e.g. Deriso, 1985; Sampson and Scott, 2011). For a better comparison with the results of previous assessments carried out both in the framework of STECF-EWGs and GFCM-WGs, the F values are standardized by dividing by the average (called Fbar) of the F values observed over a defined range of age classes (e.g. Darby and Flatman, 1994; Sampson and Scott, 2011).

5.1.2 Input data and Parameters

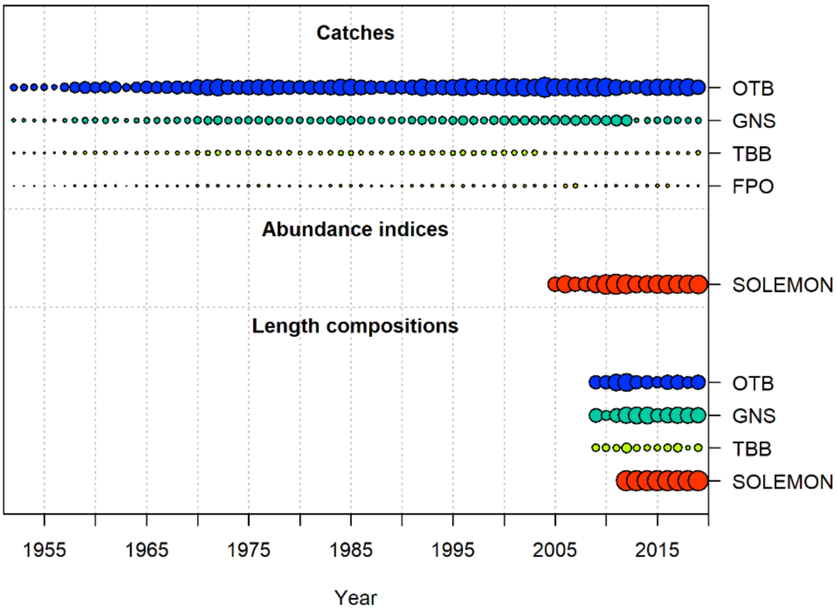

Figure 11 – Summary of the input data of the SS3 model. The size of the bubbles corresponds to the sample size used in the model

The model has been set as a length-based model where the numbers at length in the fisheries and survey data are converted into ages using the von Bertalanffy growth function. SS assumes multinomial likelihoods for the proportions-at-length in catches and survey data. The last age-class represents a "plus group" in which mortality and other characteristics are assumed to be constant.

The model allowed to specify the different source of data, providing different uncertainties estimates for each data set. Differently from last year stock assessment all data (catches, LFD, etc.) have been provided to the model divided by quarter. The total landings from 1953 to 2003 (from Fortibuoni *et al*., 2018 and FAO-FishStat source) have been divided into fleet and quarters thanks to the proportion obtained from following data rich phase (2004-2018 from DCF).

The SS3 analyses has been carried out considering the following four fleets:

1. OTB (ITA + SVN)
2. GNS + GTR
3. TBB
4. FPO + FYK

The Stock Synthesis model used in this assessment is a size structure data model based on the separate fleet LFD from 2009 to 2019; 2007 and 2008 LFD were excluded from the assessment due to the problems highlighted in the data section. Pots and traps fleet doesn't have LFD.

The age classes considered range from 0 to 6: plug group was set at age 6, in order to do not force the model but to letting perform the age slicing based on data. Even if few specimens appear to be classified as 5 or 6 ages, 4 can be considered as plus group due to the biggest number of individuals belonging to this age group and to the lower (Fig. 12).

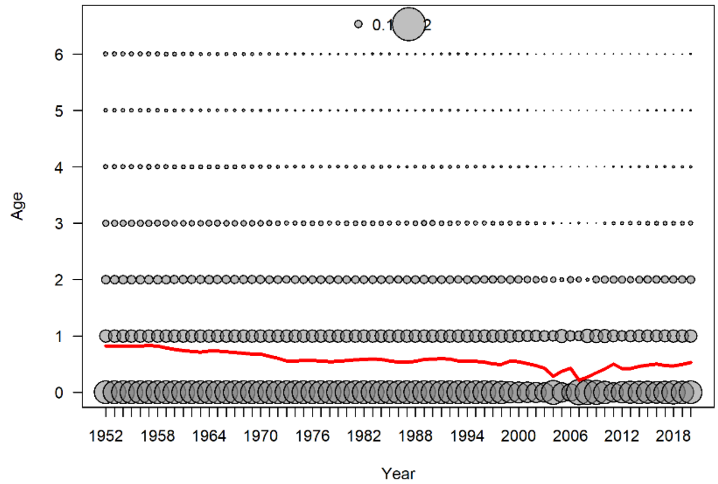

Figure 12 - Beginning of season 1 expected numbers at age in (max ~ 1.1 billion).

