Stock Assessment Form

Demersal species

Reference year:2019

Reporting year:2020

STOCK ASSESSMENT OF *Lophius budegassa* IN GSA17

The Black-bellied angler (*Lophius budegassa*) is widespread in the Adriatic Sea, mostly in the Croatian channel regions and in the open sea. Although widely distributed, this resource is not abundant and it is fished primarily with bottom trawl nets. Catches were available for Croatia from 2009 onward, while Italian data were available from 1953. Different catch reconstructions were attempted and tested for sensitivity analysis. Survey data gathered from MEDITS survey, from 1994 to 2019, showed a peak of biomass in 2004 followed by a steep decline. Biomass trend started to rise again in the last three year of the timeseries. CMSY production model indicates that biomass trend remained stable until the mid of the '80s, then it faced a steep decline resulting in B< B_{msy} in 1989. In following years, the B trend raised again until 2002, when it started to decline and went below the B_{msy} in 2011. During the last years the B trend stabilized around 0.9 B_{msy}. Exploitation pattern remained stable until the beginning of the '80s, then it sharply rose and spiked in 1987 at F/Fmsy = 1.25. In following years, the F trend declined until 1998, when it returned to values comparable to the first part of the series. From 1999 onward, the F trend restarted to rose and continued almost linearly until 2019, which registered the highest value of the timeseries. Therefore, the advice would be to fishing mortality to improve the status of the stock in term of biomass. Due to large data uncertainties, these results should be taken as qualitative.

Stock Assessment Form version 1.0 (April 2021)

Uploader: *Enrico Nicola Armelloni*

Stock assessment form

1 Basic Identification Data

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

Anglerfishes (*Lophius piscatorius* Linnaeus, 1758 and *Lophius budegassa* Spinola, 1807) are some of the target species of the Mediterranean multi-species trawl fishery (Ungaro et al. 2002). They are distributed throughout the Mediterranean basin as well as in the eastern Atlantic (Fisher et al. 1987). Both species are widespread in the entire Adriatic Sea, while the black-bellied angler (*L. budegassa)* is by far the more abundant one (Vrgoč et al. 2004). Although widely distributed, this resource is not abundant and it is fished primarily with bottom trawl nets, which catches mainly consist of immature specimens (Ungaro et al. 2002). *L. budegassa* is a benthic species found between the continental shelf and the upper slope down to 1000 m depth, it prefers sandy and muddy bottom (SIBM 2017) but its distribution is more influenced by depth than by the sediment type (Vrgoč et al. 2004). In the Adriatic Sea it is more abundant in the north-eastern edge of the Pomo/Jabuka Pit and in the transitive areas towards the channels (Vrgoč et al. 2004). *L. budegassa* is a specialized ichthyophagous predator with ambush behavior that attracts potential prey with the modified first ray of the dorsal fin that acts as a lure (Stagioni et al. 2013). Depth preference is size-dependent, with juveniles more abundant in shallow waters. This factor also influence prey preferences: juveniles mostly feed on small benthic fishes (such as mullidae) whereas adults prefers gadoids (Stagioni et al. 2013). Despite its high commercial value, there is still a significant lack of information about black anglerfish in the Adriatic Sea, biological information is scattered and in the last decades just a few studies dealt with distribution (Ikica et al. 2015), growth (La Mesa and De Rossi 2008) and feeding habits (Stagioni et al. 2013).

2.1 Stock unit

Basing on the best available information, there are not enough data to describe the stock unit characteristics of *Lophius budegassa* in the Adriatic Sea. Therefore, the present stock assessment was performed on a single GSA, which is the reference management unit in the GFCM context.

2.2 Growth and maturity

The spawning season for *L. budegassa* in the Adriatic Sea lasts at least from February to June (La Mesa and De Rossi 2008). The feature to spawn over several months is reflected in an extended hatching period of the pelagic larvae which experienced very different environmental conditions, causing high variability of individual early growth rate. The identification of distinct modal class within recruiting specimens is therefore challenging, however La Mesa and De Rossi (2008) studied growth parameters though otolith microstructure and hypothesized that *L. budegassa* settled before 80 days of age, a period considerably shorter than for *L. piscatorius* (approximately 120 days). A geographic gradient is observed in size composition of *L. budegassa* populations along the Mediterranean Sea, with the smallest specimens more abundant in the eastern areas (<30 cm) (Ungaro et al. 2002; Carlucci et al. 2009). A wide variety of factors could be on the basis of these differences, from distinct environmental conditions (e.g. oceanography and bottom topography) to different levels of fishing exploitation along the whole Mediterranean area (Ungaro et al. 2002). In the Adriatic Sea the most recent information comes from ikica et al. ((Ikica et al. 2015)), which found 70 cm as maximum size and confirms a predominance of small individuals. (Vrgoč et al. 2004) reports a size at first maturity of 33-34 cm, while (Ikica et al. 2015) estimated as 26.26 cm for males and 30.5 for females.

