Stock Assessment Form

Demersal species

Reference year:2016

Reporting year:2017

Stock Assessment of Common Sole in the The Italian fleets exploit common sole with rapido trawl and set nets (gill nets and trammel nets), while mainly trammel net is commonly used in the countries of the eastern coast. Sole is an accessory species for otter trawling. More than 80% of catche come from the Italian side. Landings fluctuated between 1,000 and 2,300 t in the period 1980-2016 XSA and Statistical Catch at Age (SS3 model) assessments were applied. Input data were provided by the Croatian, Italian and Slovenian DCF official data call. Moreover, estimations derived from the Croatian Primo Project, for the period 2008-2012 were also use. Tuning data were collected during the SoleMon survey. According to the XSA and SCAA analyses an increase of SSB is observed in 2016, while the recruitment fluctuated since 2006 without a clear trend. Based on the estimates of the current F (SS3), the fishing mortality appears higher that $F_{0.1}$ (proxy of MSY) and, hence, it can be concluded that the resource is exploite unsustainably. A reduction of fishing pressure would be recommended, also taking into account that the exploitation is mainly orientated towards juveniles and the success of recruitment seems to be strictly related to environmental conditions.

Stock Assessment Form version 1.0 (November 2015)

Uploader: *Giuseppe Scarcella*

Stock assessment form

Sommario

1 Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Solea solea	Common sole	31
1st Geographical sub-area:	2nd Geographical sub-area:	3rd Geographical sub-area:
17		
4th Geographical sub-area:	5th Geographical sub-area:	6th Geographical sub-area:
1st Country	2nd Country	3rd Country
Italy	Croatia	Slovenia
4th Country	5th Country	6th Country
Stock assessment method: (direct, indirect, combined, none)		
Indirect: XSA – SCAA (ss3)		
Authors:		
[1]Scarcella G., [1] Angelini S., [1] Donato S., [1] Santojanni A., [1] Grati F., [1]Polidori P., [1]Pellini G., [1]Vega C., [1]Punzo E., [1]Santelli A., [1]Strafella P., [1]Masnadi F., [1]Leonetti M., [2]Giovanardi O., [2]Raicevich S., [2]Sabatini L., [2]Franceschini G., [2]Fortibuoni T., [3]Vrgoc N., [3]Isajlovic I., [3]Despalatovic M., [3]Cvitković N., [4]Marceta B., [1]Fabi.G.		
Affiliation:		
[1]Institute of Marine Science, National Research Council, Italy *[2]Institute for Environmental Protection and Research, Italy* *[3]Institute of oceanography and Fishery, Croatia* *[4]Fishery Research Institute of Slovenia, Slovenia*		

2 Stock identification and biological information

Tagging experiments carried out in GSA 17 on common sole in the northern Adriatic Sea, using the traditional mark-and-recapture procedure, showed that all individuals were re-captured within the GSA (Pagotto *et al.*, 1979). Local currents, eddies and marked differences of oceanographic features of this sub-basin with respect to those of southern Adriatic and Ionian Sea (Artegiani *et al.*, 1997) may prevent a high rate of exchange of adult spawners and the mixing of planktonic larval stages from nursery areas of adjacent basins (Magoulas *et al.*, 1996). Guarnieri *et al.* (2002), taking into account differences of sole specimens from five different central Mediterranean areas in the control region sequence marker, suggested that two near-panmictic populations of common sole could exist in the Adriatic Sea. The former population would inhabit the entire GSA 17 (northern Adriatic Sea). The second unit seems to be spread along the Albanian coasts (eastern part of the GSA 18). The hydrogeographical features of this semi-enclosed basin might support the overall pattern of differentiation of the Adriatic common soles.

The northern Adriatic Sea has a high geographical homogeneity, with a wide continental shelf and eutrophic shallow-waters. The southern Adriatic in contrast, is characterized by narrow continental shelves and a marked, steep continental slope (1200 m deep; Adriamed, 2000). This deep canyon could represent a significant geographical barrier for *S. solea*.

On these bases, different actions for fishery management should be proposed for the Adriatic common sole stocks in GSA 17 and GSA 18. In the former area the stock is shared among Italy, Slovenia and Croatia, while in the latter one seems to be shared only between Montenegro and Albania.

A study supported by ADRIAMED-FAO (SoleDiff), about the population structure of common sole in the Adriatic Sea, confirmed the previous evidences about the genetic differentiation between the stocks in GSA 17 and GSA 18. Capitalizing on an available dataset of 353 *S. solea* individuals sequenced in previous projects, additional sequences for 62 individuals of *S. solea* that were collected during the SOLEMON survey 2007 in the eastern side of GSA18 (Albania and Montenegro) and 9 from GSA17 have been generated. A total alignment of 615 bp of the mitochondrial cyt b gene in 424 specimens from a geographic range covering from the Gulf of Lion to the Levantine sea in order to better understand the phylogeographic relationships of the Mediterranean common sole populations have been produced. The results of the median joining network analysis showed the presence of three main phylogeographical clades, corresponding to the West-Central Mediterranean (Balearic-Tyrrenian samples), East-Central Mediterranean (Ionian and Aegean) and Levantine Sea. In the observed pattern the specimens from the Adriatic Sea *S. solea* populations showed both the Tyrrhenian and the Aegean most frequent haplotypes, suggesting the Adriatic sea as a contact zone. Moreover, further analysis of the Adriatic populations showed a low but significant differentiation between GSA 17 and GSA 18 populations.

2.1 Stock unit

2.2 Growth and maturity

In the Mediterranean Sea, the reproduction of common sole occurs from December to May (Bini; (1968-70), Tortonese, 1975, Fisher *et al.*, 1987). Within the framework of SoleMon project, it has been observed that in the central and northern Adriatic Sea the reproduction takes place from November to March. Data on the spatial distribution of spawners provided by the project show a higher concentration of reproducers outside the western coast of Istria (Fabi *et al.*, 2009).
Length at first maturity is 25 cm (Fisher *et al.*, 1987; Jardas, 1996; Vallisneri *et al.*, 2000); this value has been estimated at 25.8 using data from SoleMon project. Females having a weight of 300 g have about 150,000 eggs, while those weighting 400 g have about 250000 eggs (Piccinetti and Giovanardi, 1984); eggs are pelagic. The male-female ratio is approximately 1:1 (Piccinetti and Giovanardi, 1984; Fabi *et al.*, 2009).
Hatching occurs after eight days and the larva measures 3 to 4 mm TL (Tortonese, 1975). Eye migration starts at 7 mm TL and ends at 10-11 mm TL. Benthic life begins after seven or eight weeks (15 mm) in coastal and brackish waters (Bini (1968-70); Fabi *et al.*, 2009).

In the Adriatic sea, growth analyses on this species have been made using otoliths, scales and tagging experiments. A great variability in the growth rate was noted: some specimens had grown 2 cm in one month, while others, of the same age group, needed a whole year (Piccinetti and Giovanardi, 1984). Von Bertalanffy growth equation parameters have been calculated using various methods. Within the framework of SoleMon project, growth parameters of sole were estimated through the length-frequency distributions obtained from surveys.

Table 2.2.1: Maximum size, size at first maturity and size at recruitment.

Somatic magnitude measured (LT, LC, etc)				**Units**	
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	Fall – Winter
Maximum size observed	40	38		**Recruitment season**	Fall
Size at first maturity			25.8	**Spawning area**	*
Recruitment size to the fishery			18-20	**Nursery area**	**

* Northern Adriatic: within meridians 13°00’ and 14°20’ E and parallels 44°10’ and 45°20’ N

** Marine coastal areas, estuarine and lagoon systems along the Italian coast of the central and northern
Adriatic Sea

Table 2.2-2: M vector and proportion of matures by size or age (Males+Females)

Age	Natural mortality	Proportion of matures
0	0.7	0
1	0.35	0.16
2	0.28	0.76
3	0.25	0.96
4	0.23	0.99
5+	0.22	1

Table 2-3: Growth and length weight model parameters

			Sex			
		Units	female	male	Combined	Years
Growth model	**L_∞**				39.6	
	K				0.4	
	t_0				-0.46	
	Data source	SoleMon project				
Length weight relationship	**a**				0.007	
	b				3.0638	
	M (scalar)					
	sex ratio (% females/total)	53				

3 Fisheries information

3.1 Description of the fleet

The common sole is a very important commercial species in the central and northern Adriatic Sea (Ghirardelli, 1959; Piccinetti, 1967; Jardas, 1996; Vallisneri *et al.*, 2000; Fabi *et al.*, 2009), representing more than 20 million of euros in term of landing value. Italian *rapido* trawlers exploit this resource providing more than 60% of landings. Sole is also a target species of the Italian, Slovenia and Croatian set netters, representing respectively 25%, 8% and 0.6% of the total landings of sole in GSA 17. Sole is an accessory species for otter trawlers.

The Italian rapido trawl fleet operating in GSA 17 was made of around 150 vessels in 2005, decreasing to 95 in 2015. Vessels ranges from 9 to 30 m in vessel length, GRT ranges from 4 to 100 and the engine power from 60 to 1000 HP. Each vessel can tow from 2 to 4 rapido trawls depending on its dimensions. The *rapido* trawl is a gear used specifically for catching flatfish and other benthic species (e.g. cuttlefish, mantis shrimp, etc.). It resembles a toothed beam-trawl and is made of an iron frame provided with 3-5 skids and a toothed bar on its lower side. These gears are usually towed at a greater speed (up to 10-13 km h^{-1}) in comparison to the otter trawl nets; this is the reason of the name "*rapido*", the Italian word for "fast". The mesh opening of the codend used by the Italian *rapido* trawlers is the same or larger (usually 50 mm stretched diamond mesh) than the legal one. The main Italian *rapido* trawl fleets of GSA17 are sited in the following harbours: Ancona, Rimini and Chioggia. In the last years also in Croatia a gear similar to rapido is employed in the area in front of Istria peninsula.