Tuning data were provided by SOLEMON survey carried out in fall for the years 2008-2019 and the LFD of the survey from 2011 to 2019 were also used as an input data. For all the fleets selectivity was estimated using a double normal function which estimates the peak, the ascending and the descending values of the selection curve. It is important to underline that “selectivity” as defined in stock assessments, generally includes both the concepts of gear selectivity and availability (i.e., the probability that an animal is the area/at the correct time which would allow it to be captured) (Punt *et al*., 2013).

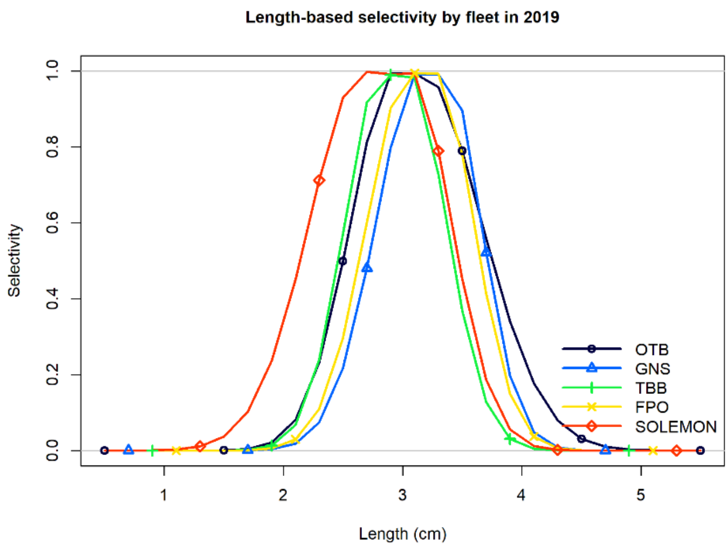

Figure 13 – Selectivity by length and by fleet used in the final run of SS3 model.

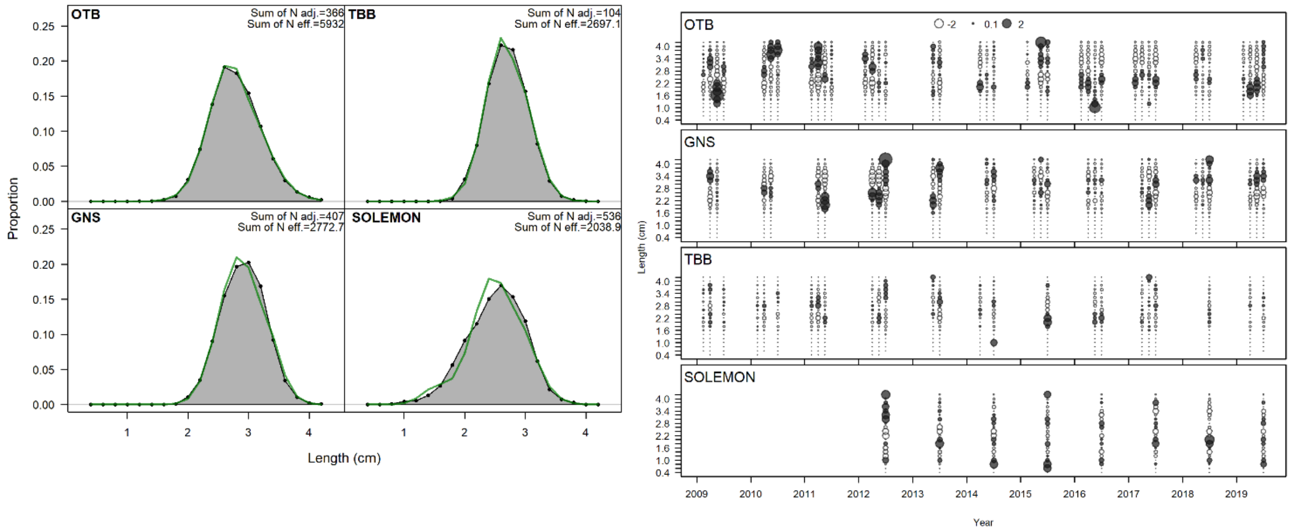

Figure 14 – Final Run Length comps fitting, aggregated across time by fleet and Final Run Pearson residuals.

No particular trends in the residuals were observed (Fig. 14).

As additional diagnostic, JABBA-residual plot (Winker et al., 2018) was performed (Fig. 15).