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

Somatic magnitude measured (LT, LC, etc)			ML	**Units**	cm
Sex	**Fem**	**Mal**	**Combined**	**Reproduction season**	Winter - Spring – Summer (La Mesa and De Rossi 2008)
Maximum size observed	67 (Ikica et al. 2015)	48.4 (Ikica et al. 2015)	67 (Ikica et al. 2015)	**Recruitment season**	Summer-Fall
Size at first maturity	30.5 (Ikica et al. 2015)	26.26 (Ikica et al. 2015)	-	**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_∞**				57.60 (SIBM 2017)	
	K				0.09 (SIBM 2017)	
	t_0					
	Data source					
Length weight relationship	**a**				0.123 (Vrgoč et al. 2004)	
	b				3.024 (Vrgoč et al. 2004)	
	M (scalar)					
	sex ratio (% females/total)					

3 Fisheries information

3.1 Description of the fleet

Like in many areas of the Mediterranean Sea (Ungaro et al. 2002), Anglerfish in the Adriatic Sea (**Table 3.1-1**) is targeted by demersal bottom trawl fleet (Vrgoč et al. 2004) and, mostly on the Croatian side, also by gillnets (STECF 2020). Lack of data is a critical issue for the assessment of *L. budegassa*, and LFDs are available only for the bottom trawl fleet. There are also no available estimates of discards, however small specimens represent a consistent portion of landings (**Figure 1**) so in the present assessment it will be assumed catches are equal to landings.

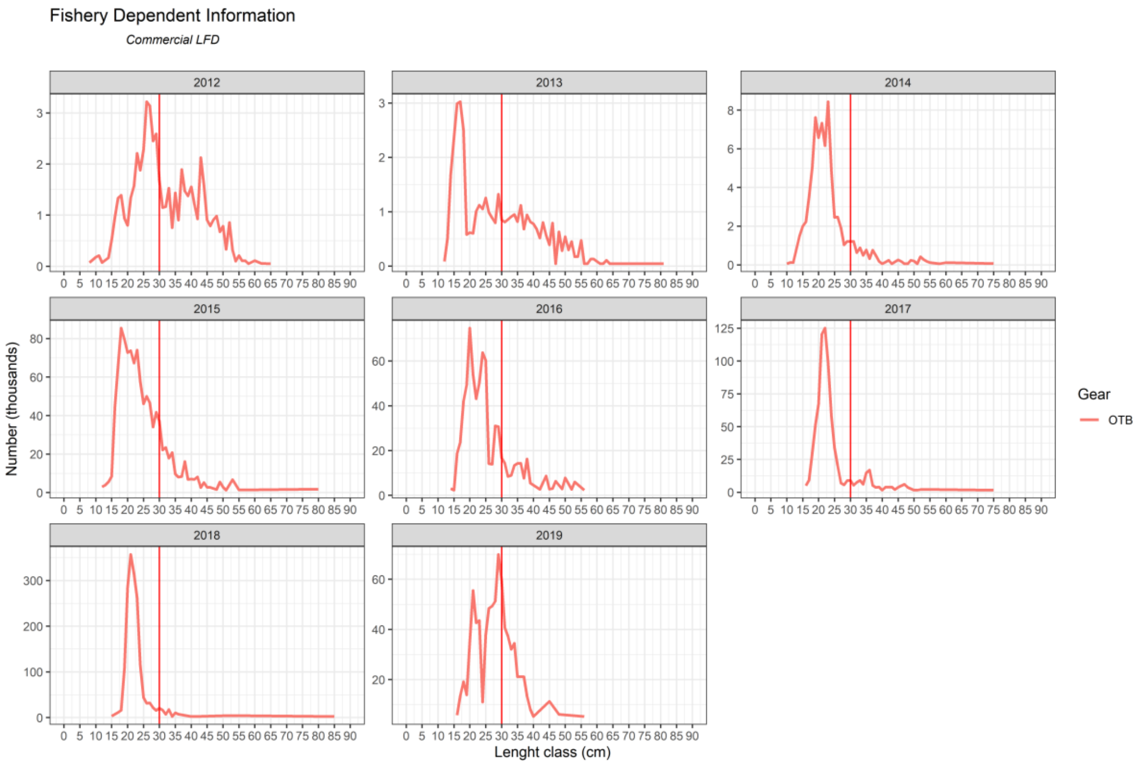

Figure 1 Length frequencies distributions of the Italian landings by gear in GSA 17. Source: DCF 2019 Italian data call. Vertical red line indicates size at first maturity.

Table 3.1-1: Description of operational units exploiting the stock

	Country	GSA	Fleet Segment	Fishing Gear Class	Group of Target Species	Species
Operational Unit 1	ITA	17	E - Trawl (12-24 metres)	98 - Other Gear (rapido trawl)	33 - Demersal shelf species	
	ITA	17		Otter trawl		

Operational Unit 2			E - Trawl (12-24 metres)		33 - Demersal shelf species	
Operational Unit 3	ITA	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets Traps	33 - Demersal shelf species	
Operational Unit 4	HRV	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	
Operational Unit 5	SVN	17	C - Minor gear with engine (6-12 metres)	07 - Gillnets and Entangling Nets	33 - Demersal shelf species	
Operational Unit 6	HRV	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	
Operational Unit 7	SVN	17	E - Trawl (12-24 metres)	Otter trawl	33 - Demersal shelf species	

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

Operational Units*	Fleet (n° of boats)*	Catch (T of the species assessed)	Other species caught (names and weight)	Discards (species assessed)	Discards (other species caught)	Effort (days at sea)
Operational Unit 1		22.88				
Operational Unit 2		406.1				
Operational Unit 3		1.96				
Operational Unit 4		9.95				
Operational Unit 5		0.04				
Operational Unit 6		83.39				
Operational Unit 7		0.04				
Total		524.36				