Table 3-1: Description of operational units exploiting the stock

	Country	GSA	Fleet Segment	Fishing Gear Class	Group of Target Species	Species
Operational Unit 1	ITA	17	E - Trawl (12-24 metres)	98 - Other Gear (rapido trawl)	33 - Demersal shelf species	Sole
Operational Unit 2	ITA	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	
Operational Unit 3	ITA	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	Sole
Operational Unit 4	HRV	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	Sole
Operational Unit 5	SVN	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	Sole

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

Operational Units*	Fleet (n° of boats)*	Catch (T or kg of the species assessed)	Other species caught (names and weight)	Discards (species assessed)	Discards (other species caught)	Effort (units)
ITA 17 E 98 33 - SOL	95	1588	*Solea solea*	*Bolinus brandaris, Chelidonichthys lucernus, Sepia officinalis, Squilla mantis, Pecten jacobeus, Melicertus kerathurus*		*Aporrhais pespelecani, Ostrea edulis, Liocarcinus depurator, Anadara inaequivalvis, Anadara demiri*
ITA 17 C 07 33 - SOL	800	388	*Solea solea*	*Bolinus brandaris, Chelidonichthys lucernus, Squilla mantis*		*Aporrhais pespelecani, Ostrea edulis, Liocarcinus vernalis, Astropecten irregularis,*
HRV 17 C 07 33 - SOL	302	168	*Solea solea*			
SVN 17 C 07 33 - SOL	126	12	*Solea solea*			
Total	1323	2156				

<u>Italian effort trends of GSA 17</u>

Italian effort data from DCF show a clear decreasing pattern of the fleets exploiting common sole in GSA 17 (Fig. 1)

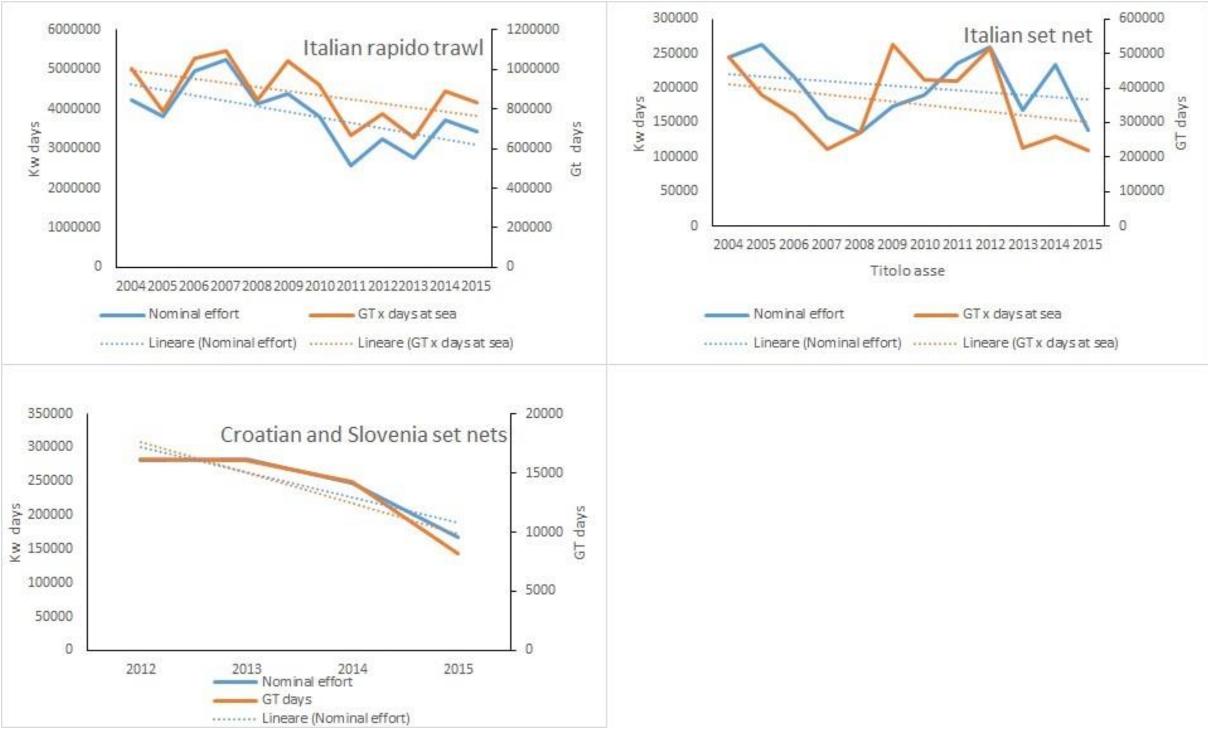


*Figure 1 – Effort data (GT*days at sea and Kw * days at sea) of the main Adriatic fleets exploiting common sole in GSA 17.*

<u>Spatial distribution of rapido trawl fishing effort</u>

Figure 2 shows the fall rapido-trawl effort of Italian vessels over the years 2006–2011 in GSA 17. The first zone of effort concentration is inshore between 3 and 9 nautical miles from the Italian coast, between 43° and 44° latitude, and is mainly exploited by vessels belonging to Ancona and Rimini Harbours. The second zone is between Po river mouth and Venice lagoon and is concentrated at the same distance from the coast as the first region. This region is mainly exploited by the Chioggia rapido trawl fleet. The third area of effort concentration is offshore, near Istria peninsula and is exploited by both Chioggia and Rimini rapido trawl fleets. As expected, the area is characterized by a low abundance of sole, as suggested by survey data in Grati *et al.* (2013), and has a relatively low fishing effort. The area southward of this last region is not exploited by rapido trawlers mainly due to the high concentrations of debris and benthic communities that are dominated by holothurians (Despalatović *et al.*, 2009; Santelli *et al.*, 2016). The data presented in the Figure 2 are important to justify the population selectivity curves used in the SS3 model in order to carry out the Statistical Catch at Age analysis (see discussion below).

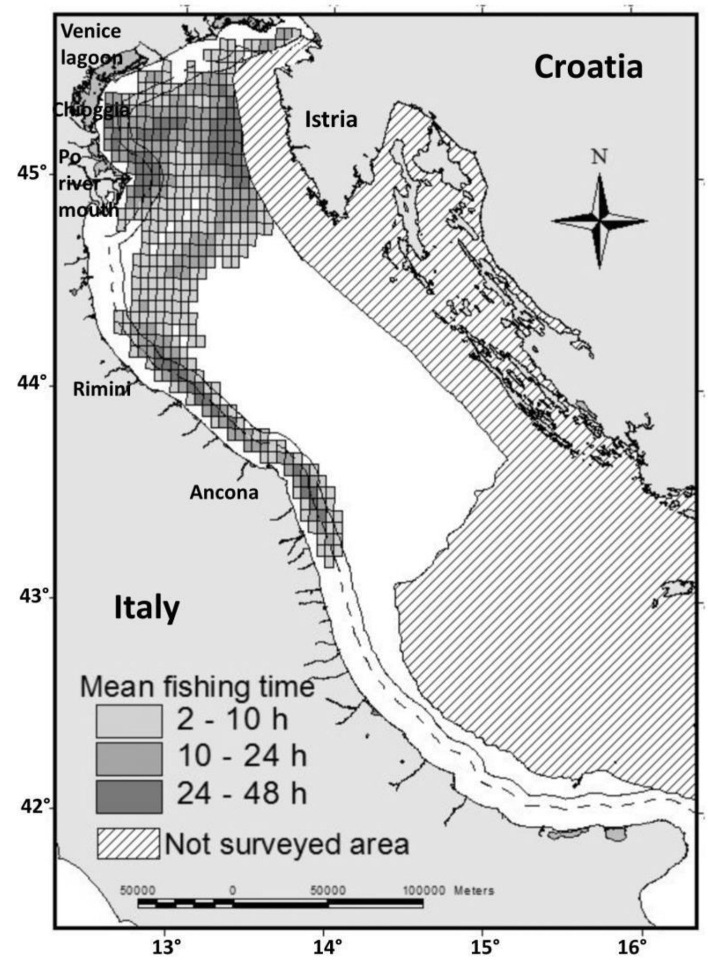


Figure 2 – Spatial distribution of Italian rapido trawl fishing effort.

Moreover, a decrease of the activity of rapido trawl has been observed within the 6 nm of the Italian coast in the period 2006 to 2014 (Fig. 3).

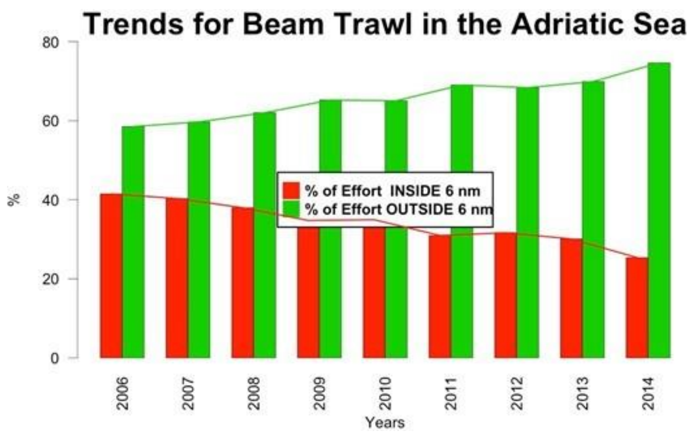


Figure 3 – Percentage of Italian rapido trawl fishing effort within and outside the Italian 6 nm estimated from VMS data.

3.2 Historical trends

Common sole landings estimated by FishStatJ – GFCM database and in the framework of Croatian, Italian and Slovenian Official Data Collection submitted in the data call 2017 are showed in figure 4, together with Croatian data provided in the Croatian Primo Project for the period 2008-2012.

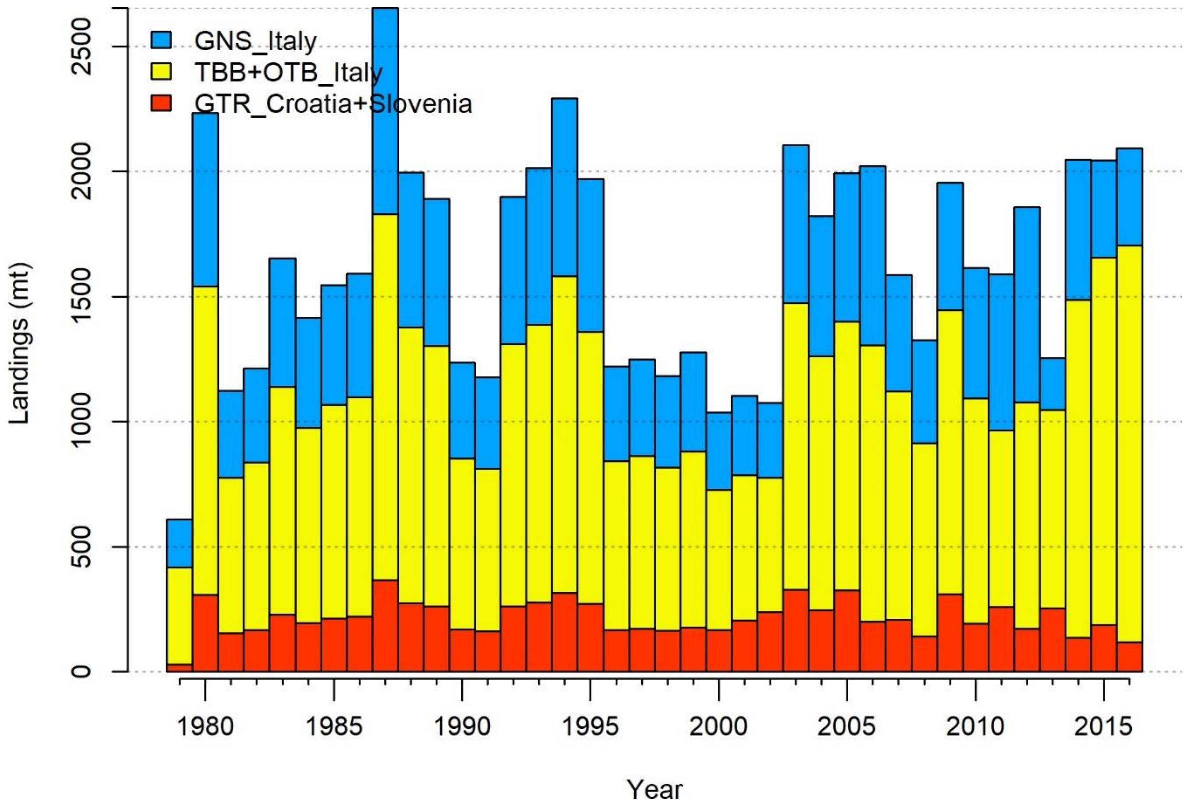


Figure 4 – Landings of common sole in GSA 17.