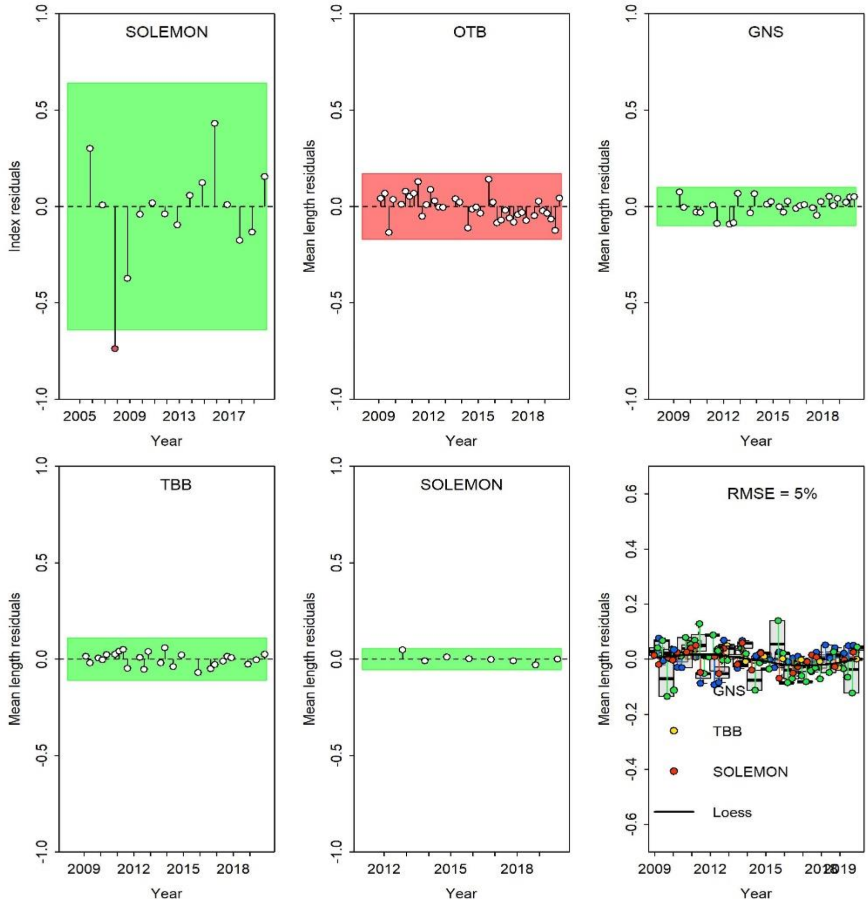

Figure 15 – Jabba-residual plot.

Apart from OTB, all the LFD data series showed no auto-pattern in residuals, confirmed by the color of the background of the plots. Green background indicates no evidence ($p > 0.05$) to reject the hypothesis of a randomly distributed time-series of residuals, while red background indicates evidence ($p < 0.05$) to reject the hypothesis of randomly distributed residuals. However, the RMSE calculation, considered as a stronger diagnostic, provided a value of 5%, that is a really good estimation. In fact, a relatively small JABBA-RMSE (≤ 30%) is considered an indication of a good model fit to data.

Since the model did not fit 2 points in the time series of the tuning index (SOLEMON) (Fig. 16), an additional diagnostic was performed on it.

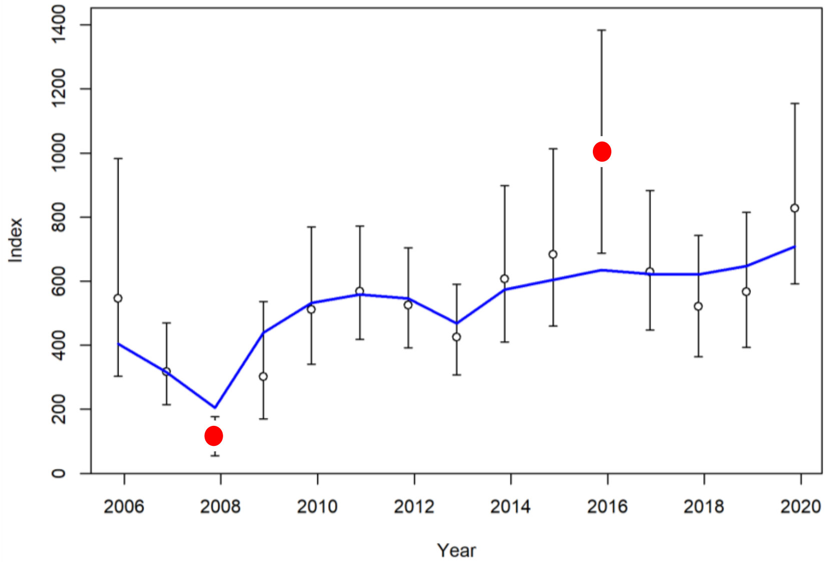

Figure 16 – Model fit to SOLEMON index.

Hindcasing test, progressively deleting the last year, by observing whether it would have correctly predicted, showed again good results (Fig. 17).

