Stock Assessment Form of Red Mullet in GSA 20

Reference period: 1994-2017

Reporting year: 2018

Red mullet (*Mullus barbatus*) is one of the main target species of the demersal fisheries, particularly the bottom trawlers, in the Ionian waters (GSA-20) with annual landings in the reference period varying between 200-400 tons. The stock status is assessed using FAO production data and abundance indices obtained from the MEDITS trawl surveys during the 1994-2016 period. The assessment was based on a surplus production model carried out with the SPiCT package under the R language environment, using custom made scripts. Results show that the stock is sustainably exploited and the current F is well below F_{msy} levels.

Stock Assessment Form version 1.0 (January 2014)

Uploader: *G. Tserpes*

Stock assessment form

1. Basic Identification Data

Scientific name:	Common name:	ISCAAP Group:
Mullus barbatus	[Red mullet]	[MUT]
1st Geographical sub-area:	**2nd Geographical sub-area:**	**3rd Geographical sub-area:**
[GSA_20]		
4th Geographical sub-area:	**5th Geographical sub-area:**	**6th Geographical sub-area:**
1st Country	**2nd Country**	**3rd Country**
Greece		
4th Country	**5th Country**	**6th Country**
Stock assessment method: (direct, indirect, combined, none)		
Indirect: Biomass model (SPICT)		
Authors:		
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Hellenic Centre for Marine Research (HCMR) - Institute of Marine Biological Resources and Inland Waters		

The ISSCAAP code is assigned according to the FAO 'International Standard Statistical Classification for Aquatic Animals and Plants' (ISSCAAP) which divides commercial species into 50 groups on the basis of their taxonomic, ecological and economic characteristics. This can be provided by the GFCM secretariat if needed. A list of groups can be found here:

http://www.fao.org/fishery/collection/asfis/en

Direct methods (you can choose more than one):

- Trawl survey

Indirect method (you can choose more than one):

- Biomass models

2. Stock identification and biological information

2.1 Stock unit

GSA 20 has been considered as a unique area for management purposes.

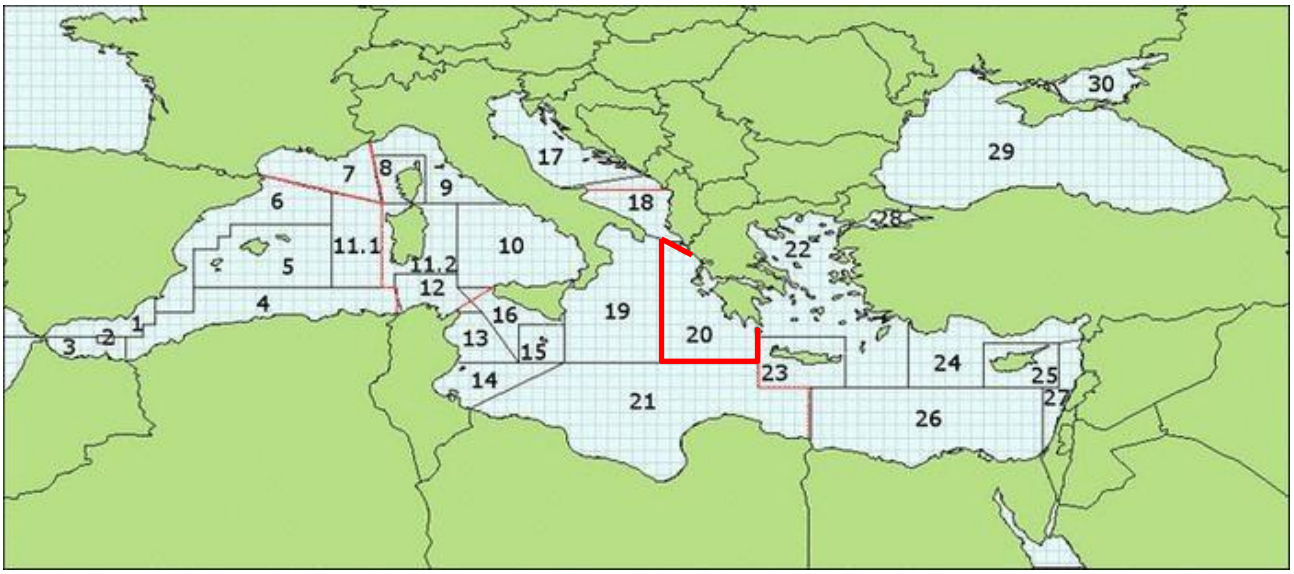


Figure 2.1-1. FAO Geographical Subdivisions (GSAs). *GSA20 delineated in red.*

2.2 Growth and maturity

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

Somatic magnitude measured (LT)				**Units**	Cm
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	Late spring-early summer
Maximum size observed			31	**Recruitment season**	October-November
Size at first maturity	9			**Spawning area**	Continental shelf
Recruitment size to the fishery	8			**Nursery area**	Coastal areas

Table 2- 2.2: M vector and proportion of matures by size or age (sexes combined).

Age	Natural mortality	Proportion of matures
0	1	0.16
1	0.61	0.92
2	0.54	1
3+	0.5	1

Table 2- 3: Growth and length weight model parameters.