3.3 Management regulations

<u>Italy and Slovenia :</u>

- In Italy and Slovenia the main rules in force are based on the applicable EU regulations (mainly EC regulation 1967/206):
- Minimum landing sizes: 20 cm TL for sole.
- 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

Croatia

Since the accession of Croatia to the EU the 1st of July 2013, the same regulations of Italy and Slovenia are implemented. Furthermore the following regulations are applied:

- Beam trawl ("*rapido*"), according to the Fishing acts (Narodne novine, 148/2010, 25/2011), is gear for catching only shellfish, and the rate of other species in the catches cannot exceed 20%. Allowed mesh size for "rapido" is 40 mm (from knots to knots), and it is allowed to use only two rapido per vessel. Each rapido can be wide up to 4 meters.
- Common sole is mainly caught with trammel nets, and minimum mesh size for trammel nets is 40 mm (inner nets) and 150 mm (outer nets). Maximum length of the nets allowed on the vessel is 6,000 m. If only one fisherman present on the vessel, the maximum allowed length is 4,000 m; for each additional fisherman an extra 1,000 m of net is allowed, up to 6000 m of total length per vessel. Maximum height of the nets is 4 m. Trammel nets can be used only in the period from 10 September to 15 January.

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					
F			F0.1	0.26	
Y					
CPUE					
Index of Biomass at sea					

4 Fisheries independent information

4.1 *SoleMon*

Ten *rapido* trawl fishing surveys were carried out in GSA 17 from 2005 to 2014: two systematic “pre-surveys” (spring and fall 2005) and four random surveys (spring and fall 2006, fall 2007-2013) stratified on the basis of depth (0-30 m, 30-50 m, 50-120m). Hauls were carried out by day using 2-4 *rapido* trawls simultaneously (stretched codend mesh size = 46). The following number of hauls was reported per depth stratum (Tab. 1).

Tab. 1 Number of hauls per year and depth stratum in GSA 17, 2005-2016

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

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, spawning females and juveniles. 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 4.1-1: Trawl survey basic information

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

Table 4.1-2: Trawl survey sampling area and number of hauls 2016

Stratum	**Total surface (km^2)**	**Trawlable surface (km^2)**	**Swept area (km^2)**	**Number of hauls**
1	11512		1.343	39
2	8410		0.55	18
3	22466		0.36	10
HRV	6000		0.09	7

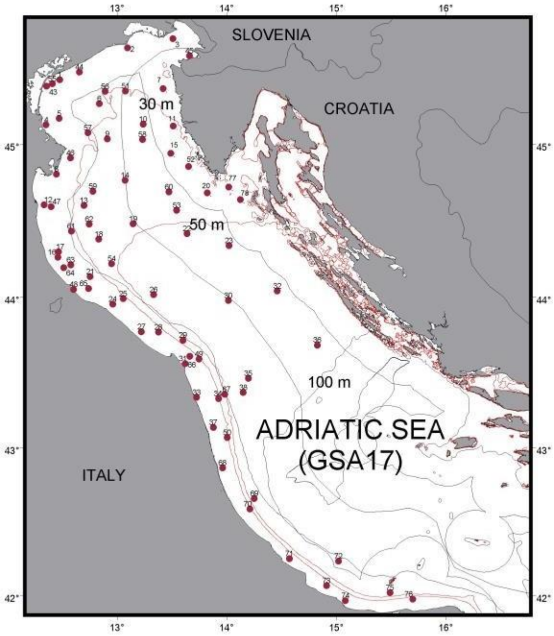


Figure 5 – Solemon map of hauls positions

Table 4.1-3: Trawl survey abundance and biomass results

Stratum	Years	kg per km²	St Dev	Relative * biomass All age groups	CV or other	N per km²	St Dev	Relative * abundance All age groups	CV or other
	2005	27.13	4.13			305.05	60.91		
	2006	35.82	5.64			327.14	72.16		
	2007	39.34	7.17			433.37	102.9		
	2008	29.59	5.37			244.74	46.30		
	2009	29.11	5.78			479.48	169.2		
	2010	28.72	4.48			285.85	53.91		
	2011	32.39	5.69			430.87	106.6		
	2012	42.85	5.47			438.01	74.55		
	2013	50.59	6.98			726.74	119.2		
	2014	90.17	13.44			917.17	202.0		
	2015	60.7	9.56			604.2	128.5		
	2016	65.7	9.89			608.8	70.41		

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

Slicing method

LFDA 5.0

Maturity at Age						
PERIOD	0	1	2	3	4	5+
2006-2014	0	0.16	0.76	0.96	0.99	1.00

Table 4.1-4: Trawl surveys; recruitment analysis summary

Survey	**SoleMon**	**Trawler/RV**	**Dallaporta**
Survey season		Fall	
Cod –end mesh size as opening in mm		46	
Investigated depth range (m)		0-120	
Recruitment season and peak (months)		Settember-October-November	
Age at fishing-grounds recruitment		0	
Length at fishing-grounds recruitment		17-20	

Table 4.1-5: Trawl surveys; recruitment analysis results

Years	Area in km^2	N of recruit per km^2	St DEv
2005		201.05	29.92
2006		99.85	57.91
2007		299.8	31.98
2008		90.57	35.56
2009		379.87	43.94
2010		119.31	29.56
2011		316.29	31.55
2012		199.23	28.12
2013		497.11	22.34
2014		342.37	46.71
2015		306.5	105.92
2016		144.4	41.07

The recruitment is mainly localised in the coastal close to Po river mouth. The recruits have been estimated on the base of the LFD observed from the survey (0-20 cm; Fig. 6)

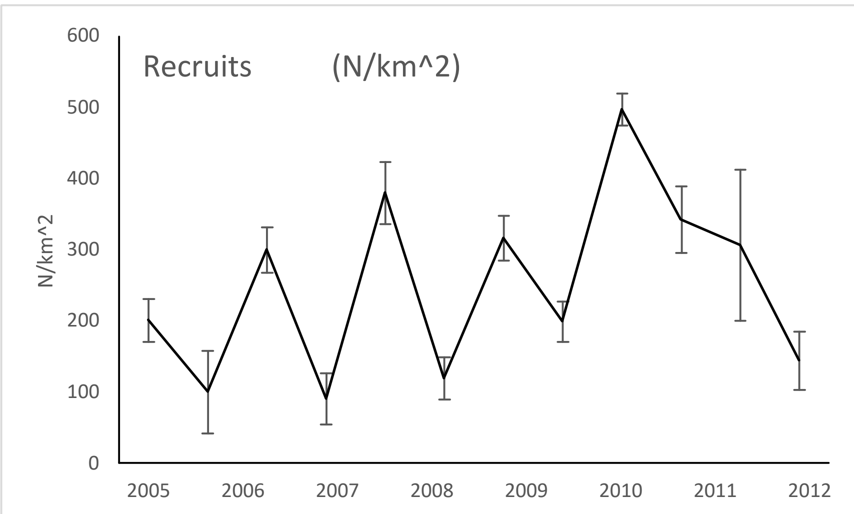


Figure 6 – Abundance indices (± s.d.) of sole recruits obtained from SoleMon surveys.

Direct methods: trawl based Spawner analysis

Table 4.1-6: Trawl surveys; spawners analysis summary

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

Table 4.1-7: Trawl surveys; spawners analysis results

Surveys	Area in km²	N (N of individuals) of spawners per km²	St Dev	SSB per km²	St Dev	Relative SSB	CV or other
2005		61.6	12.91	12.79	2.8		
2006		71.08	13.17	12.37	2.15		
2007		103.21	24.74	21.85	5.33		
2008		83.65	20.11	17.9	4.52		
2009		66.52	11.87	12.53	2.5		
2010		40.38	6.77	8.43	1.62		
2011		49.2	9.19	10	2.02		
2012		101.57	12.93	18.88	2.52		
2013		91.63	21.24	16.55	4.45		
2014		175.38	22.08	31.79	4.22		
2015		167.27	32.98	33.5	6.06		
2016		121.16	16.05	23.90	3.33		

The spawners aggregates in the north sector of the sub-basin mainly in front of the Istria peninsula, the trend of spawners abundance are showed in figure 7 (> 25.5 cm).

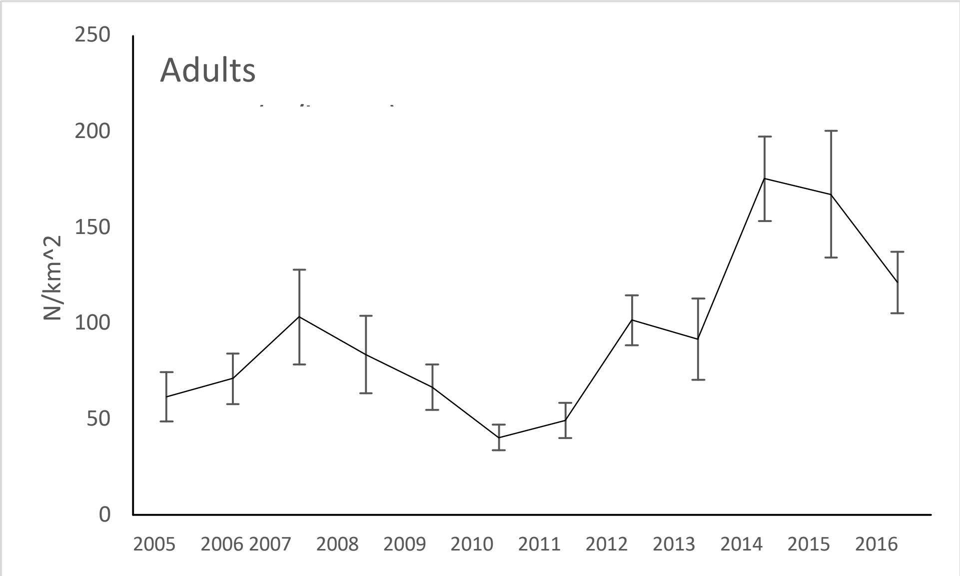


Figure 7- *Abundance indices (± s.d.) of sole adults obtained from SoleMon surveys.*

4.1.1 Spatial distribution of the resources

According to data collected during SoleMon surveys (Scarcella *et al.*, 2014), age class 0+ aggregates inshore along the Italian coast, mostly in the area close to the Po river mouth (Fig. 8). Age class 1+ gradually migrates offshore and adults concentrate in the deepest waters in at South West from Istria (Fig. 8).