3.2 *Historical trends*

Landings dataset was reconstructed by exploring different data source (**Errore. L'origine riferimento non è stata trovata.**), however it should be considered that reliability can differ among countries and period considered due to changes in the level of accuracy of fishery statistic reporting (Mannini and Massa 2000). In most of the cases the catch data for *L. budegassa* were not available or confounded with *L. piscatorius*: in **Figure 2** is shown the landing trend by species, where it is possible to observe some improbable oscillation in the proportion of *L. budegassa* and *L. piscatorius*. Since the ratio between *L. piscatorius* and *L. budegassa* in MEDITS data was almost steadily 1:9 (**Figure 5**, section 4), catches for *Lophius spp.* were considered to be representative of *L. budegassa.* Nonetheless, this assumption was tested within the sensitivity analysis (more details in section 6.1.5).Total catches for *Lophius spp*. (**Figure 3**) were gathered as follows: for the Italian side data from 1972 to 1999 were obtained from Fortibuoni et al. (2018), which digitalized Italian official data for the considered period. For the period 2000-2003 the data were provided by the Italian government and for the period 2004-2018 data were available from the EU DCF (Data call Med). For the Croatian side, data from 2009 to 2011 were available from FishstatJ (FAO 2017) and from 2012 to 2019 from STECF (2020).

Due to different fisheries restriction imposed in the past (personal communication) was not possible to reconstruct Croatian missing landings. However, the magnitude of Croatian catches was not negligible, so it was necessary to identify an expedient to estimate the potential effect of alternative catch trajectories. To obtain the data for a sensitivity analysis, ten different timeseries for Croatian landings were simulated as random walks catch trajectories, taking as starting value (x_t) the observed catches for Croatia in 2009 and simulating x_{t-1} as $x_t + w_t$, where w_t comes from a normal distribution with mean = 0 and standard deviation = standard deviation in Croatian catches in the available data (**Figure 4**). More details on data reconstruction and on the sensitivity analysis are given in section 6.1.5.

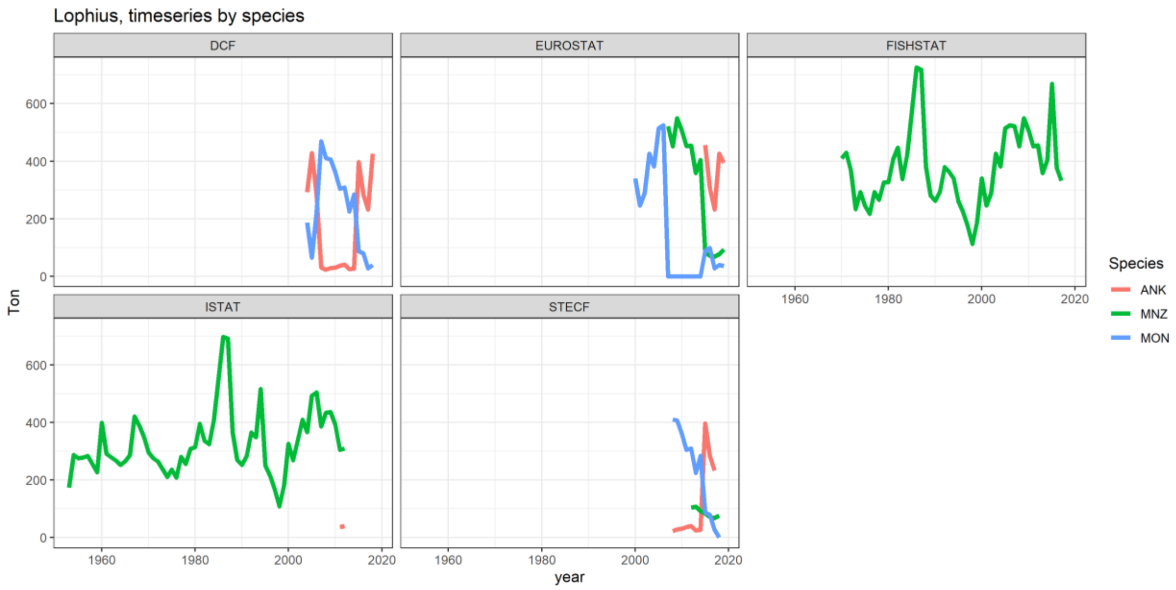

Figure 2*:* in the panels are shown annual landings by data source, with colors indicating the reference species: MNZ stands for *Lophius spp*.; ANK for *Lophius budegassa,* MON for *Lophius*

piscatorius.