			Sex			
		Units	**female**	**male**	**Combined**	**Years**
Growth model	**L_∞**	cm			27.7	
	K	y-1			0.23	
	t_0	y			-1.16	
	Data source					
Length weight relationship	**a**	g/cm^b			0.0083	
	b	-			3.1134	
	M (scalar)					
	sex ratio (% females/total)					

3. Fisheries information

3.1 Description of the fleet

Red mullet is exploited by bottom trawlers and various artisanal fisheries using gillnets. Most catches are coming from the Greek fleets exploiting the area and the majority originates from bottom trawlers (~70%). The Greek bottom trawl fishery has multi-species characteristics and similarly to most Mediterranean demersal trawl fisheries, captures more than 100 commercial species. However, few species, such as red mullets, hake and shrimps compose the main bulk of landings, with red mullet being one of the most important targets.

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*	GRC	20	E-Trawl (12-24 meters)	03 - Trawls	33 - Demersal shelf species	MUT
Operational Unit 2	GRC	20	F-Trawl (>24 meters)	03 - Trawls	33 - Demersal shelf species	MUT
Operational Unit 3	GRC	20	M - Polyvalent (12-24 metres)	07 - Nets	33- Demersal shelf species	MUT
Operational Unit 4	GRC	20	B - Minor gear with engine (<6 metres)	07 - Gillnets and entagling nets	34 - Demersal shelf species	MUT
Operational Unit 5	GRC	20	C - Minor gear with engine (6-12 metres)	07 - Gillnets and entagling nets	34 - Demersal shelf species	MUT

3.2 Historical trends

Landings in the reference period (1994-2016) are mostly between 200-400t (Figure 3.2-1).

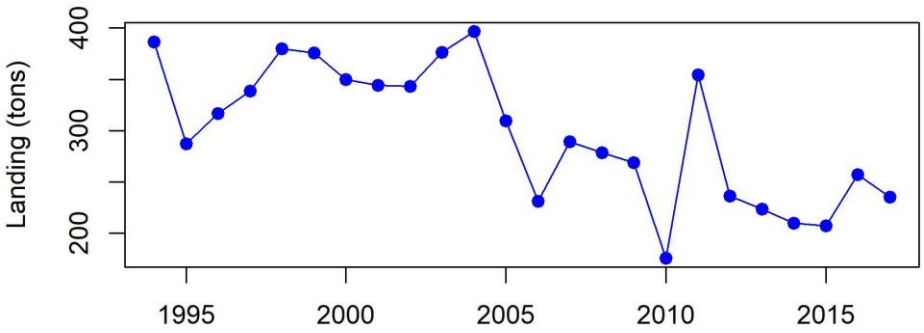


Figure 3.2-1: Time series of landings (tons) of red mullet in GSA20 according to FAO statistics.

Table 3.2- 1: Total landings (tons) of red mullet by year in GSA20 according to FAO statistics.

Year	Landings
1994	386.2
1995	287.1
1996	316.7
1997	338.4
1998	380
1999	376
2000	350
2001	344
2002	343.1
2003	376.2
2004	396.7
2005	309.8
2006	231
2007	289.3
2008	278.5
2009	268.9
2010	175.8
2011	354.2
2012	236.1
2013	223.7
2014	209.5
2015	207.3
2016	257.1
2017	235

3.3 Management regulations

As with all demersal fisheries in GSA 20, those catching red mullet are managed according to EU regulation 1967/2006, which include spatial fishery closures for the bottom trawlers, gear configuration specifications and minimum landing sizes. Additional national measures include a temporal (4.5 months) closure of the bottom trawl fisheries accompanied by certain localized spatio-temporal closures.

3.4 Reference points

Fishing mortality and biomass reference points based on the F/F_{msy} and B/B_{msy} ratios were adopted in the frame of the EU adopted Management plan for bottom trawlers (Anonymous, 2013). A rate equal to one was considered as a target for both ratios.

Anonymous, 2013. Management Plan for the Greek Bottom Trawl Fisheries. EU Ref. Ares(2013) 548016 - 05/04/2013, (https://tinyurl.com/kb6qfzv)

Table 3.4-1: List of reference points and empirical reference values previously agreed.

Indicator	Limit Reference point/empirical reference value	Value	Target Reference point/empirical reference value	Value	Comments
B			B/Bmsy	1	
SSB					
F			F/Fmsy	1	
Y					
CPUE					
Index of Biomass at sea					

4. Fisheries independent information

4.1 MEDITS Trawl Survey

4.1.1 Brief description of the direct method used

The "MEDITS" bottom trawl surveys are accomplished in GSA 20 since 1994 on an annual basis. However, no surveys were accomplished in 2003, 2009-2013 and in 2015. Sampling includes sampling in 43 pre-defined stations following a standardized protocol. Trawling was made by means of a standard net GOC 73 having a cod-end mesh opening of 20 mm and selection of stations was based on a depth-stratified sampling scheme that included five depth zones: 10-50, 50-100, 100-200, 200-500 and 500-800 m. Collected data included number, weight, gonad maturation stage and total length measurements for a wide range of fish, cephalopod and crustacean species (MEDITS Handbook v9, 2017). From the collected data, standardized abundance indexes by year, expressed in terms of kg per square km of swept area (kg/km^2), were calculated for red mullet.