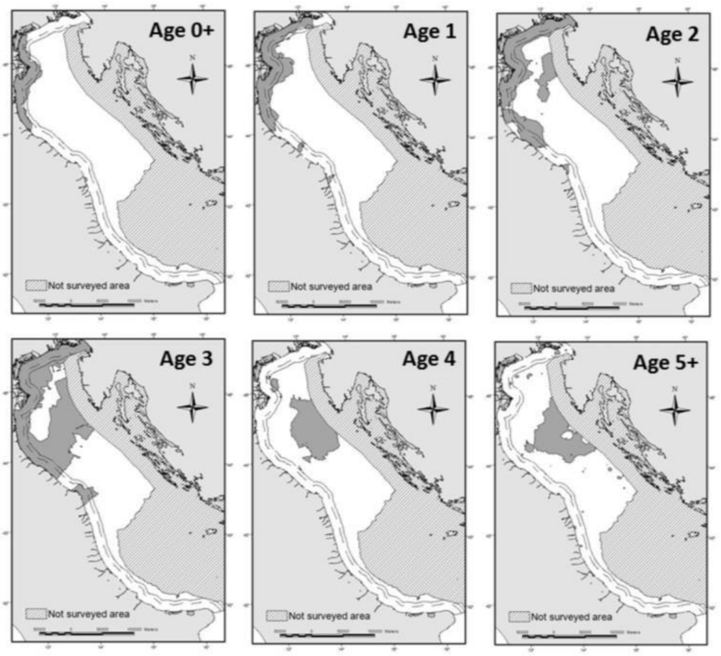


Figure 8 – Maps of hotspots calculated for the age classes of soles. The 6 and 9 nautical miles from the Italian coast are shown respectively by broken and continuous black lines (Scarcella et al., 2014).

4.1.2 Historical trends

The SoleMon trawl surveys provided data either on sole total abundance and biomass as well as on important biological events (recruitment, spawning). Figure 9 shows the biomass indices of sole obtained from 2005 to 2015; slightly increasing trends occurred till fall 2007, followed by a decrease in fall 2008-2009, and an increase in 2010-2016.

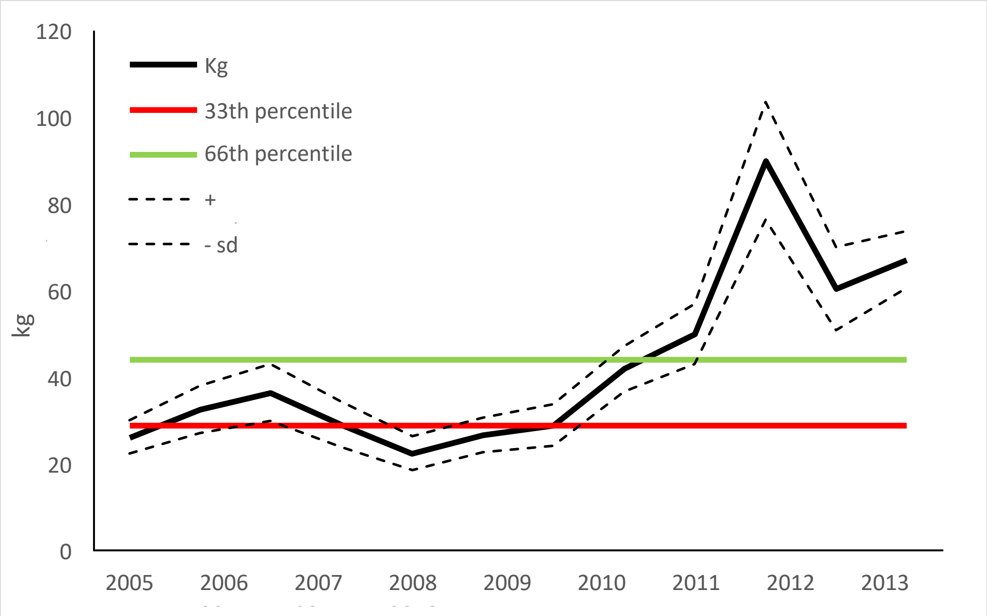
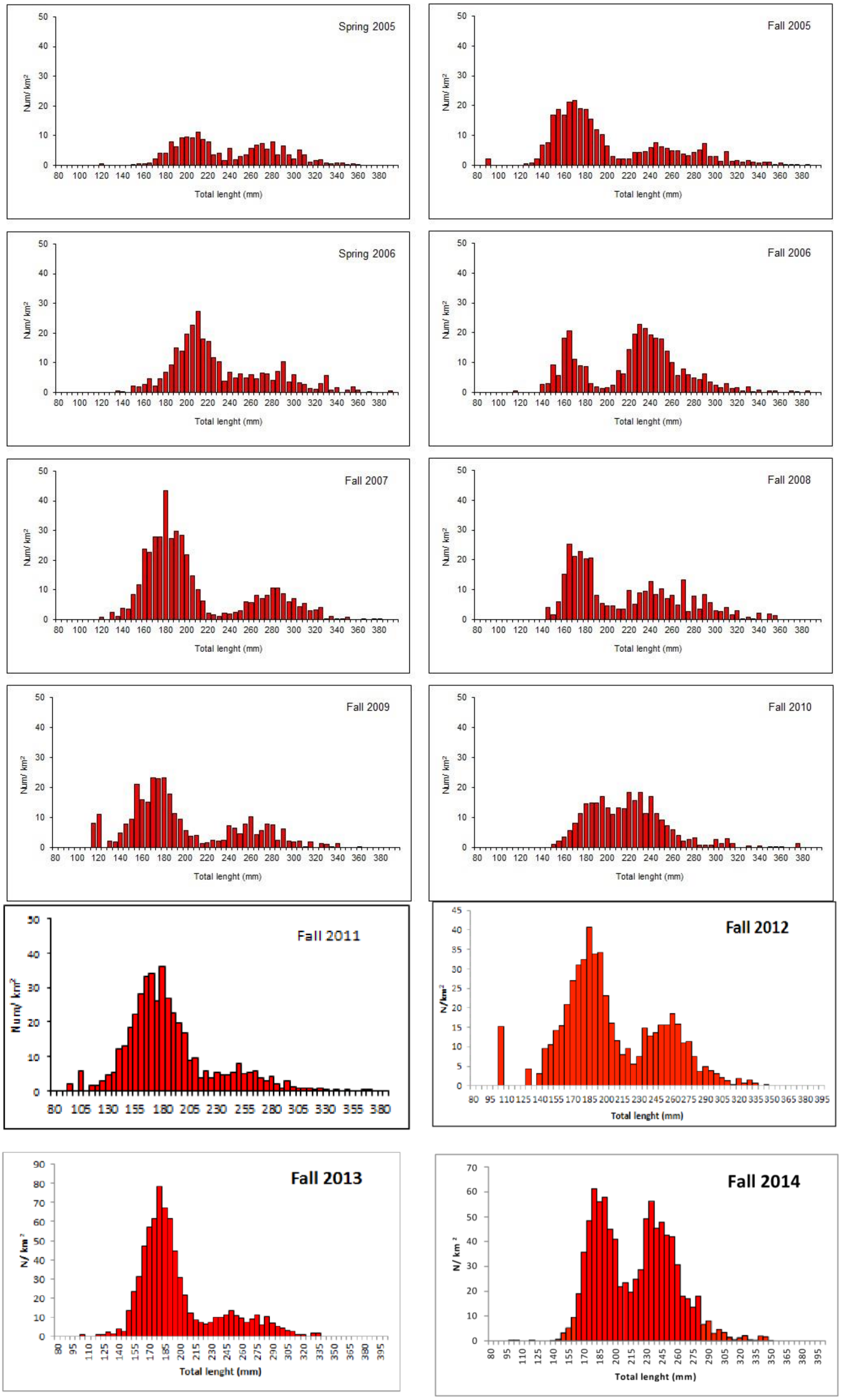
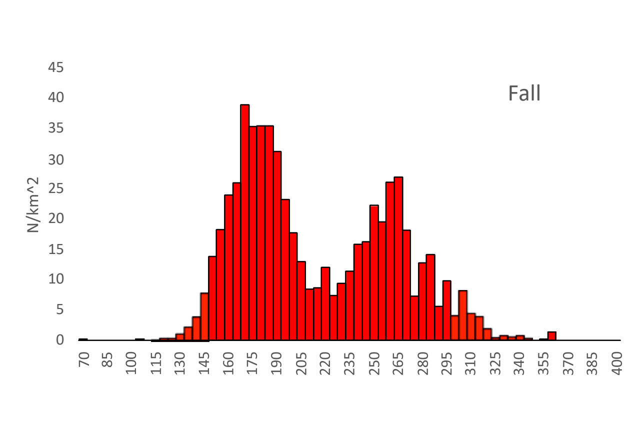


Figure 9- *Biomass indices (± s.d.) of sole obtained from SoleMon surveys.*

Figure 10 displays the stratified abundance indices obtained in the GSA 17 in the years 2005-2015.





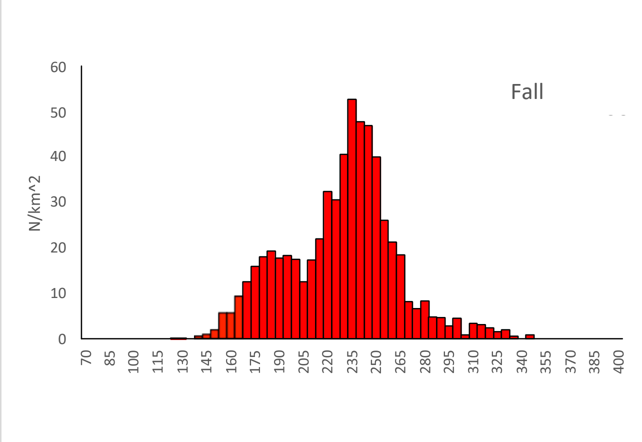


Figure 10 – Stratified abundance indices by size, 2005-2016.