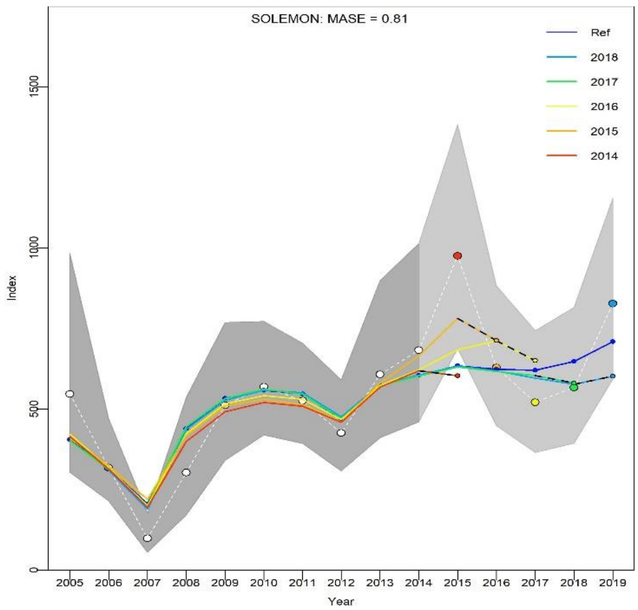

Figure 17 – Hindicasting test for tuning index.

Steepness and sigmaR were set from the last year model. SS3 Diagnostics in the form of retrospective have been performed and is shown in Figure 18. Retrospective analysis is diagnostic approach to evaluate the reliability of parameter and reference point estimates and to reveal systematic bias in the model estimation. It involves fitting a stock assessment model to the full dataset. The same model is then fitted to truncated datasets, where the data for the most recent years are sequentially removed. The retrospective analysis has been conducted to the reference model for the last 5 years of the assessment time horizon to evaluate if there were any strong changes in model results.

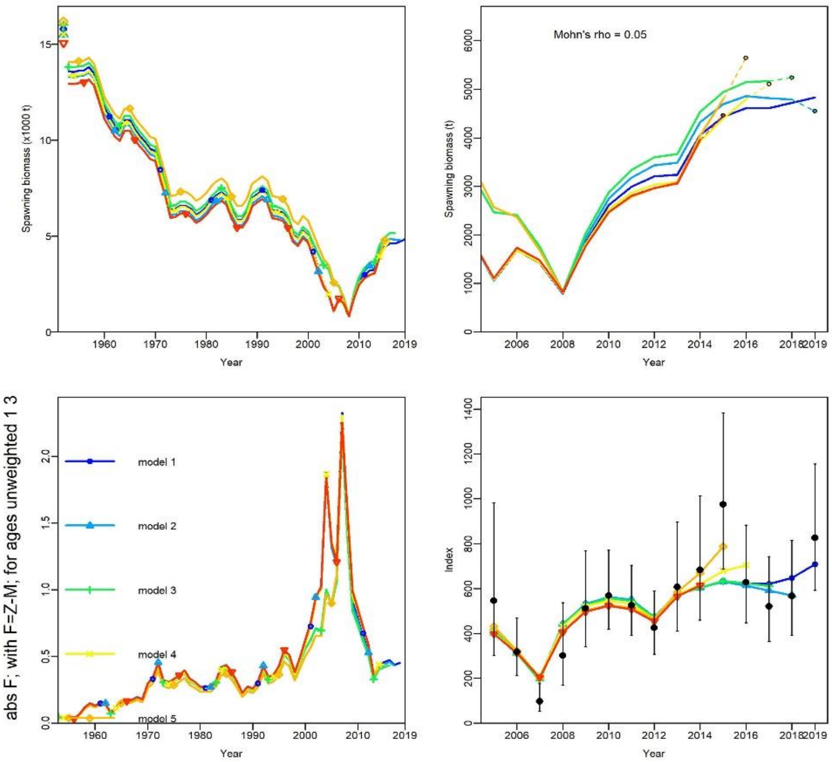

Figure 18 – Final Run retrospective analyses.

5.1.3 *Results*

Here will be presented the main results from the SS3 model run: spawning stock biomass (SSB), fishing mortality ($Fbar_{1\text{-}3}$ and by fleet), and recruitment.

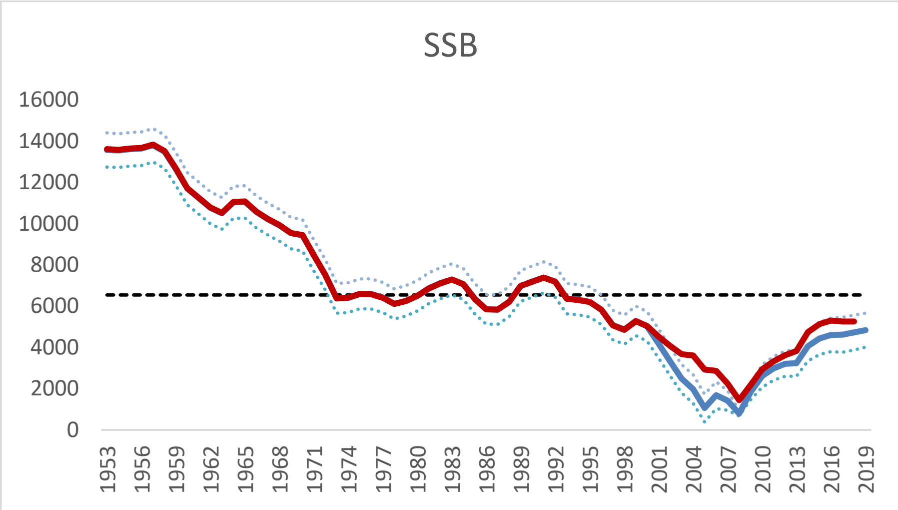

Figure19 – Spawning Stock Biomass and standard deviation calculated by SS3 model (blue), with SSB40% (black dotted line) percentile. In red the results of the SS3 model in 2018.