Table 4.1- 1: Trawl survey basic information.

Survey	MEDITS	**Trawler/RV**	
Sampling season	Summer		
Sampling design	Depth stratified random sampling		
Sampler (gear used)	GOC-73		
Cod –end mesh size as opening in mm	20		
Investigated depth range (m)	30-800		

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

Stratum	Total surface (km^2)	Trawlable surface (km^2)	Swept area (km^2)	Number of hauls
10-50	2916			6
50-100	4365			11
100-200	2536			7
200-500	3158			9
500-800	3848			10
Total	16823			43

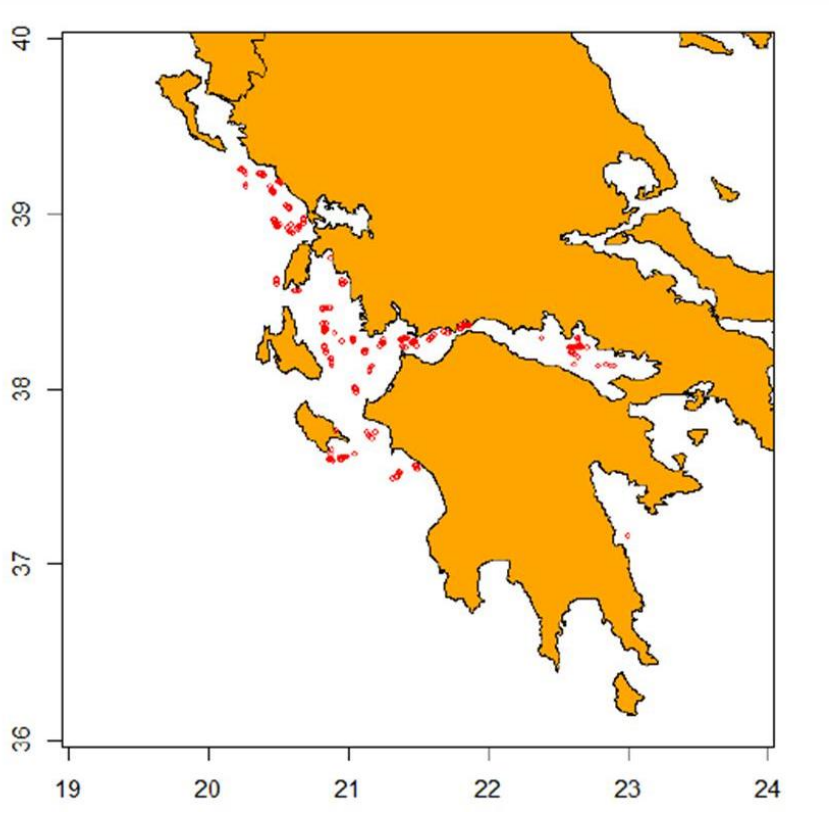


Fig. 4.1-1 MEDITS stations in GSA 20.

Table 4.1- 3: Trawl survey abundance and biomass results.

Depth Stratum	Years	kg per km^2	CV or other	N per km^2	CV or other
	1994	14.70			
	1995	9.08			
	1996	7.54			
	1997	13.60			
	1998	32.44			
	1999	28.90			
	2000	16.30			
	2001	47.96			
	2003	31.20			
	2004	47.28			
	2005	51.79			
	2006	32.58			
	2008	49.95			
	2014	28.59			
	2016	49.04			
Total (… – … m)	……				

4.1.2 Spatial distribution of the resources

4.1.3 Historical trends

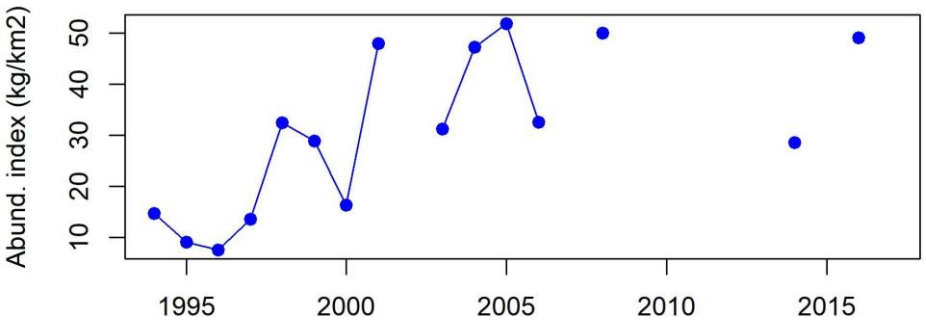


Fig. 4.1.3-1 Abundance time series from the MEDITS survey in kg/km^2 for red mullet in GSA20.