5 Ecological information

5.1 Protected species potentially affected by the fisheries

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

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

Taxa	**Stratum 0-30 (kg km^{-2})**	**Stratum 30-60 (kg km^{-2})**
Annelida		
Aphrodite aculeata	0.096	4.706
Glycera spp	0.001	0.006
Polychaeta	0.248	0.027
Cnidaria		
Alcyonum spp		0.112
Calliactis parasitica	0.002	0.033
Unidentified anemone	0.019	0.600
Unidentified colonial hydroid		0.065
Virgularia mirabilis	0.018	3.405
Crustacea		
Alpheus glaber	0.002	0.001
Corystes cassivelaunus	0.023	
Goneplax rhomboides	10.385	16.042
Inachus comunissimus	0.030	
Inachus phalangium	1.979	0.004
Inachus spp	0.531	0.002
Liocarcinus depurator	8.292	178.664
Liocarcinus vernalis	9.168	0.609
Lysmata seticaudata		0.019
Medorippe lanata	4.375	2.979
Melicertus kerathurus	0.208	0.213

Nephrops norvegicus	0.006	0.044
Pagurus excavatus	0.019	0.045
Pagurus spp	0.364	0.299
Parapenaeus longirostris		0.154
Parthenope angulifrons	0.755	
Pilumnus hirtellus	0.033	
Squilla mantis	5.197	0.397
Echinodermata		
Astropecten irregularis	28.562	8.210
Holothuroidea	0.135	1.771
Marthasterias glacialis	0.174	4.511
Ophiura ophiura	2.592	
Schizaster canaliferus	0.413	0.020
Spatangoida	0.033	
Trachythyone elongata	0.238	2.194
Trachythyone spp	0.022	0.368
Trachythyone tergestina	0.125	3.270
Mollusca		
Acanthocardia paucicostata	0.238	0.072
Acanthocardia tubercolata	0.307	0.146
Aequipecten opercularis	0.136	
Alloteuthis media	0.025	0.003
Antalis dentalis	0.047	
Antalis inaequicostata	0.639	0.001
Antalis spp	0.168	
Aporrhais pespelecani	299.666	6.160
Atrina pectinata	0.190	0.909
Bolinus brandaris	11.135	0.625
Calliostoma spp	0.008	0.310
Cassidaria echinophora		0.784
Chamelea gallina	0.183	

Chlamys varia	0.082	0.004
Corbula gibba	43.145	0.030
Flexopecten glaber glaber	1.389	0.007
Glossus humanus		0.710
Hexaplex trunculus	0.712	0.089
Illex coindetii	0.012	0.004
Mytilus galloprovincialis	2.774	0.907
Nassarius lima	0.068	0.010
Nassarius mutabilis	0.577	0.002
Nassarius reticulatus	0.748	0.001
Naticarius hebraea	0.025	
Naticarius stercusmuscarum	2.219	
Neverita josephinia	0.030	
Nucula nitidosa	0.002	0.004
Nucula nucleus	0.006	0.021
Nucula sulcata	0.003	0.203
Ostrea edulis	94.311	3.043
Pectinidae	0.112	0.060
Polinices nitida	0.001	
Scapharca demiri	30.051	0.009
Scapharca inaequivalvis	137.864	0.290
Scaphodopa	0.077	
Sepia elegans	0.026	0.122
Sepia officinalis	0.465	0.367
Solecurtus strigilatus	0.217	
Turritella communis	0.808	2.758
Unidentified nudibrancs	0.553	
Venerupis aurea	2.552	
Osteichthyes		
Arnoglossus laterna	0.820	1.101
Blennius ocellaris		0.152

Boops boops	0.291	0.033
Buglossidium luteum	0.150	0.110
Cepola macrophthalma		0.487
Chelidonichthys lucernus	3.727	1.214
Citharus linguatula	0.005	0.083
Diplodus annularis	0.130	
Engraulis encrasicolus	0.032	0.019
Eutrigla gurnardus	0.002	0.239
Gobius niger	1.114	0.675
Lesueurigobius friesii	0.005	0.048
Merluccius merluccius	0.129	0.256
Mullus barbatus barbatus	0.234	0.095
Pagellus erythrinus	0.150	0.104
Sardina pilchardus	0.039	0.046
Sardinella aurita	1.081	0.635
Scorpaena notata	0.005	0.239
Serranus hepatus	0.010	0.200
Solea solea	0.128	0.004
Spicara maena	0.058	0.046
Spicara smaris		0.017
Trachurus mediterraneus	0.051	0.007
Porifera		
Unidentified sponge	0.017	0.376
Tunicata		
Ascidiacea		0.189

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

6 Stock Assessment

6.1 XSA

6.1.1 Model assumptions

The errors associated with the measurement of catch at age matrixes are assumed as null.

6.1.2 Scripts

```
library(FLCore) library(FLEDA) library(FLXSA)
library(FLAssess) library(FLash) #read stock file sole.stk
<- readFLStock("SOLEIND17.DAT", no.discards=TRUE)
#set up the stock (create the empty matrix)
units(harvest(sole.stk))<-"f"
range(sole.stk)["minfbar"] <- 1
range(sole.stk)["maxfbar"] <- 4
#Set the plus group sole.stk
<- setPlusGroup(sole.stk, 5)
#read index (tuning file)
sole.idx <- readFLIndices("TUNEFF.DAT")
FLXSA.control.sole <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3,
fse=1, rage=0, qage=4, shk.n=TRUE, shk.f=TRUE, shk.yrs=6, shk.ages=6,
window=100, tsrange=20, tspower=3, vpa=FALSE)
###Final settings
#Running the assessments with different settings
sole.xsa <- FLXSA(sole.stk, sole.idx,
FLXSA.control.sole)
#Add the results to the stock files
sole.stk <- sole.stk+sole.xsa
plot(sole.stk)
```

6.1.3 Input data and Parameters

Catch at age data series of the period 2006-2016 were provided by official statistics from the 2017 DCF data call (Fig. 11). Croatian catch at age data were reconstructed in 2006-2012 on the base of the total landings suggested by Croatian colleagues and catch at age data composition observed for set netters (mainly using trammel nets).

The total catch numbers at age were rescaled based on the SOP correction observed between the reconstructed total catch and the total catch provided by 2017 Italian, Croatian and Slovenia DCF official statistics and Croatian colleagues. The following analyses are carried out using rescaled catch numbers at age.

Figure 11 – Catch at age data used in the VPA and XSA runs.

Maturity at age, Length-Weight relationships, growth parameters were provided in the framework of SoleMon project.

Tuning data were provided by SoleMon surveys, carried out in fall for the years 2006-2016.

A vector of natural mortality rate at age was estimated using the PRODBIOM spreadsheet (Abella et *al.*, 1997).

Input data and parameters.

Catch at age (x 1000)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
2006	2954	10508	1633	704	27	5
2007	430	8471	1399	949	32	7
2008	870	7438	602	436	19	4
2009	5967	7771	927	1030	50	10
2010	5316	6198	654	596	29	6
2011	5173	7266	1189	721	41	12
2012	8134	9058	1030	475	23	4
2013	1415	6553	186	1173	32	6
2014	646	15798	1805	544	27	5
2015	827	11671	2035	451	75	30
2016	750.299	15322.9	1103.0	346.8	55.6	1
Survey index (N km^2)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
2006	56.8	171.3	82.3	8.3	0.8	0.2
2007	74.8	195.4	75.0	27.8	3.1	0.6
2008	24.0	109.9	72.4	14.9	5.3	1.4
2009	72.7	107.0	60.4	7.7	2.9	0.2
2010	15.7	200.0	41.2	9.1	1.3	2.5
2011	68.1	246.5	45.0	7.7	1.4	0.9
2012	52.1	254.5	107.0	10.6	2.6	0.1
2013	181.6	421.4	90.6	14.9	3.2	0.1

2014	75.7	608.2	213.4	15.0	4.6	0.3
2015	227.0	242.7	123.0	12.8	1.3	3.1
2016	72.687	394.534	95.479	33.548	1.712	2.76
Mean catch weight at age (kg)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
2006	0.07	0.13	0.19	0.36	0.45	0.52
2007	0.07	0.13	0.19	0.36	0.45	0.52
2008	0.08	0.13	0.21	0.36	0.45	0.52
2009	0.08	0.14	0.22	0.36	0.45	0.52
2010	0.08	0.16	0.25	0.36	0.45	0.52
2011	0.07	0.12	0.20	0.36	0.45	0.52
2012	0.07	0.11	0.18	0.27	0.45	0.52
2013	0.07	0.12	0.19	0.22	0.45	0.52
2014	0.05	0.13	0.15	0.34	0.45	0.52
2015	0.05	0.13	0.15	0.34	0.45	0.52
2016	0.05	0.13	0.15	0.34	0.45	0.52
Mean stock weight at age (kg)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
2006	0.02	0.10	0.21	0.30	0.38	0.52
2007	0.02	0.10	0.21	0.30	0.38	0.52
2008	0.02	0.10	0.21	0.30	0.38	0.52
2009	0.02	0.10	0.21	0.30	0.38	0.52
2010	0.02	0.10	0.21	0.30	0.38	0.52
2011	0.02	0.10	0.21	0.30	0.38	0.52
2012	0.02	0.10	0.21	0.30	0.38	0.52
2013	0.02	0.10	0.21	0.30	0.38	0.52
2014	0.02	0.10	0.21	0.30	0.38	0.52
2015	0.02	0.10	0.21	0.30	0.38	0.52
2016	0.02	0.10	0.21	0.30	0.38	0.52

Mean weight in stock (kg)						
PERIOD	0	1	2	3	4	5+
2006-2014	0.024	0.104	0.207	0.304	0.380	0.522
Maturity at Age						
PERIOD	0	1	2	3	4	5+
2006-2014	0	0.16	0.76	0.96	0.99	1.00
Natural mortality (M)						
PERIOD	0	1	2	3	4	5+
2006-2014	0.70	0.35	0.28	0.25	0.23	0.22

Sensitivity analyses were conducted to assess the effect of the main parameters, i.e. shrinkage (fse) and age above which q is independent from age (q_{age}). Values ranging from 0 to 2 (0.5 increasing) for the shrinkage and from 0 to 5 for the q_{age} parameter have been tested. As a result, the setting that minimized the residuals and showed the best diagnostics output both of the residuals and retrospective analyses were used for the final assessment.

On the base of the sensitivity analyses the XSA run were made using the following settings:

- Catchability dependent on stock size for ages = 0.
- Catchability independent of age for ages >= 4.
- S.E. of the mean to which the estimates are shrunk = 1.
- Minimum S.E. for population estimates derived from each fleet = 0.30.
- Number of years used for the shrinkage = 7.
- Number of ages used for the shrinkage = 7.
- Ages used for tuning from the survey = 0-4.

The other setting employed were:

- F_{bar} = 1-4.
- Proportion of M before spawning = 0.
- Proportion of F before spawning = 0.

The figure 12 presents the main results from the XSA run: fishing mortality $Fbar_{0-4}$ (harvest), spawning stock biomass (SSB), recruitment (in thousands) and catches (in tons).

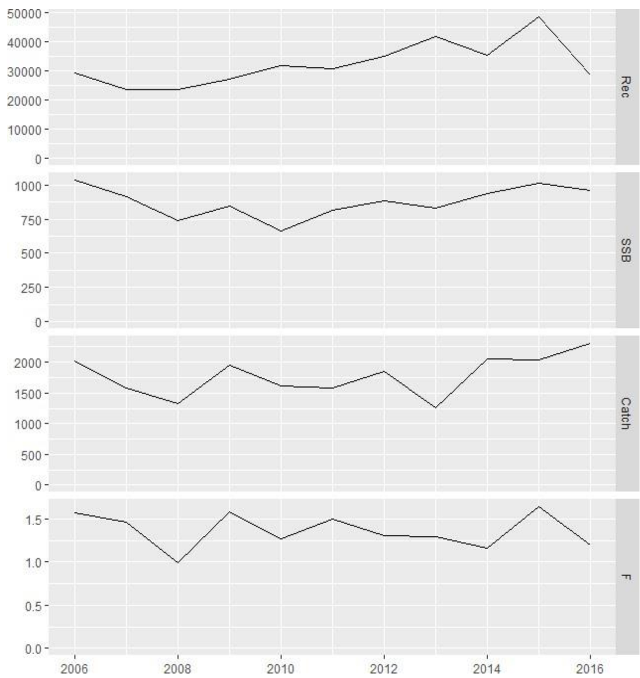


Figure 12 – Final assessment results XSA run.