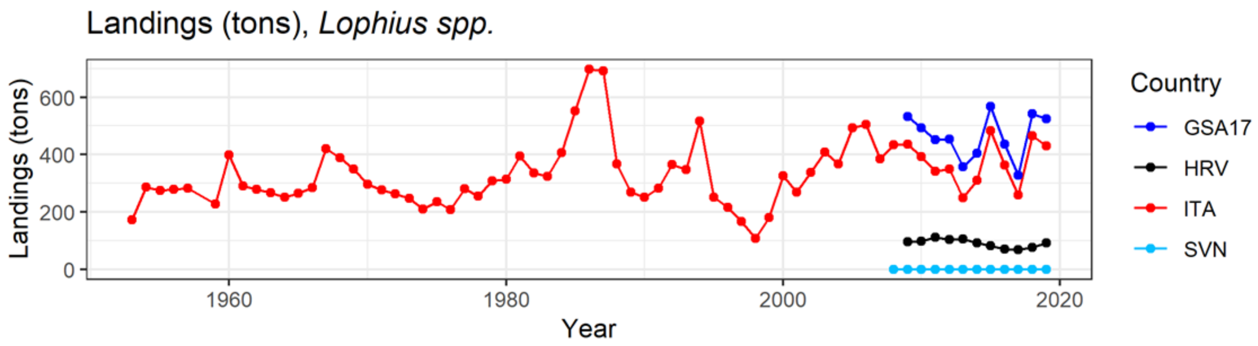

Figure 3: aggregated landings timeseries for *Lophius spp.* in GSA 17

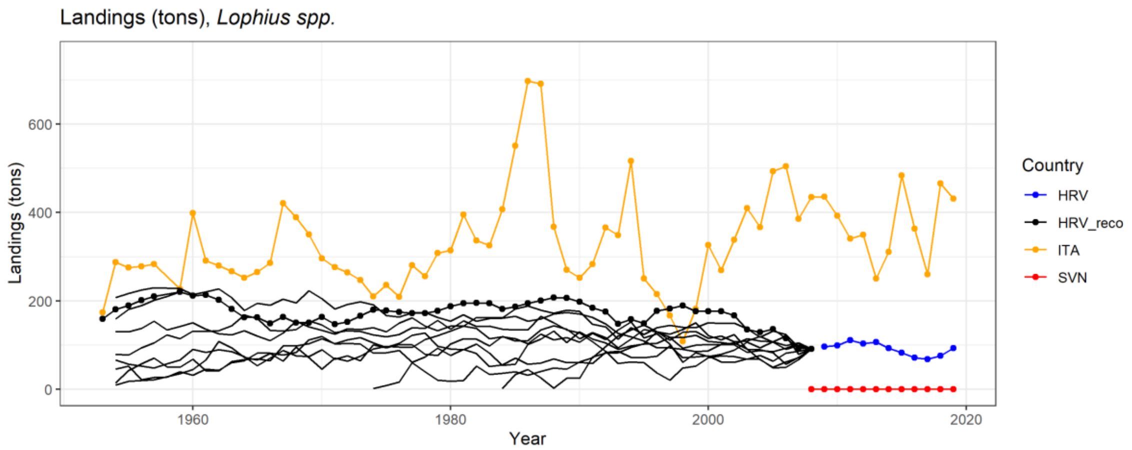

Figure 4*:* aggregated landings timeseries for *Lophius spp.* in GSA 17 and random walk simulation for Croatian landings (black lines)

3.3 Management regulations

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

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

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

- Minimum of 45 days of absolute ban during summer, whitin a period varying according to maritime compartments (Fully observed).

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

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

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			B_{MSY}		
SSB					
F			F_{MSY}		
Y					
CPUE					
Index of Biomass at sea					

4 Fisheries independent information

MEDITS survey data (**Figure 5**) were available from the official Data call for GSA 17 from 1994. All the Countries are covered by the survey data. For the present assessment the data from 1994 to 2019 were used. The long duration and the shift in the survey time in some years (Italy) was considered of not having a great influence on *L. budegassa*, due to its extended spawning period. The proportion between *L. budegassa* and *L. piscatorius* is provided in support to the decision to merge catch data for these species.