5. Ecological information

5.1 Protected species potentially affected by the fisheries

5.2 Environmental indexes

6. Stock Assessment

6.1 Surplus production model with SPiCT

Stock assessment was based on a surplus production model which was implemented with the SPiCT package in R environment. SPiCT does a state-space implementation of the Pella-Tomlinson surplus production model in continuous time, which assumes that both the biomass (process equation) and survey index equation (observation equation) are subject to errors. Additionally, SPiCT assumes that the catch equation is subject to error.

Pedersen MW and CW Berg (2017) A stochastic surplus production model in continuous time. *Fish and Fisheries*, **18**: 226–243.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

6.1.1 Model assumptions

Surplus production models aim to predict the biomass and exploitation level of stocks in cases where catch-at-age data are not available. The data required to fit the model are a time series of catches and a time series of effort or abundance indices. The model assumes that the rate of change of the total biomass is a function of the net biomass added or removed from the population through the processes of recruitment, growth and natural mortality (surplus production) and the biomass removed through fishing (the catch). The surplus production is the result of a constant density-independent growth rate, *r* (which incorporates recruitment, growth and natural mortality) and a density-dependent term that reduces the rate of growth when the biomass approaches the carrying capacity, K. The catch removed from the population is assumed to be proportional to the current biomass, B, and the fishing mortality, F. A second equation links the survey abundance index time series with the biomass equation, assuming that the abundance index is proportional to the biomass through a constant coefficient *q* that represents the catchability.

6.1.2 Scripts

The R scripts used are available for downloading from: https://tinyurl.com/yclxbjsx

6.1.3 Input data and Parameters

The input data are the time series of landings from 1994-2017 and a time series of abundance indices from the MEDITS trawl survey (1994-2016) (Table 6.1.3-1). The abundance index time series has a number of missing values, i.e. years when the sampling did not take place. Initially the fits were performed using default SPiCT parameterization, which did not converge. To achieve convergence, the assessment was repeated using a Schafer production curve (i.e. fixing n=2). A number of different model fits were investigated, keeping n=2 and exploring combinations of two other factors: a) use a prior for the growth rate and c) interpolate to fill in the missing records of the abundance index time series. A prior estimate of growth rate was determined using the demographic method of Krebs, utilizing literature data on fecundity, maturity and mortality (Table 6.1.3-2).

Interpolation was done in R 3.4.2 with na.interpolation function of the imputeTS package (Moritz 2017) with method “stine”. All other SPiCT parameters were set to default.

Table 6.1.3-1 Landings and abundance index by year for red mullet in GSA 20.

Year	Landings (tones)	Abundance index	Interpolated Abund. index
1994	386.2	14.7	14.7
1995	287.1	9.1	9.1
1996	316.7	7.5	7.5
1997	338.4	13.6	13.6
1998	380	32.4	32.4
1999	376	28.9	28.9
2000	350	16.3	16.3
2001	344	48.0	48.0
2002	343.1	-	39.6
2003	376.2	31.2	31.2
2004	396.7	47.3	47.3
2005	309.8	51.8	51.8
2006	231	32.6	32.6
2007	289.3	-	41.3
2008	278.5	49.9	49.9
2009	268.9	-	49.0
2010	175.8	-	44.9
2011	354.2	-	39.3
2012	236.1	-	33.7
2013	223.7	-	29.7
2014	209.5	28.6	28.6
2015	207.3	-	34.1
2016	257.1	49.0	49.0
2017	235	-	49.0

Table 6.1.3-2 Input parameters and model settings forred mullet in GSA 20.

	μ (mean of the log)	σ (std of the log)	Mean	Sd
r	-0.25	0.44	0.86	0.4

Moritz S. 2017. imputeTS: Time Series Missing Value Imputation. R package version 2.5. https://CRAN.R-project.org/package=imputeTS

6.1.4 Results

All fits produced very similar results in terms of stock status (see section 6.1.7). The fit with prior *r* was considered the best fit by the group and is presented below (Figure 6.1.4-2, Table 6.1.4-1 and Table 6.1.4-2). Residual analysis didn’t show any significant patters or bias and no significant deviation from normality (Fig. 6.1.4-3). The assessment indicates that the red mullet stock is exploited in a sustainable way and current (2017) F is well below F_{msy} (Table 6.1.4-1 and Fig. 6.1.4-2).