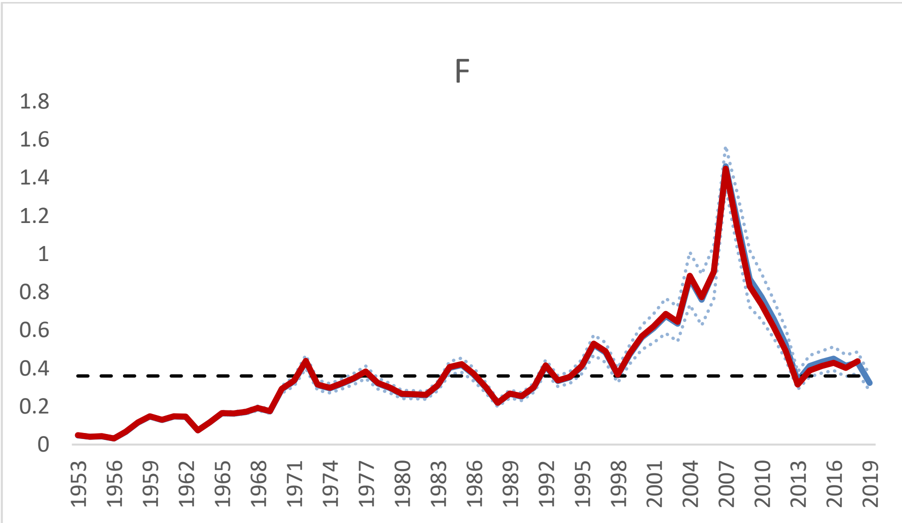

Figure 20 – Fishing effort and standard deviation calculated by SS3 model (blue), and F40% (black dotted line). In red the results of the SS3 model in 2018.

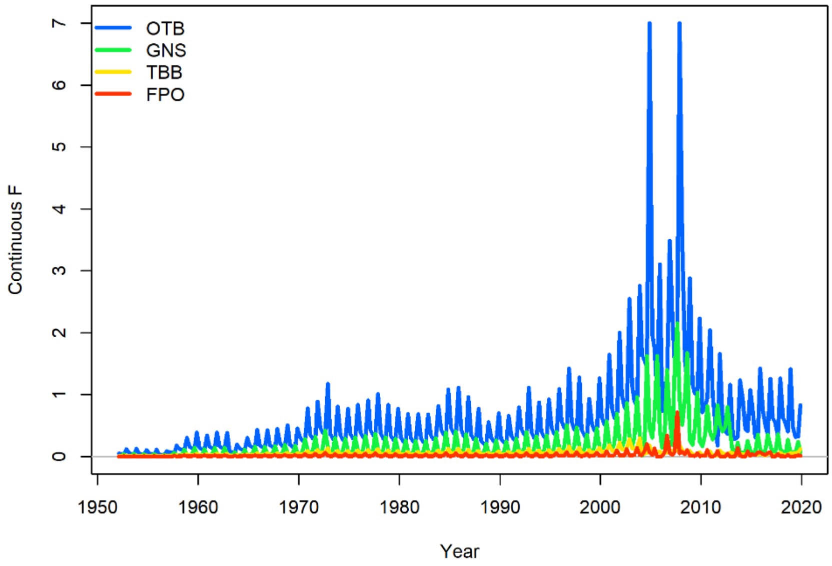

Figure 21 – Fishing effort divided by fleet.

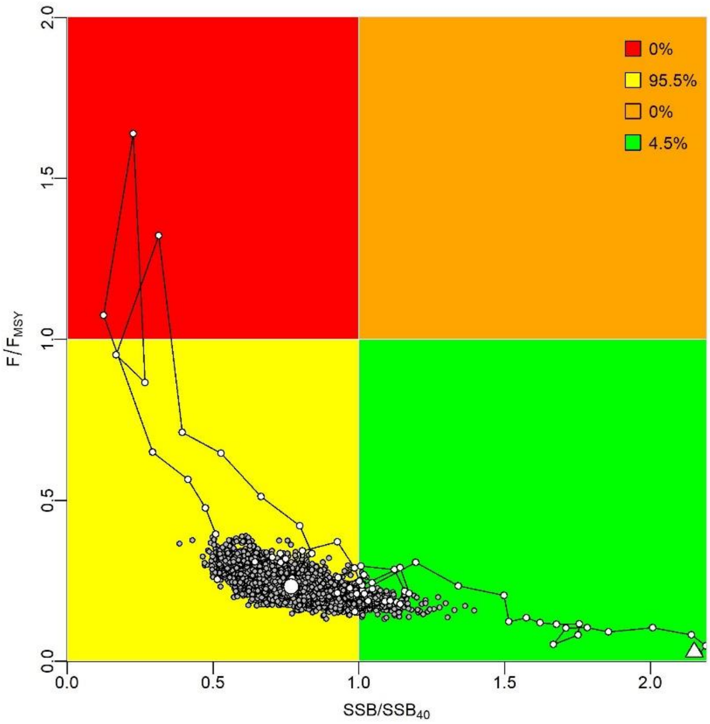

Figure 22 – Kobe plot from SS3 model.