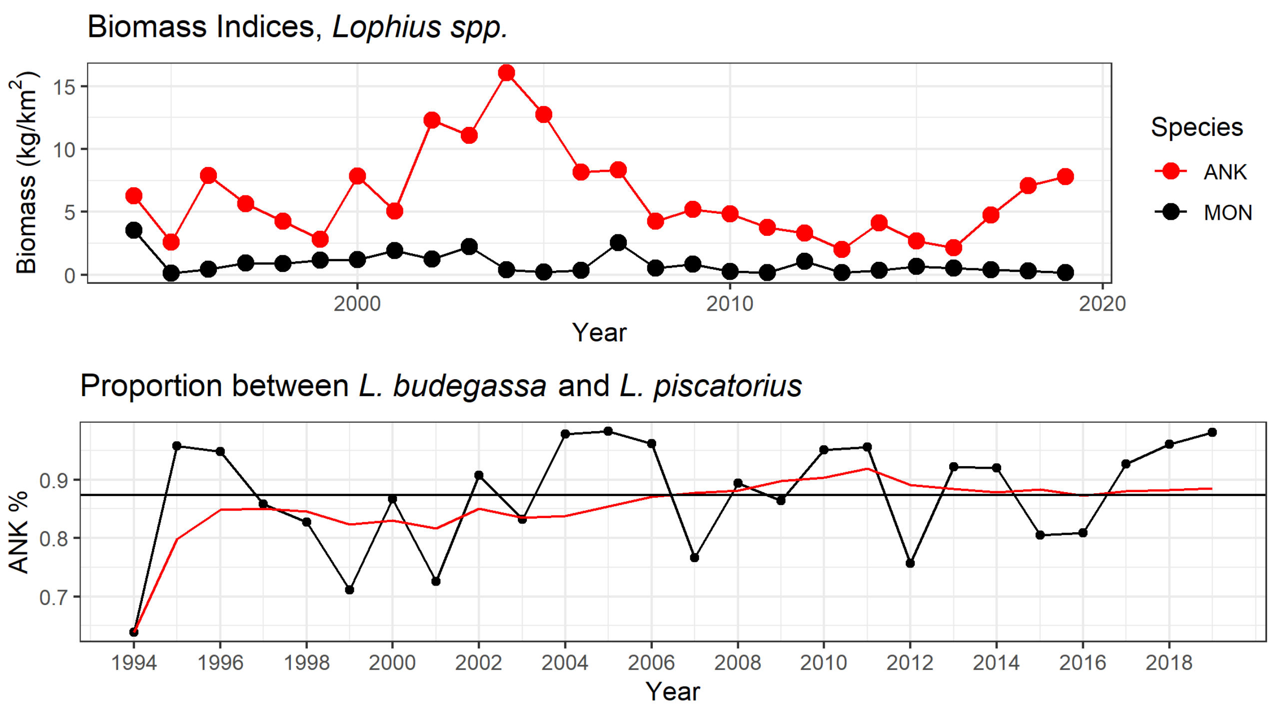

Figure 5: (top panel) MEDITS biomass Indices for L. *budegassa* (ANK) and L. *piscatorius* (MON); (low panel) annual ratio of L. *budegassa* (ANK) biomass over *Lophius spp*. biomass

5 Ecological information

5.1 Protected species potentially affected by the fisheries

No list of protected species that can be potentially affected by the fishery is currently available.

5.2 Environmental indexes

There is currently no evidence for any environmental index to be relevant for the fishery.

6 Stock Assessment

6.1 C-MSY

6.1.1 Model assumptions

CMSY (Froese et al. 2017) is a Monte-Carlo method that estimates fisheries reference points (MSY, F_{MSY}, B_{MSY}) as well as relative stock size (B/B_{MSY}) and exploitation (F/F_{MSY}) from catch data, CPUE timeseries and broad priors for resilience or productivity (r) and for stock status (B/k) at the beginning and the end of the time series. Probable ranges for the maximum intrinsic rate of population increase (r) and for unexploited population size or carrying capacity (k) are filtered with a Monte Carlo approach to detect 'viable' r-k pairs. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors.

The CMSY version referred in the present assessment (CMSY_2019_8q.R, available at http://oceanrep.geomar.de/33076/) is newer than the one used in Froese et al. (2017). The main differences are faster execution because of parallel processing, new diagnostic plots and more emphasis on management by the addition of the Kobe plot.

6.1.2 Priors selection

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

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

- Resilience: priors were obtained from the database SeaLifeBase (Palomares and Pauly).
- Exploitation (Initial and medium): a summary of the status of the fishery in the Adriatic Sea is available from several sources. Basing on the reliability of the author, the trends provided in Marini et al. (2017) were taken as baseline to derive the exploitation status at the beginning of the timeseries, which was set as "Low depletion" in 1953 and "Medium depletion" in 1994.
- Exploitation (Final): this prior was set equal to the output of another Bayesian model: AMSY (Froese et al. 2020). AMSY is a Bayesian Surplus production model, which can provide information on stock status (depletion) using CPUE data. Required input data for AMSY are (1) time-series of cpue, (timeseries 1994-2019 for MEDITS Biomass trend) , (2) prior ranges for r (information from SeaLifeBase) and (3) relative stock size Bt/k in a given year, set as 0.5-0.85 in year 2004 basing on catches trend.

6.1.3 Input data and Parameters

Detail on reconstruction of dataset are given in paragraph 3.2. For the present assessment, the timeseries considered included years from 1953 to 2019 (**Figure *6***). Biomass data were provided by MEDITS surveys, carried out in fall for the years 1994-2019 (**Errore. L'origine riferimento non è stata trovata.**). Priors obtained with methodology explained in par. 6.1.2 are resumed in the **Table** 6.1.3.1.