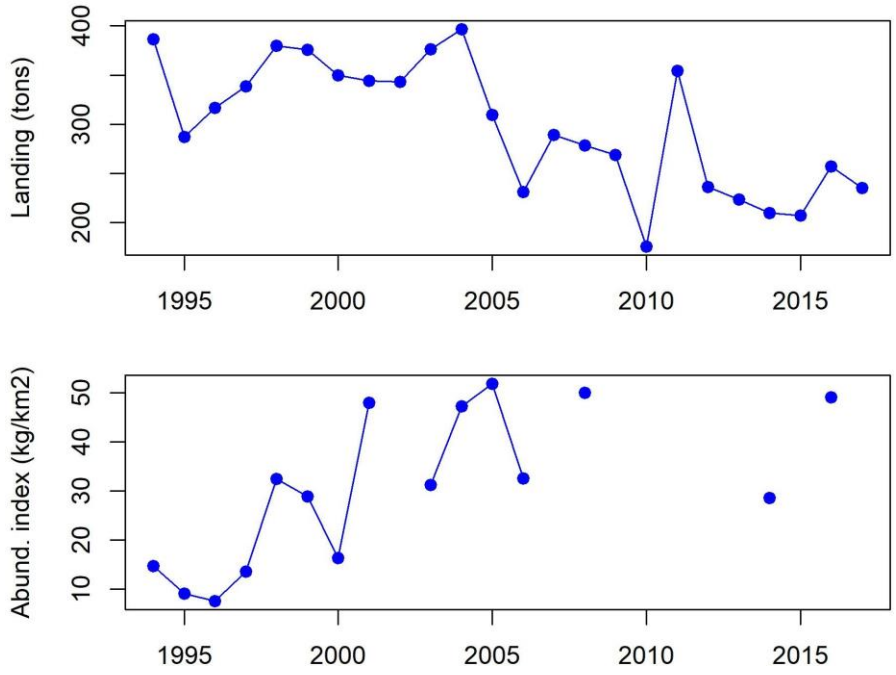


Fig. 6.1.4-1 Red mullet in GSA 20. Annual FAO landings and abundance indexes from the MEDITS surveys.

Table 6.1.4-1. Average estimates of model parameters. The last two columns indicate relative biomass and fishing mortality levels in 2017.

K	r	MSY	Bmsy	Fmsy	BBmsy	FFmsy
1558	1.250	481	771	0.62	1.74	0.29

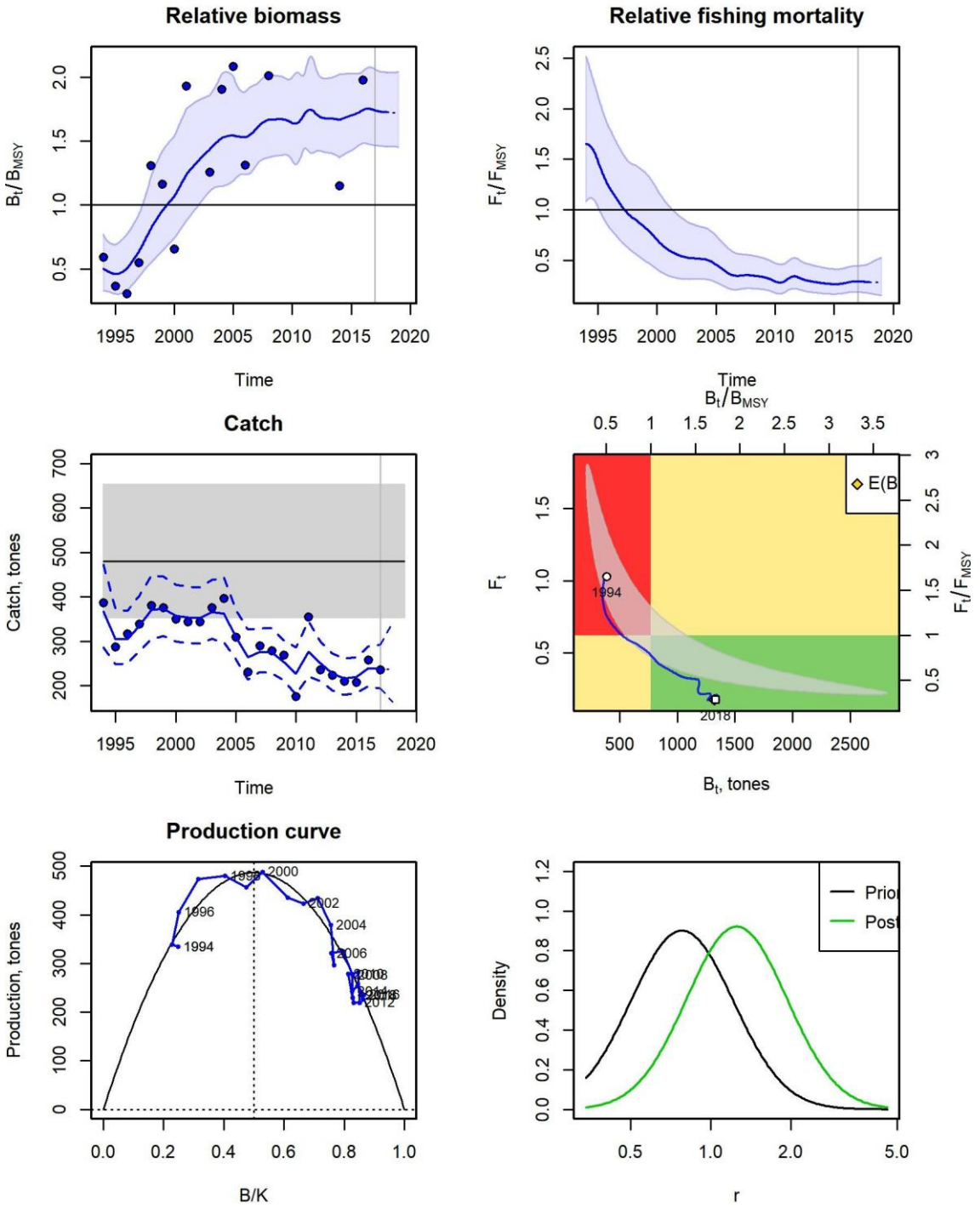


Fig. 6.1.4-2. Stock assessment results for red mullet in GSA-20. Upper row: Median (blue solid line) of relative biomass and relative fishing mortality with 95% CI (blue shaded area). Middle row: Observed (blue points) and estimated catch with 95% CIs (left) and Kobe plot of relative fishing mortality versus relative biomass (right). Bottom row:) Production curve (left) and comparison of prior and posterior distributions of the n parameter, which determines the shape of the production curve in the Pella-Tomlinson model (right).