<u>State of exploitation</u>: for the exploitation pattern it was observed a variable trend from the beginning of the time-series, with a more pronounced increase from 2000 to 2010; after this year a reduction occurred.
<u>State of the juveniles (recruits):</u> Recruitment varied in the last period from; in the last year estimate recruits are 956,319,000
<u>State of the adult biomass:</u> The SSB showed a decreasing trend in all the period analyzed (minimum in 2008-2009) but, from 2010, the SSB returns to increase.

5.1.4 Reference points

For fishing effort reference point, it was considerd F40% as estimated directly by the model (0.36). The reference point for biomass was also taken directly by the model; it is SSB40%. In case of species with fast growth, high natural mortality and high steepness, it is advised to use these indicators instead of msy, due to the difficulty of the model to estimate a correct YpR curve.

Reference points were also calculated as last year, to compare the results:

F0.1	0.37	**B 33th**	5058 tons
Fcurr/F0.1	0.88	**Bcurr**	4832 tons
StockStatus	**Sustainable exploitation**	**StockStatus**	**Relative low biomass**

5.1.5 Comments

Several issues have been identified in the data for *S. mantis* in GSA 17.
First of all, the available time series of complete commercial length data of landings is short (2007 – 2018) and 2007-2008 data was deleted because of the limited sampling period (LFD was sampled only in the 4th quarter of the year).
During WGSAD 2017 MEDITS data for this species were considered completely unreliable for several reasons: a change in the measuring methodology between 2009 and 2011, the few numbers of specimens measured and the huge temporal extension of the MEDITS survey in 2014 (from May to November).
Moreover, the Working Group recommends for the future a revision/update of the VB growth parameters based on the fact that in recent times, looking at the LFD, there is a high density of larger specimens (>41 mm CL) that were not present in the past when the growth study was carry on (Froglia *et al*., 1996).

5.1.6 Other models

In order to confirm the results obtained with SS3 model and exclude all the issue relative to the growth parameters and LFDs, a production model have been performed, namely CMSY (Froese et al., 2017). CMSY is a Monte-Carlo method that estimates fisheries reference points (MSY, Fmsy, Bmsy) as well as relative stock size (B/Bmsy) and exploitation (F/Fmsy) from catch data and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (= fragmented) abundance data.

The script used is CMSY_2019_9q.R, a newer version than the one presented in the paper. Prior for resilience, (Medium corresponding to 0.37 - 0.84 from SeaLifeBase) and for the initial and final biomass were selected. The prior for initial biomass have been assumed to be 0.4 - 0.8 corresponding to “Low depletion”, since the time series of landings starts in 1953, beginning of the fishery; while for the final biomass it was set to “Medium depletion”, considering trends in time series, together with expert judgement.