State of exploitation: Exploitation varied without any trend in the years 2006-2016, reaching the minimum in 2008. The fishing mortality (F_{1-4}) in 2016 was estimated with a value of 1.2. As showed in Table 6.1.3-1 the higher values of F are observed for the age 1.

State of the juveniles (recruits): Recruitment varied without any trend in the years 2006-2011, reaching a minimum in 2008; this trend was followed by an increase in 2011-2015, and a decrease in 2016.

State of the adult biomass: The SSB showed a stable trend from 2006 to 2013, and increased in 2014-2015 (SSB_{2016}: 957 tons).

Table 6.1.3-1 Fishing mortality by age estimated from the XSA.

age	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0	0.15	0.02	0.05	0.34	0.24	0.25	0.38	0.05	0.02	0.02	0.04
1	1.56	1.40	1.45	1.48	1.19	1.04	2.07	1.20	1.49	1.66	1.49
2	0.82	1.08	0.38	0.73	0.49	0.95	0.46	0.24	1.12	1.40	0.80
3	2.44	2.52	1.78	3.03	2.24	2.62	1.96	2.88	1.58	1.75	1.12
4	1.46	0.85	0.38	1.12	1.18	1.39	0.77	0.86	0.48	1.76	1.38
5+	1.46	0.85	0.38	1.12	1.18	1.39	0.77	0.86	0.48	1.76	1.38

6.1.4 Robustness analysis

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

A retrospective analysis was also carried out. The retrospective analysis confirm the stability of the estimates of XSA (Fig. 13).

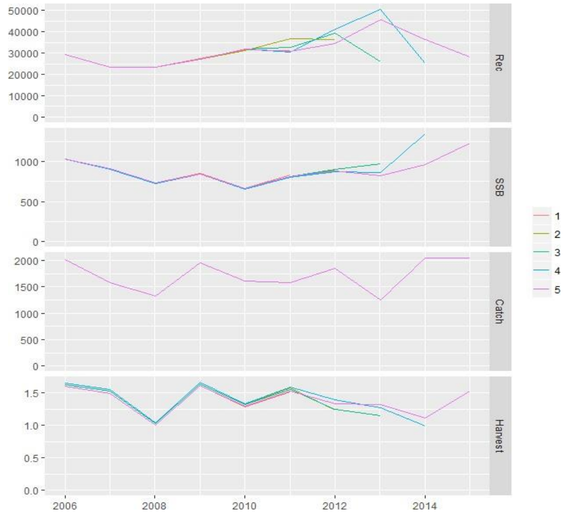


Figure 13 – Retrospective analyses on rescaled data.

XSA Diagnostics in the form of residuals by survey data are shown in the figure 14.

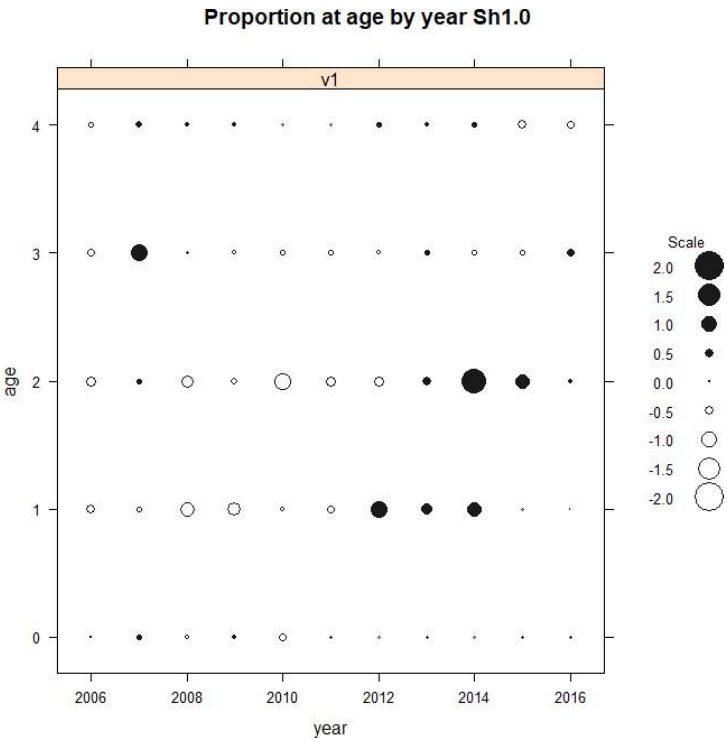


Figure 14 – Residuals by survey.

No trends in the residuals were observed.

6.1.6 Assessment quality

The retrospective analysis and the residuals confirm the stability of the estimates of XSA.

6.2 Statistical catch at age (SS3 model)

6.2.1 Model assumptions

Stock Synthesis 3.3 provides a statistical framework for the calibration of a population dynamics model using fishery and survey data. The model is designed to accommodate both population age and size structure data and multiple stock sub-areas can be analysed. It uses forward projection of population in the "statistical catch-at-age" (hereafter SCAA) approach. SCAA estimates initial abundance at age, recruitments, fishing mortality and selectivity. 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 age- specific by fleet, with the ability to capture the major effect of age-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. Some SS features include ageing error, growth estimation, spawner-recruitment relationship, movement between areas;

in the present assessment such features are not summarized in the results. The ADMB C++ software in which SS is written searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian methods. 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., Derio et *al.*, 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 and with the outputs of the XSA carried out in the present assessment, the F values are standardized by dividing by the average (called F_{bar}) of the F values observed over a defined range of age classes (e.g., Darby and Flatman, 1994; Sampson and Scott, 2011).

The same SOP corrected data and parameters utilized in the XSA were employed. The model allowed specifying the different source of data, providing different uncertainties estimates for each data set. Moreover also the total landings presented from 1980 to 2005 (FAO-FishstatJ source) has been used in the model, together with the DCF and Croatian data for the period 2006-2015. Also in this case the model considered the different sources of the data sets and treated the error separately for each period. In order to facilitate the convergence of the model a higher number of ages has been employed for natural mortality, fecundity and weight at age (Fig. 14).

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

1. Italian gill netters
2. Italian rapido and otter trawler
3. Croatian and Slovenian set netters.

The catch at age for the three fleets are summarized in figure 15.

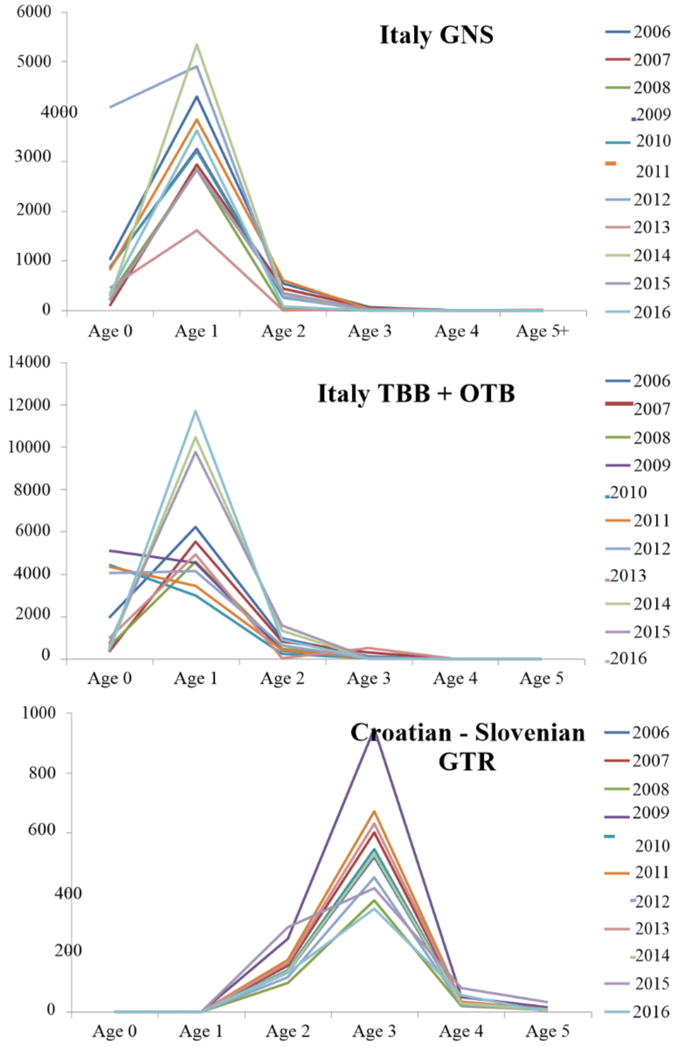
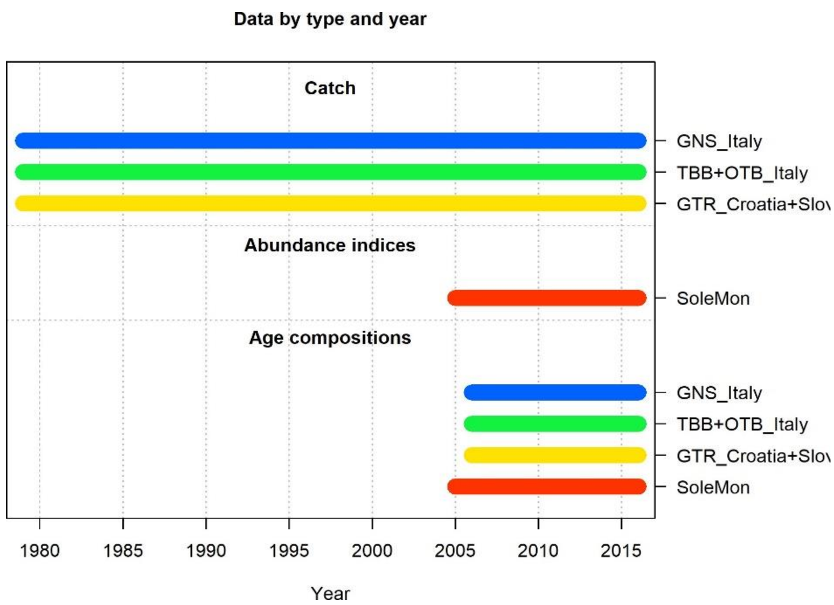


Figure 15 – Catch at age data used in SCAA analysis.

6.2.2 Input data and Parameters

Input data and parameters are the same used for the XSA.