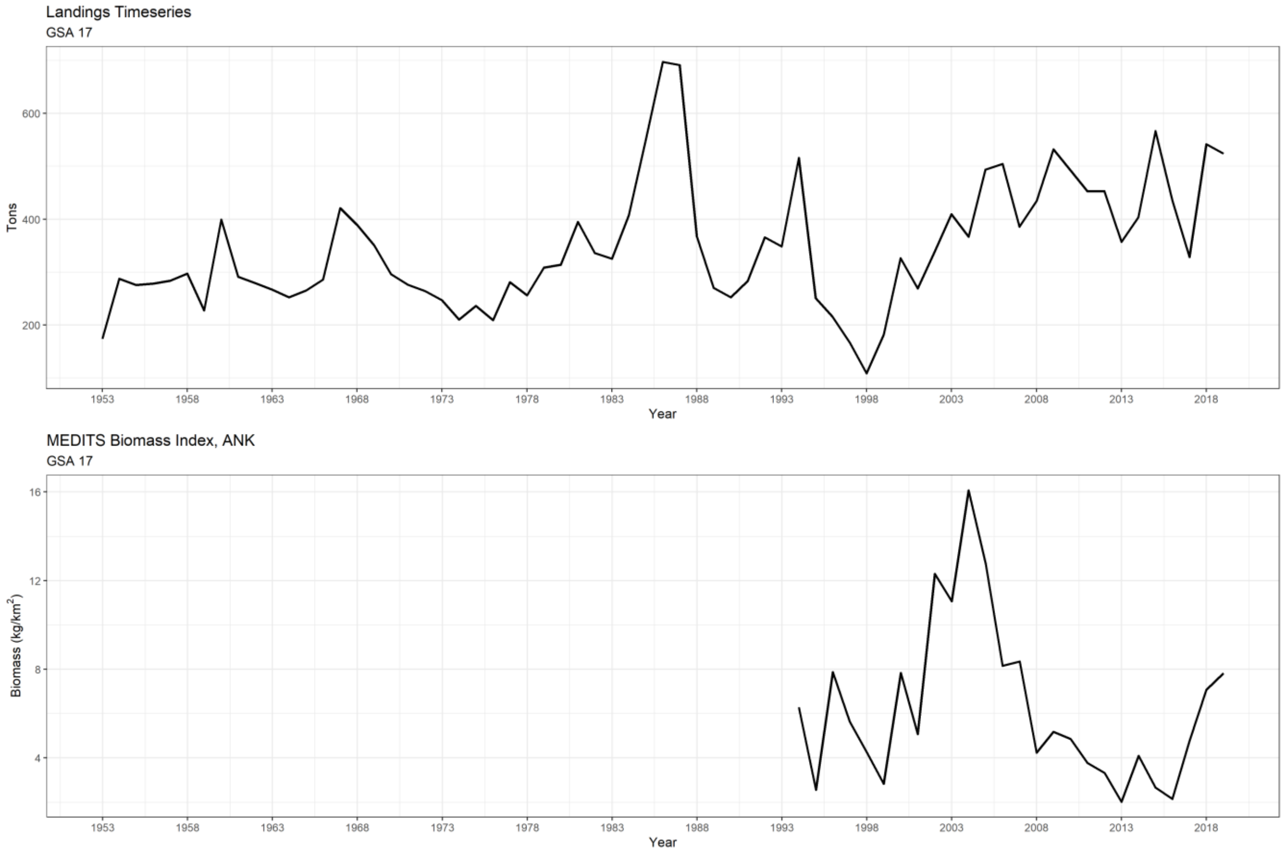

Figure 6: a) Landings data (tons) used in C-MSY model; b) CPUE index used in C-MSY model

Table 6.1.3-1 Model priors

Species	Min of year / Start year	Max of year / End year	Resilience	Stb.low	Stb.hi	Int.yr	Intb.low	Intb.hi	Endb.low	Endb.hi	btype
Black bellied Anglerfish	1953	2019	0.25-0.66	0.6	0.9	1994	0.2	0.6	0.2	0.68	CPUE

6.1.4 Model results

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

```
-------------------------------------
Species: Lophius budegassa , stock: ANK
Lophius spp.
Region: Mediterranean Sea , North Adriatic Sea
Catch data used from years 1953 - 2019 , abundance = CPUE
Prior initial relative biomass = 0.6 - 0.9 expert
Prior intermediate rel. biomass= 0.2 - 0.6 in year 1994 expert
Prior final relative biomass   = 0.2 - 0.68 expert
Prior range for r = 0.25 - 0.66 expert, , prior range for k = 2.68 - 8.03
Prior range of q = 0.00185 - 0.006 , assumed effort creep 0.2 %

Results of CMSY analysis
-------------------------
Altogether 54235 viable trajectories for 10143  r-k pairs were found
r   = 0.466 , 95% CL = 0.319 - 0.681 , k = 3.67 , 95% CL = 2.57 - 5.24
MSY = 0.427 , 95% CL = 0.348 - 0.514
Relative biomass in last year = 0.461 k, 2.5th perc = 0.224 , 97.5th perc = 0.652
Exploitation F/(r/2) in last year = 1.33 , 2.5th perc = 0.941 , 97.5th perc = 2.74

Results from Bayesian Schaefer model (BSM) using catch & CPUE
---------------------------------------------------------
q   = 0.0025 , lcl = 0.00172 , ucl = 0.00363
r   = 0.442 , 95% CL = 0.301 - 0.651 , k = 3.73 , 95% CL = 2.68 - 5.19 , r-k log correlation = -0.919
MSY = 0.412 , 95% CL = 0.353 - 0.481
Relative biomass in last year = 0.449 k, 2.5th perc = 0.258 , 97.5th perc = 0.661
Exploitation F/(r/2) in last year = 1.38 , 2.5th perc = 0.829 , 97.5th perc = 2.64

Results for Management (based on BSM analysis)
---------------------------------------------------------
Fmsy = 0.221 , 95% CL = 0.15 - 0.325 (if B > 1/2 Bmsy then Fmsy = 0.5 r)
Fmsy = 0.221 , 95% CL = 0.15 - 0.325 (r and Fmsy are linearly reduced if B < 1/2 Bmsy)
MSY  = 0.412 , 95% CL = 0.353 - 0.481
Bmsy = 1.86 , 95% CL = 1.34 - 2.59
Biomass in last year = 1.67 , 2.5th perc = 0.962 , 97.5 perc = 2.46
B/Bmsy in last year  = 0.897 , 2.5th perc = 0.516 , 97.5 perc = 1.32
Fishing mortality in last year = 0.305 , 2.5th perc = 0.207 , 97.5 perc = 0.529
Exploitation F/Fmsy  = 1.38 , 2.5th perc = 0.829 , 97.5 perc = 2.64
Comment: NA
--------------------------------------------------------
```

Figure 7 shows the diagnostic panels. The good overlap of the blue (CMSY) and red (BSM) crosses (panels B and C) and lines (panels D and E) support the coherence between stock trajectories estimated by the BSM (based on Catches + CPUE) and by the CMSY model (Catch only model). In panel D the trajectories estimated by CMSY and BSM are consistent along the years, indicating a very similar value for the last year.