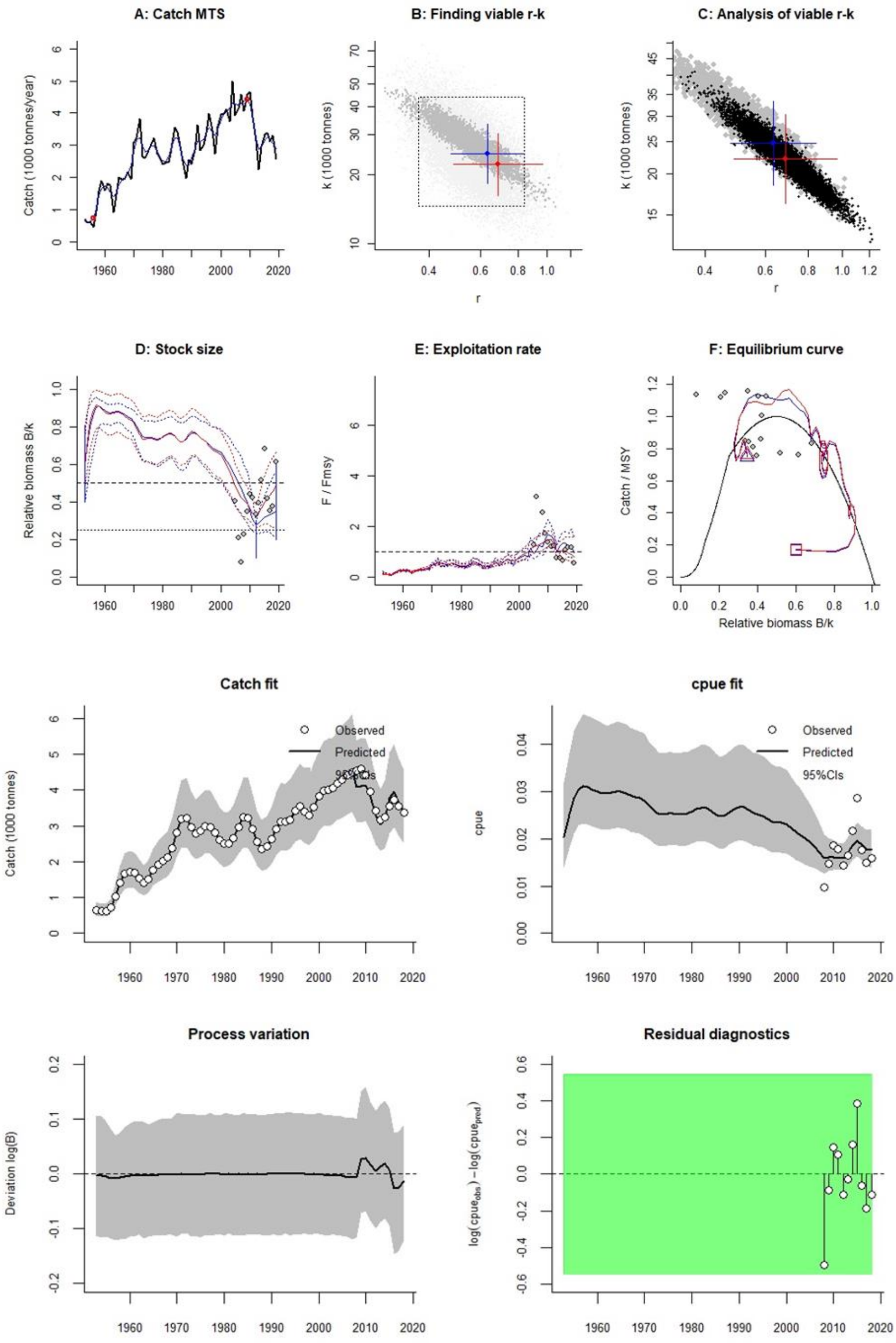

Figure 23 – Model diagnostics

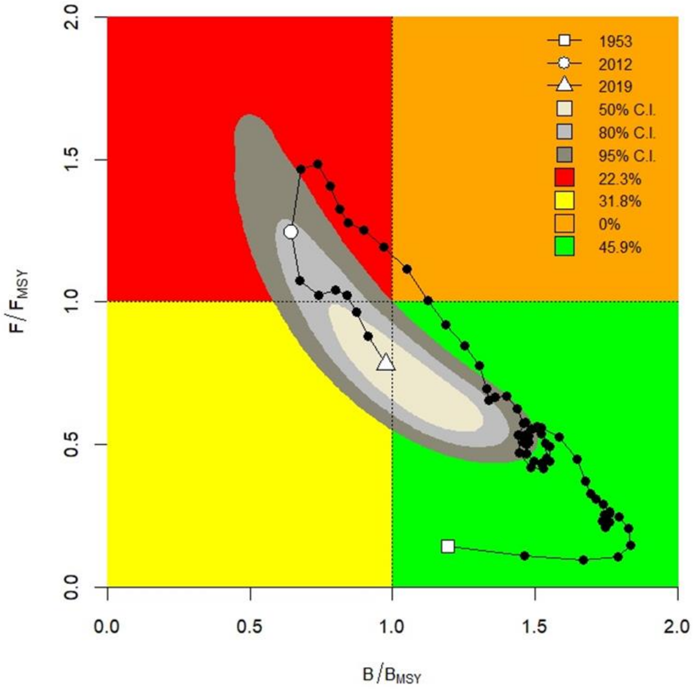

Figure 24 – Kobe plot

The results obtained with this second method are in line with the ones from SS3 model.

Draft scientific advice

Considering the results of the analyses conducted the mantis shrimp in GSA 17 is subjected to sustainable exploitation, being the current F(1-3) estimates with SS3 model of 0.33, lower than the proposed reference point ($F_{40\%}$ = 0.36).

Base on the biomass level (SSB) the stock result in a state of low biomass being the current SSB estimated by the SS3 model 4832 tons; lower than SSB40%.

The advice is to reduce fishing mortality.

Stock Status:

F_{curr}/F_{msy}=0.9 → **S: Sustainable exploitation**

Bcurr=4832 → **(O): Overexploited**

Do not increase in fishing mortality would be recommended.