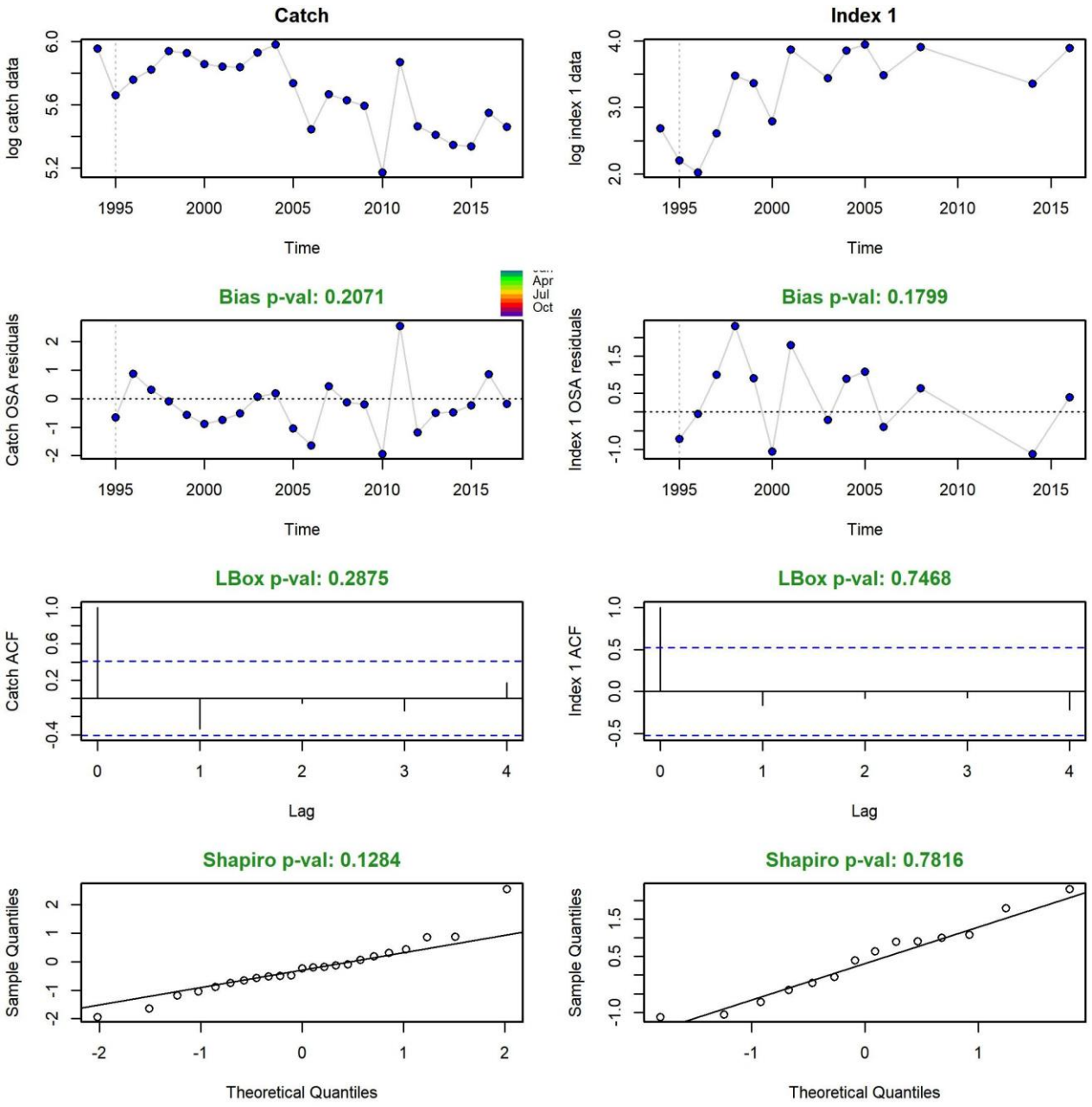


Fig. 6.1.4-3Diagnostic test of the fit for the residuals of the catch and abundance index series. Log of input data series (first row), residuals plot (second row), autocorrelation of residuals (third row) and normality of residuals (fourth row). If the header is green the test is not significant, otherwise the header is red.

Table 6.1.4-2 Estimated biomass and fishing mortality for red mullet in GSA20 with upper and lower 95%CIs.