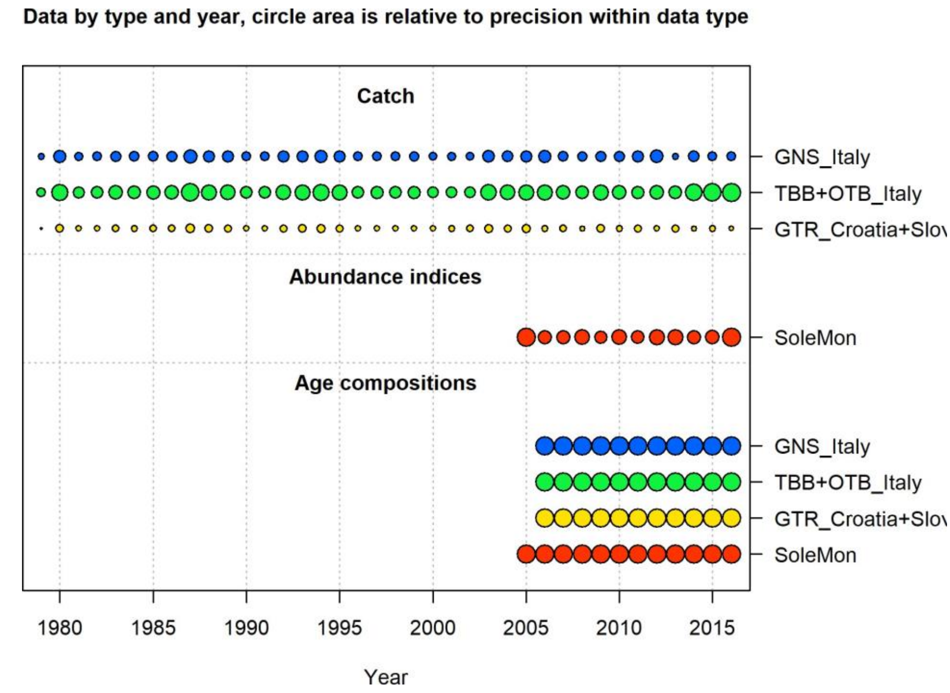


Figure 16 – Input data and relative precision imputed in the SS3 model.

Considering the information provided before the selectivity patterns of the fleets and the survey have been rescaled as in the Fig. 17, assuming a dome shaped selectivity for each fleet and the survey.

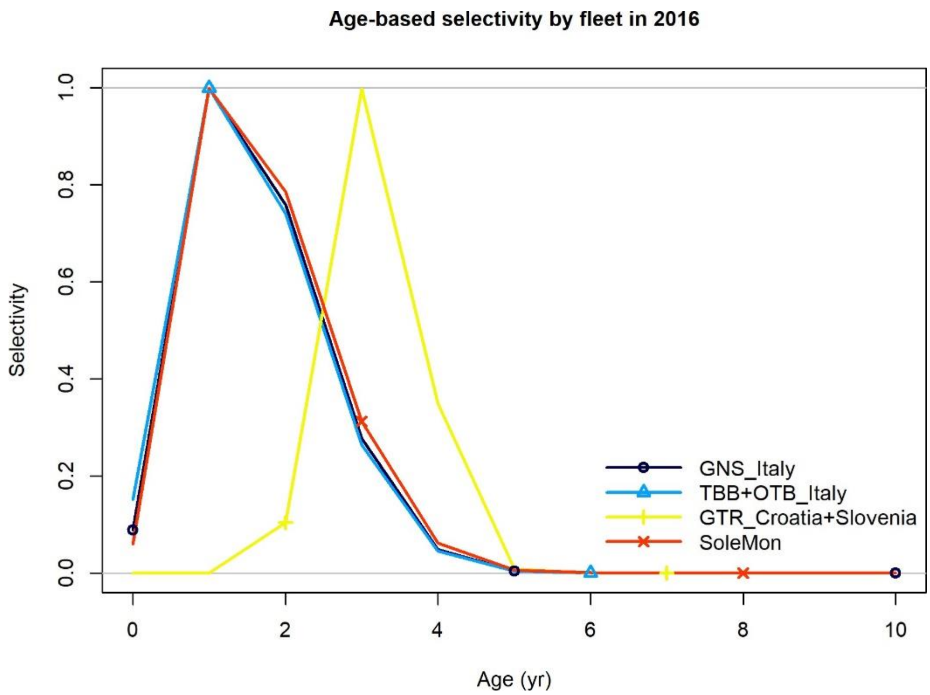


Figure 17 – Selectivity by age utilized in the SS3 model.

6.2.3 Robustness analysis

6.2.4 Retrospective analysis, comparison between model runs, sensitivity analysis

A retrospective analysis was also carried out. The retrospective analysis confirm the stability of the estimates of XSA (Fig. 18). The model is composed by 33 active parameters. None of them were near to the bounds, the Hessian matrix converged and the final gradient was 2.39418e-005.

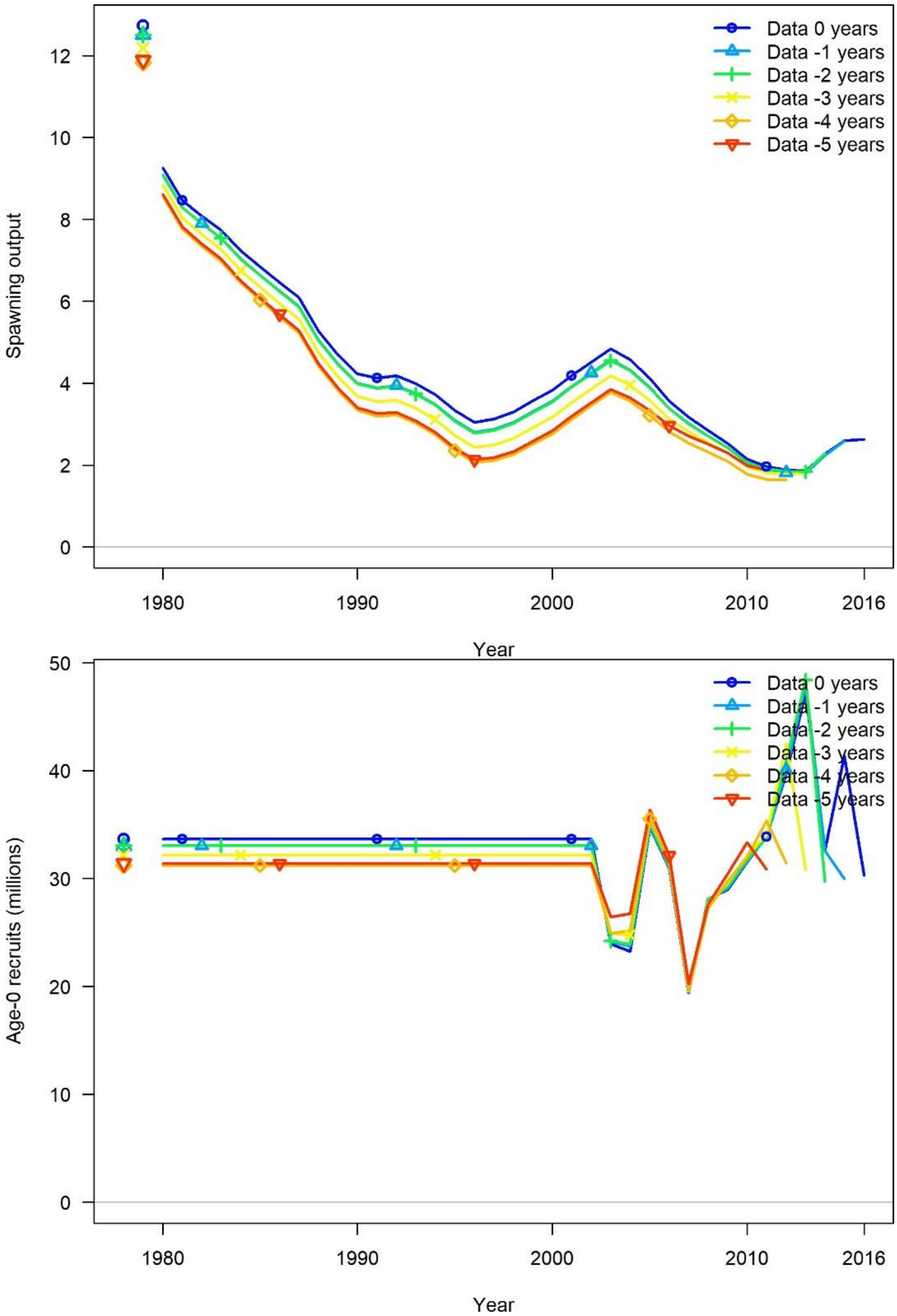


Figure 18 – *Retrospective analyses on rescaled data.*

SS3 Diagnostics in the form of residuals data are shown in the figure 19.

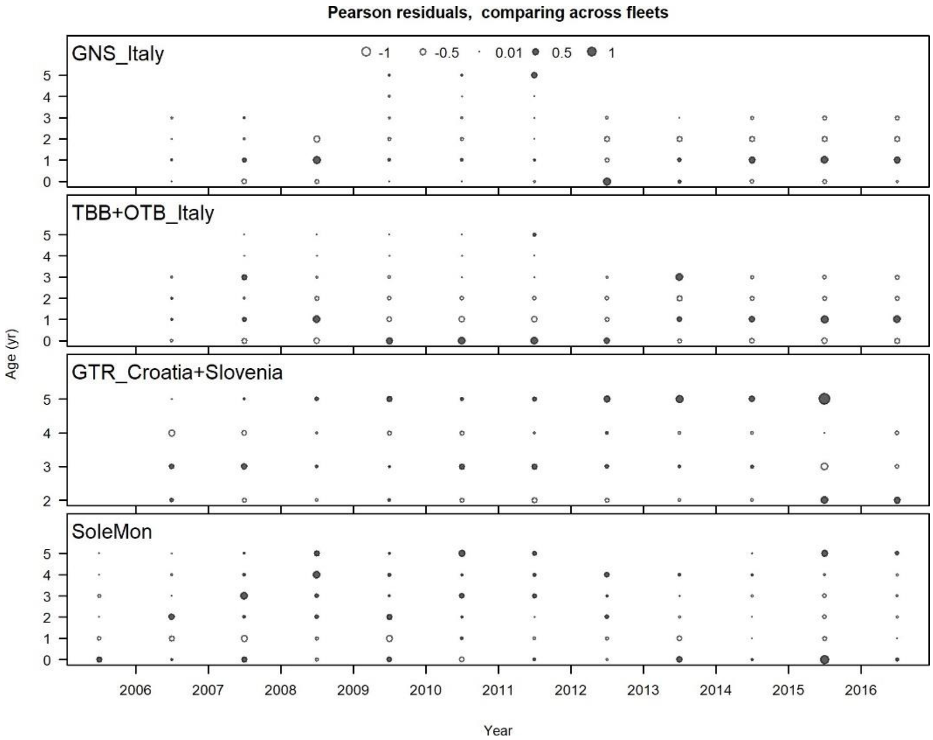


Figure 19 – Pearson residuals for SoleMon survey and the fleets.

No trends in the residuals were observed.

Fig. 20 presents the main results from the SCAA run: fishing mortality ($Fbar_{0-4}$ and by fleet), recruitment and spawning stock biomass (SSB).

<u>State of exploitation</u>: Exploitation increased from the beginning of the time-series, with a more pronounced increase after 2000. In the period 2012-2015 the F_{bar} showed important decrease. In 2016 the value of mean fishing mortality (F_{bar} 1-4) increased toward 0.41.

<u>State of the juveniles (recruits)</u>: Recruitment varied without any trend in the years 1980-2016.

<u>State of the adult biomass</u>: The SSB showed a strong decrease since the beginning of the series. The last estimate of SSB in 2016 is around 5250 tons.