Figure 8 shows the comparison between priors and posterior understanding of the model. The posterior distribution for K was narrower in comparison to the priors, and resulting small prior to posterior variance ratio (PPVR) indicate that the input data was very informative about K. Regarding r the plot indicates a good agreement between the density distributions, however the larger PPVR value indicates that the data were not informative about r as they were about K. Prior for initial and final depletion are also within the prior interval, while the prior for intermediate depletion went above the upper boundary of the prior distribution.

Figure 9 shows additional information on model diagnostic, included in the last version of CMSY. The catch fit is good, whereas the CPUE fit present some issues. In particular, the CPUE trend (MEDITS survey biomass index) was so oscillatory that the most extremes values (in particular 2008 and 2010) were not properly caught, resulting in the red coloration of the right lower panel.

Figure 10 shows the graphs meant to inform management. The catch trajectory compared to the MSY (left upper panel) show that the catches in recent years were above the Maximum Sustainable Yeld, and the stock size is shrinking below B_{MSY}. Exploitation level is raising accordingly, and from 2010 onward it was continuously above the F_{MSY} reference point.

Figure 11 represent the Kobe plot. The timeseries begun in the 1950's when the biomass quite above the B_{MSY}. During the period considered, the effort level was highly oscillatory and were observed high spikes followed by period of lower impact, causing recursive pattern of stock size erosion and recovery. However, in recent years the F level steadily raised above the F_{MSY}, causing an erosion of the biomass that went below the reference point. As a consequence, in 2019 the stock trajectory is located in the red panel (with 69 % of probabilities).