Year	B (t)	Upper limit	Lower limit	F(t)	Upper limit	Lower limit
1994	387.072	964.961	155.265	1.028	3.091	0.342
1995	354.173	1103.392	113.684	0.921	2.781	0.305
1996	388.691	1279.185	118.107	0.756	2.314	0.247
1997	490.265	1513.373	158.824	0.646	1.935	0.216
1998	628.928	1839.327	215.052	0.571	1.683	0.194
1999	738.550	2156.917	252.887	0.513	1.537	0.171
2000	823.113	2438.066	277.891	0.438	1.319	0.146
2001	954.132	2761.742	329.635	0.374	1.117	0.125
2002	1036.442	3023.841	355.248	0.338	1.010	0.113
2003	1107.653	3264.705	375.806	0.323	0.960	0.109
2004	1176.169	3520.631	392.934	0.317	0.944	0.106
2005	1192.740	3588.332	396.460	0.285	0.865	0.094
2006	1180.279	3542.244	393.270	0.234	0.716	0.076
2007	1237.243	3646.326	419.812	0.216	0.650	0.071
2008	1287.558	3781.347	438.417	0.217	0.649	0.073
2009	1289.635	3806.418	436.935	0.207	0.623	0.069
2010	1266.943	3778.451	424.815	0.181	0.550	0.059
2011	1318.453	3862.619	450.036	0.191	0.571	0.064
2012	1324.312	3927.221	446.576	0.205	0.615	0.068
2013	1293.865	3824.332	437.746	0.181	0.546	0.060
2014	1286.133	3800.286	435.267	0.169	0.510	0.056
2015	1313.349	3841.825	448.975	0.163	0.489	0.055
2016	1347.235	3927.539	462.132	0.172	0.512	0.058
2017	1343.497	3969.527	454.710	0.179	0.539	0.060

6.1.5 Robustness analysis

The robustness of the model fit was assessed by checking the sensitivity of the fit to the initial values of the parameters, using the SPiCT function check.ini() with ntrials=50. From the 50 runs, 8 did not converge, 41 resulted to the same parameter estimates (i.e. those of Table 6.1.4-1), and 1 resulted in different parameter estimates (which however was unrealistic as the carrying capacity estimate was well below the observed landings). Hence, the model fit is considered robust.

6.1.6 Retrospective analysis

Retrospective plots show consistent trends of relative biomass and relative fishing mortality among the different runs, with very small deviation between the runs suggesting model/data consistency and robustness of the results (Fig. 6.1.6-1).

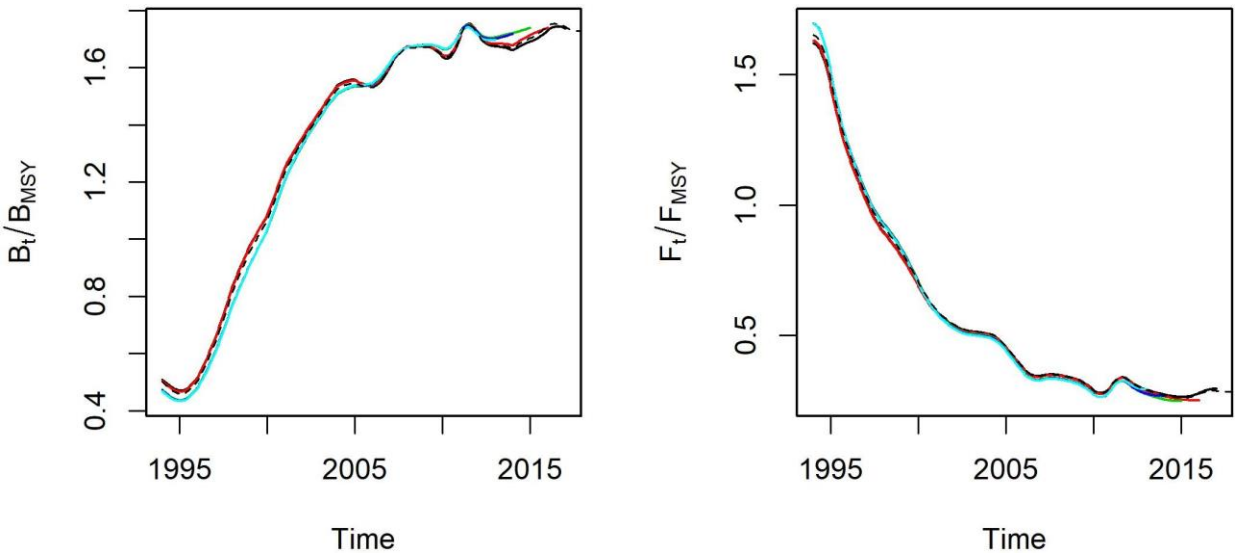
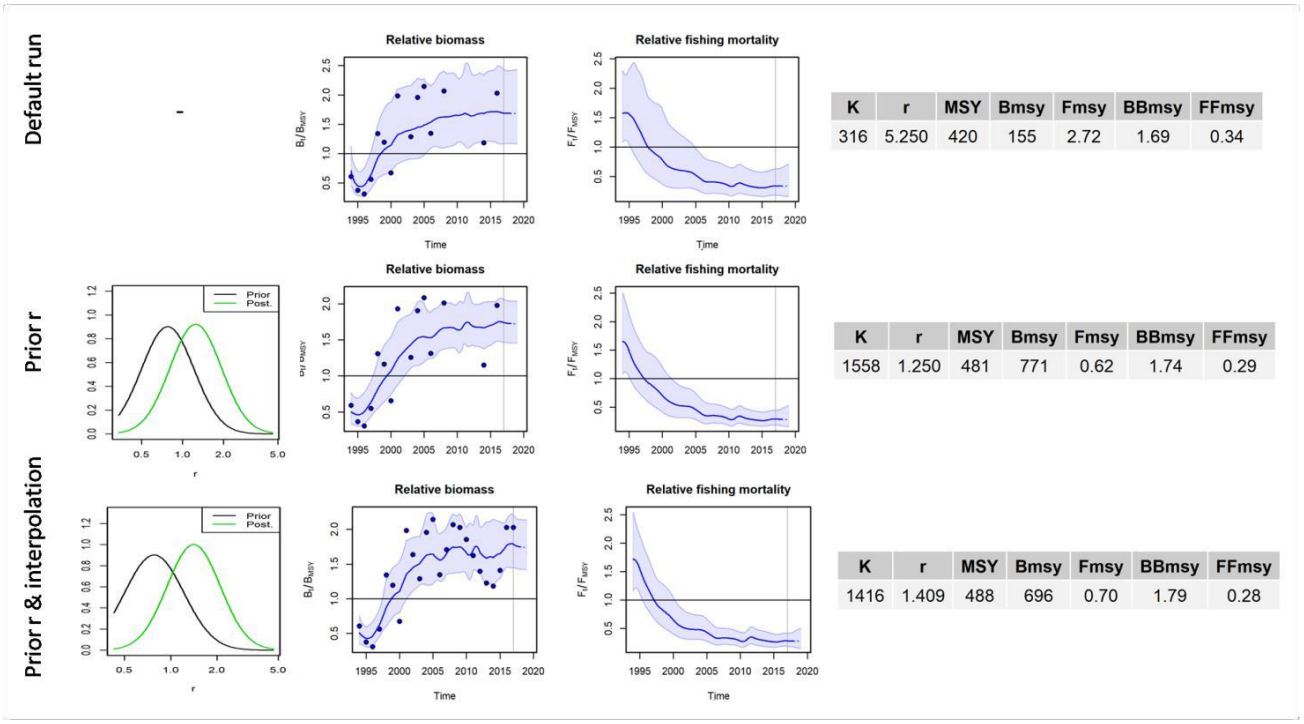