6.2.5 Assessment quality

The retrospective analysis and the residuals confirm the stability of the estimates of SS3. However is important to stress that the present assessment the data of the SoleMon survey carried out in 2016 inside the Croatian waters were not utilized. Moreover, the indices of abundance at age have been estimated using age at length keys of otoliths that have been read only in the years 2008-20012.

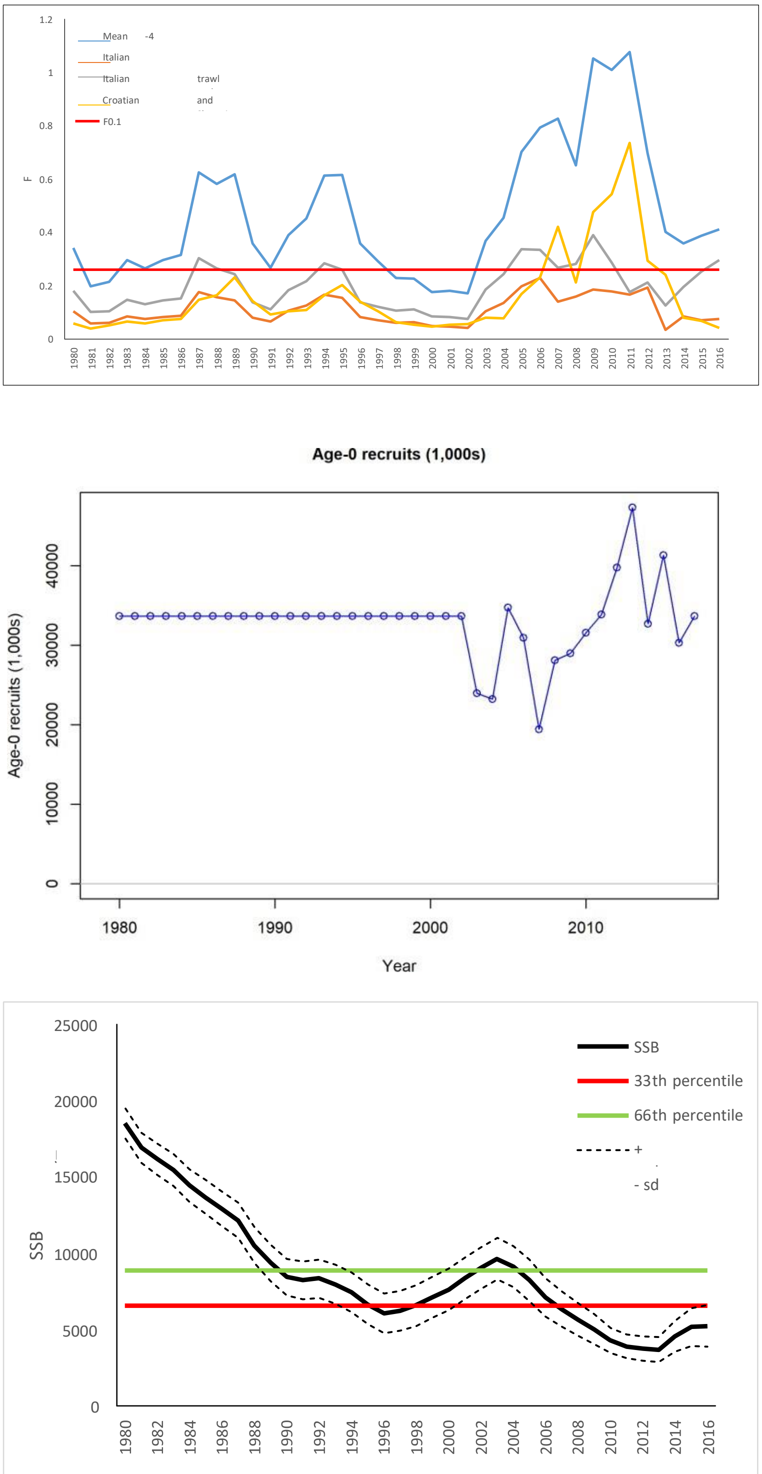


Figure 20 – Final assessment results SCAA run.

7 Stock predictions

Due to the short time series it was not possible to estimate a stock recruitment relationship. As a consequence the biological reference point has been estimated using the Yield per Recruits approach, where $F_{0.1}$ is considered a proxy of FMSY. Biological reference points have been estimated using the XSA and SCAA input data and selectivity patterns.

RPs suggest an overfishing situation for the *S. solea* stock both for the XSA and SS3 (Fig. 20).

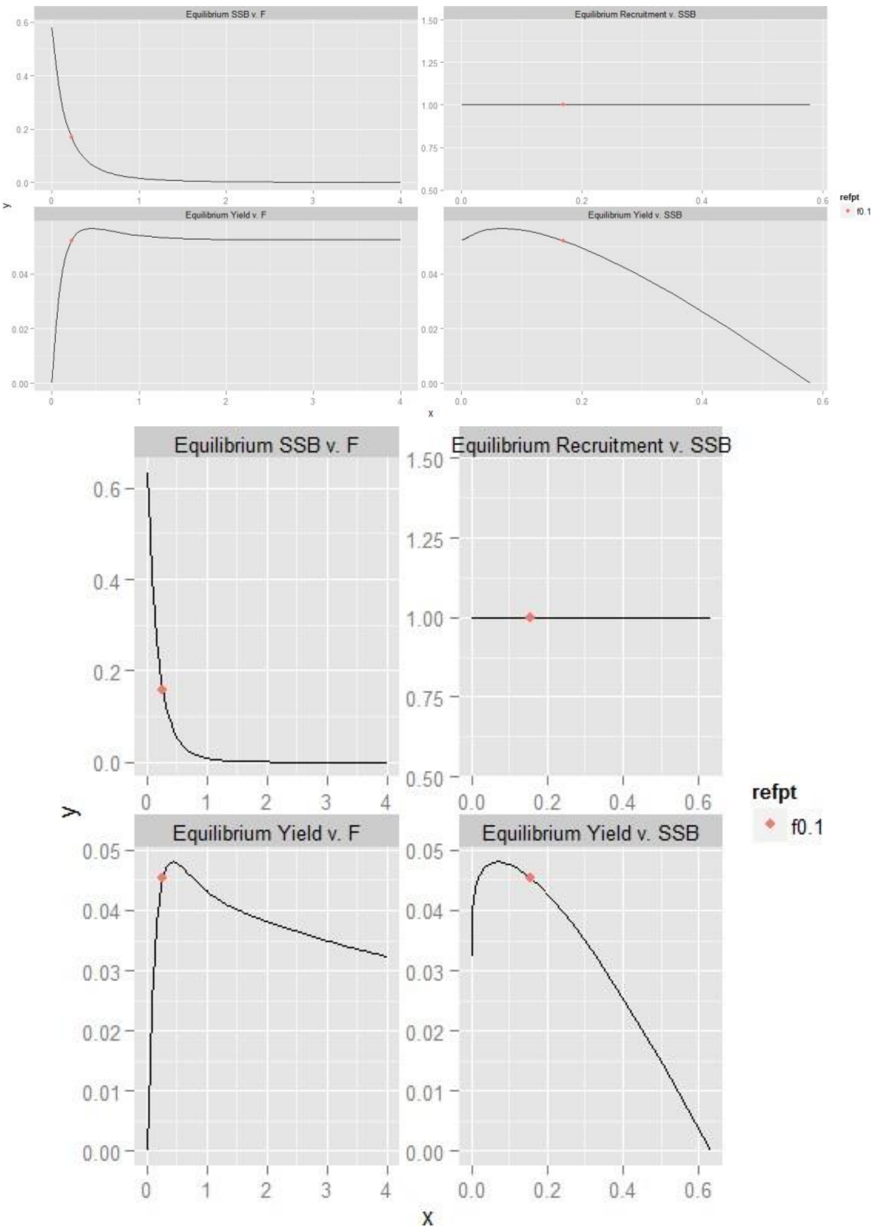


Figure 20 - Yield per Recruit analyses for XSA (above) and SS3 (below)

Table 7.1 - Yield per Recruit outputs for XSA and SCAA.

	Current F ($F_{BAR\ 1\text{-}4}$)	Reference Points	Harvest	Yield/R	SSB/R	Total biomass/R
XSA	1.20	$F_{0.1}$	0.24	0.052	0.17	0.229
		F_{max}	0.45	0.057	0.06	0.11
SS3	0.41	$F_{0.1}$	0.26	0.045	0.16	0.21
		F_{max}	0.43	0.048	0.072	0.16

8 Draft scientific advice

Considering the results of XSA and SCAA analyses, it can be concluded that the resource is overfished. A reduction of fishing mortality is recommended. SSB shows general stable trends in the XSA run, while the SCAA showed a clear increasing trend of SSB in the last 3-4 years. It is important to point out that the absolute values of XSA are underestimated due to the use of a costant catchability at the older ages. Differently, the SS3 model allows the assumption of a dome-shaped population selection curve, which determines more reliable values of SSB if compared with the historical yields. Nevertheless the clear decreasing pattern of SSB observed in the SCAA analysis since the beginning of the series appears quite alarming, considering that at the moment the level of SSB is less than the 33th percentile.

The group believes that, due to the reasons expressed in paragraph before, the more accurate methodology to assess the stock is the SCAA carried out with SS3. The calculation of reference point has been updated according to the new methodology applied and the value proposed is $F_{0.1} \leq 0.30$ as proxy for F_{MSY}. Such value is little bit higher than the historical value presented in the previous years ($F_{0.1}$ = 0.26). Given the results of the present analysis, (current F is around 0.35 as the average of the last 3 years), the stock appeared to be subject to overfishing.

GFCM-WGSAD recommends to reduce the fishing mortality towards the proposed reference point FMSY. Considering the intermediate overfishing and low biomass situation of the sole stock in GSA 17 a reduction of fishing effort and an improvement in exploitation pattern is advisable, especially of Italian rapido trawlers and gillnetters, which mainly exploit juveniles.

GFCM-WGSAD considered that the best option to reduce effort and improve the exploitation pattern for sole in GSA 17, would be to continue and increment the closure for rapido trawling within 6 nm of the Italian coast especially during the summer-fall period (June- December).

GFCM-WGSAD noted that in recent years, some Italian artisanal fleets fish with gill net in the main spawning area during periods when trawling is prohibited. Additional measures to restrict exploitation of sole in the spawning area are desirable, to afford further protection to the Adriatic sole stock.

The scientific advices in the following table are based on the SCAA using SS3 model results.

Based on	Indicator	Analytic al reference point (name and value)	Current value from the analysis (name and value)	Empirical reference value (name and value)	Trend (time period)	Stock Status
Fishing mortality	Fishing mortality	($F_{0.1}$ = 0.26, F_{max}= 0.43)	0.41		D	IO_I
Stock abundance	Biomass	5263 (SSB from SS3)	6568 (SSB from SS3)	33_{th} percentile:	I	O_L
Recruitment					C	
Final Diagnosis		Intermediate overfishing and low biomass				

8.1 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)*