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 (1953-2018)	Stock Status
Fishing mortality	Fishing mortality	F40% = 0.36	F_{curr} = 0.33			
	Fishing effort					
	Catch					
Stock abundance	Biomass					
	SSB		B_{curr}=4832	B40%=6542		
Recruitment						
Final Diagnosis	Sustainable exploitation and overexploited					

5.2 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)*

6 References

Abellò, P. And Sardà F. (1989) Some observations on the biology and fishery of Squilla mantis L. in the Catalan area (NW Mediterranean Sea). - In: E.A. Ferrero (Ed.) - Biology of Stomatopods.*U.Z.I. Selected Symposia and Monographs*, 3: 229-239.

Atkinson, R. J. A., Froglia, C., Arneri, E., & Antolini, B. (1997). Observations on the burrows and burrowing behaviour of: Squilla mantis L. Crustacea: Stomatopoda. *Marine Ecology*, *18*(4), 337-359.

Cassie, R.M. (1954) - Some use of probability paper in the analysis of size frequency distributions. *Australian Journal marine freshwater Research*, 5: 513-522.

Colella, S., Donato, F., Panfili, M., & Santojanni, A. (2016). REPRODUCTIVE PARAMETERS AND SEXUAL MATURITY OF SQUILLA MANTIS L., 1758 (CRUSTACEA: STOMATOPODA) IN THE NORTH-CENTRAL ADRIATIC SEA (GSA 17). *Biologia Marina Mediterranea*, *23*(1), 258.

Darby, C. D. and Flatman S. (1994) Lowestoft VPA Suite Version 3.1 User Guide. MAFF: Lowestoft.

Deriso, R. B. (1985) Management of the North Pacific halibut fishery. 11. Stock assessment and new evidence of density-dependence, p. 49-59. In Weal- time fishery management. University sf Washington Sea Grant Tech. Rep. WSG-85-1, Seattle, WA.

Do Chi, T. (1975) Analyse biométrique de la structure d'âge et données préliminaires sur le cycle biologique bentique de Squilla mantis (Crustacea Stomatopoda) dans le Nord du Golfe du Lion. *Comptes Rendus de l'Academie des Sciences, Paris*, (D) 280: 1729-1732.

Ferrero, E.A., Marzari, R., Mosco, A. And Riggio, D. (1988) Dynamics of morphometric and biochemical parameters of the reproductive condition of Squilla mantis fished by creels in the Gulf of Trieste. Use of VTGs as biochemical markers. *Bollettino della Società adriatica di Scienze*, 70: 47-59.

Fisheries and aquaculture software. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2016. [Cited 8 November 2019]. http://www.fao.org/fishery/

Fortibuoni, T., Libralato, S., Arneri, E., Giovanardi, O., Solidoro, C., & Raicevich, S. (2018). Erratum: Fish and fishery historical data since the 19th century in the Adriatic Sea, Mediterranean. Scientific *data, 5, 180144.*

Froese, R., Demirel, N., Coro, G., Kleisner, K. M. and Winker, H. (2017) Estimating Fisheries Reference Points from Catch and Resilience. Fish and Fisheries, 18 (3). pp. 506-526. DOI 10.1111/faf.12190.

Froglia, C. (1996). *Growth and behaviour of Squilla mantis (mantis shrimp) in the Adriatic Sea. EU Study DG XIV*. MED/93/016, Final Report.

Manning, R. B., & Heard, R. W. (1997). Stomatopod crustaceans from the Carolinas and Georgia, southeastern United States. *Gulf and Caribbean Research*, *9*(4), 303-320.

Piccinetti, C. And Piccinetti Manfrin, G. (1970) Osservazioni su alcuni aspetti della biologia di Squilla mantis L. *Pubblicazioni della Stazione Zoologia, Napoli*; 38 suppl.: 119-124.

Piccinetti, C. And Piccinetti Manfrin, G. (1971) Osservazioni sulla pesca di *Squilla mantis L*.. Note del Laboratorio di Biologia marina e Pesca Fano; 4: 27-38.

Sampson, D.B., Scott, R.D. (2011) A spatial model for fishery ageselection at the population level. *Can. J. Fish. Aquat*. Sci. 68, 1077–1086.

Sartor, P., Abelló, P., & Maynou, F. (2004). A review of the fisheries biology of the mantis shrimp, Squilla mantis (L., 1758)(Stomatopoda, Squillidae) in the Mediterranean. *Crustaceana*, *77*(9), 1081-1099.

Scientific, Technical and Economic Committee for Fisheries (STECF): The 2019 Annual Economic Report on the EU Fishing Fleet (STECF 19-06), Carvalho, N., Keatinge, M. and Guillen Garcia, J. editor(s), EUR 28359 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-09517-0, doi:10.2760/911768, JRC117567.

Vasconcelos, P., Carvalho, A. N., Piló, D., Gaspar, M. B., & Cristo, M. (2017). First record of the spottail mantis shrimp, Squilla mantis (Stomatopoda, Squillidae), in the Ria Formosa lagoon (Algarve coast, southern Portugal). Crustaceana, 90(13), 1665-1671.

https://www.sealifebase.ca/summary/Squilla-mantis.html