Fig.6.1.6-1 Retrospective plots of relative biomass and relative fishing mortality for red mullet, produced by repeating the stock assessment after excluding 1 (black line) to 5 (cyan line) final year observations of the catch and abundance index time series. The dotted black lines are the estimates when the full time series is considered.

6.1.7 Assessment quality

The assessment was considered stable, as all model fits converged to the same output in terms of stock status. Below, a comparison between three fits is presented. Apart from the *r*, *K* pair estimates, all other parameter estimates deviate slightly between model runs. Note that the run with default parameters gives an unrealistically high estimate or growth rate (r=5.25) and an estimate of *MSY* that is above the carrying capacity (K). For this reason, the use of a prior for *r* in the assessment was considered necessary.



K	r	MSY	Bmsy	Fmsy	BBmsy	FFmsy
316	5.250	420	155	2.72	1.69	0.34

K	r	MSY	Bmsy	Fmsy	BBmsy	FFmsy
1558	1.250	481	771	0.62	1.74	0.29

K	r	MSY	Bmsy	Fmsy	BBmsy	FFmsy
1416	1.409	488	696	0.70	1.79	0.28

Fig.6.1.7-1 Comparison between three model fits. From top to bottom: fit with default parameters, fit with a prior for r and fit with a prior for r and interpolation of the abundance index time series. From left to right: prior and posterior distributions of r, observed (points) and predicted relative biomass (median with 95%CI), predicted relative fishing mortality (median with 95%CI) and table with median value of estimated parameters. Note that n was fixed to 2 in all cases (Schaefer production curve).

7. Stock predictions

7.1 Short term predictions

7.2 Medium term predictions

7.3 Long term predictions

8. Draft scientific advice

Based on	Indicator	Analytic al reference point (name and value)	Current value from the analysis (name and value)	Empirical reference value (name and value)	Trend (time period)	Stock Status
Fishing mortality	Fishing mortality	$F/F_{msy}=1$	0.29		D	S
Stock abundance	Biomass	$B/B_{msy}=1$	1.78		I	S
Recruitment						
Final Diagnosis		The stock has healthy biomass and is exploited in a sustainable way				

The stock of red mullet in GSA20 was assessed with a surplus production model using SPiCT. The assessment was robust to different parameterizations, assumptions regarding the growth rate and to removing 1 to 5 last observations (retrospective analysis). The diagnosis is that the stock is sustainably exploited with biomass above the reference level (B_{msy}) and fishing mortality below the reference level (F_{msy}).

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)*