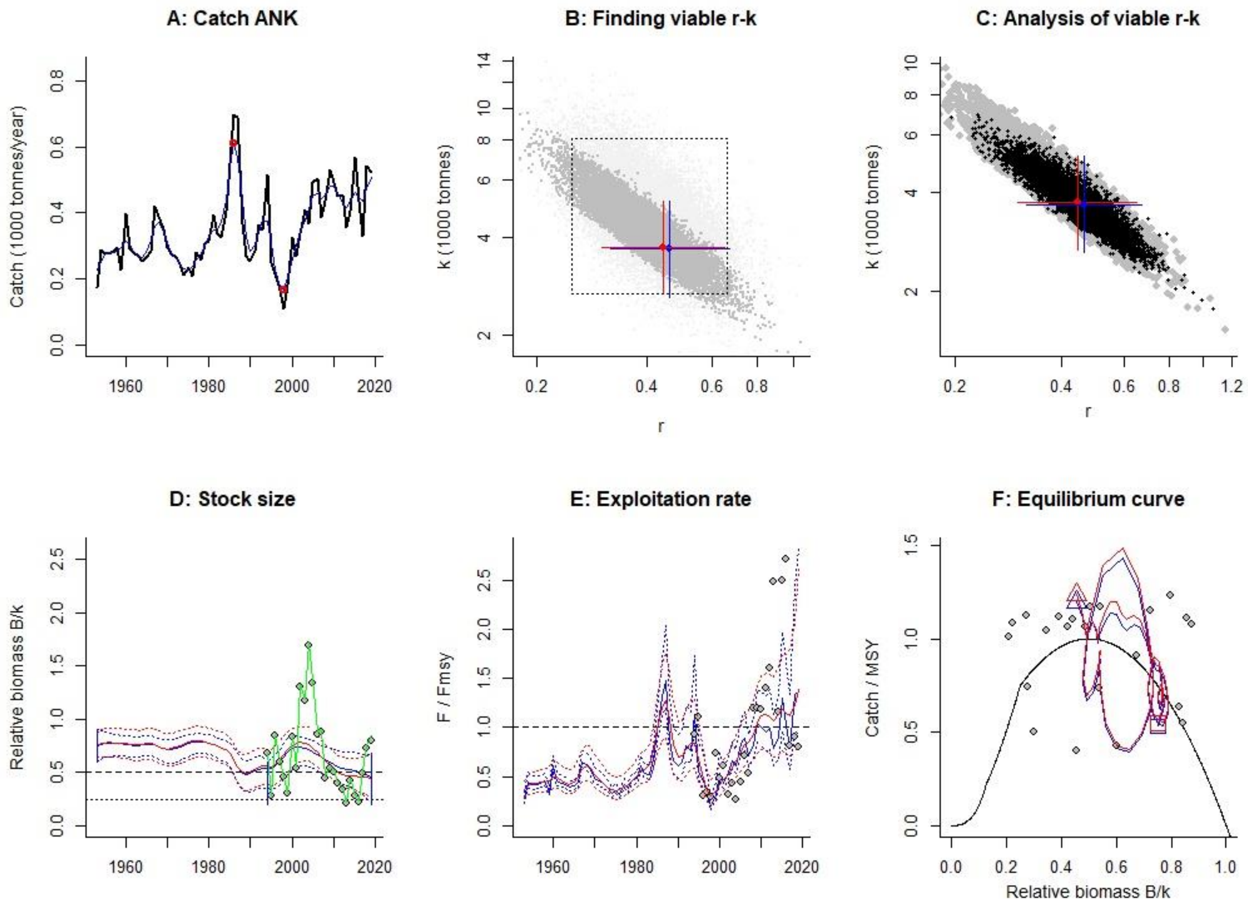

Figure 7: Diagnostics results of final C-MSY run. **Panel A** shows in black the time series of catches and in blue the three-years moving average with indication of highest and lowest catch, as used in the estimation of prior biomass by the default rules. **Panel B** shows the explored multivariate normal distribution of r-k in log space and in dark grey the r-k pairs which were found by the model to be compatible with the catches and the prior information. The dotted rectangle indicates the range of the priors provided in the ID file. The blue cross is the most likely r-k pair predicted by CMSY, and the red cross predicted by BSM. **Panel C** shows the most probable r-k pair and its approximate 95% confidence limits in blue. The black dots are possible r-k pairs found by the BSM model, with a red cross indicating the most probable r-k pair and its 95% confidence limits. **Panel D** shows the available abundance data in red, scaled to the BSM estimate of B_{MSY} = 0.5 k, and in blue the biomass trajectory estimated by CMSY. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. **Panel E** shows in red the harvest rate (catch/abundance) scaled to the r/2 estimate of BSM, and in blue the corresponding harvest rate from CMSY. **Panel F** shows the Schaefer equilibrium curve of catch/MSY relative to B/k, here indented at B/k < 0.25 to account for reduced recruitment at low stock sizes. The red dots are scaled by BSM estimates and the blue dots are scaled by CMSY estimates.

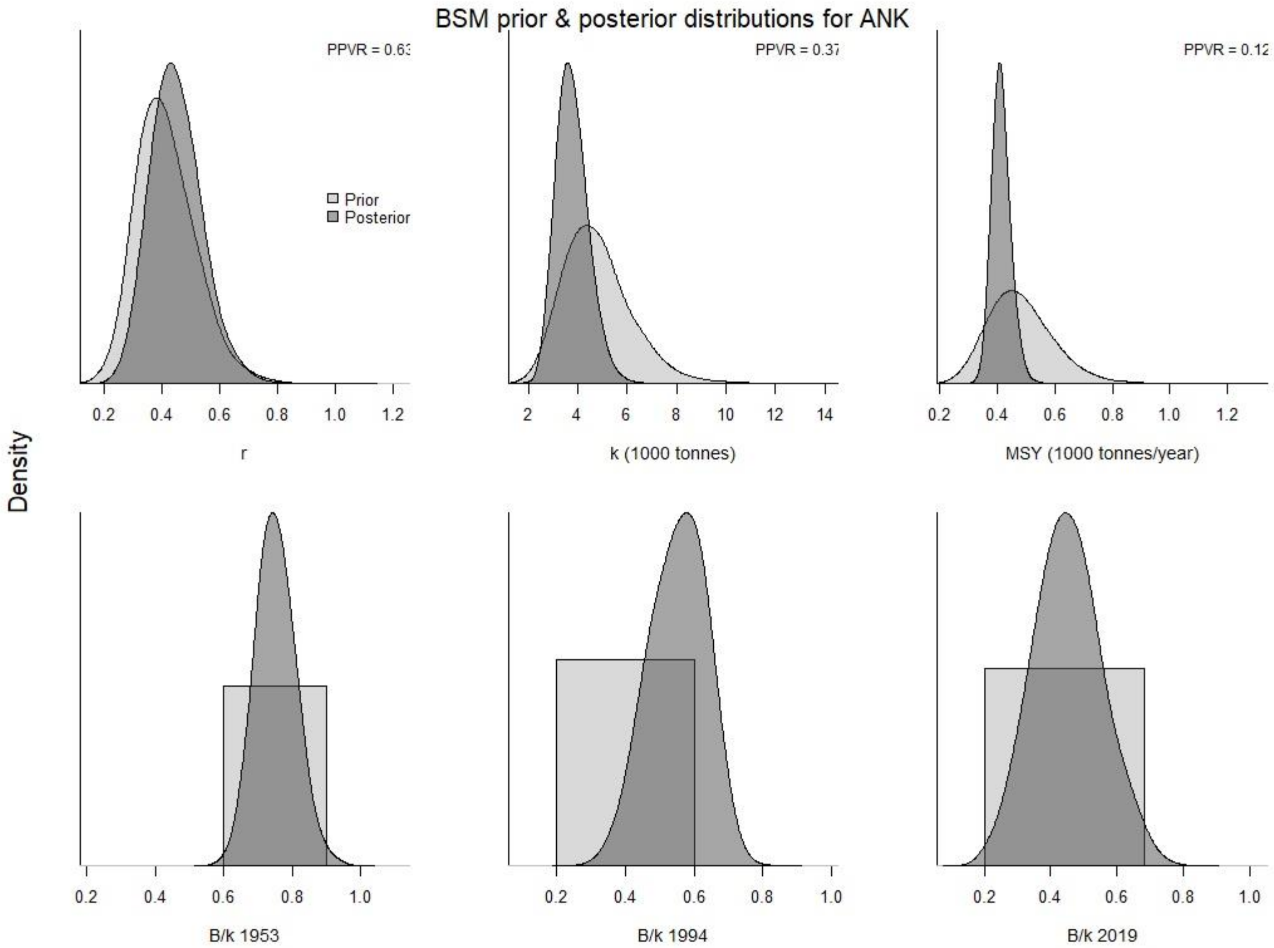

Figure 8: Marginal posterior distributions along with prior densities. The lower the prior-posterior variance ratio (PPVR), the more the posterior knowledge is improved relative to prior knowledge

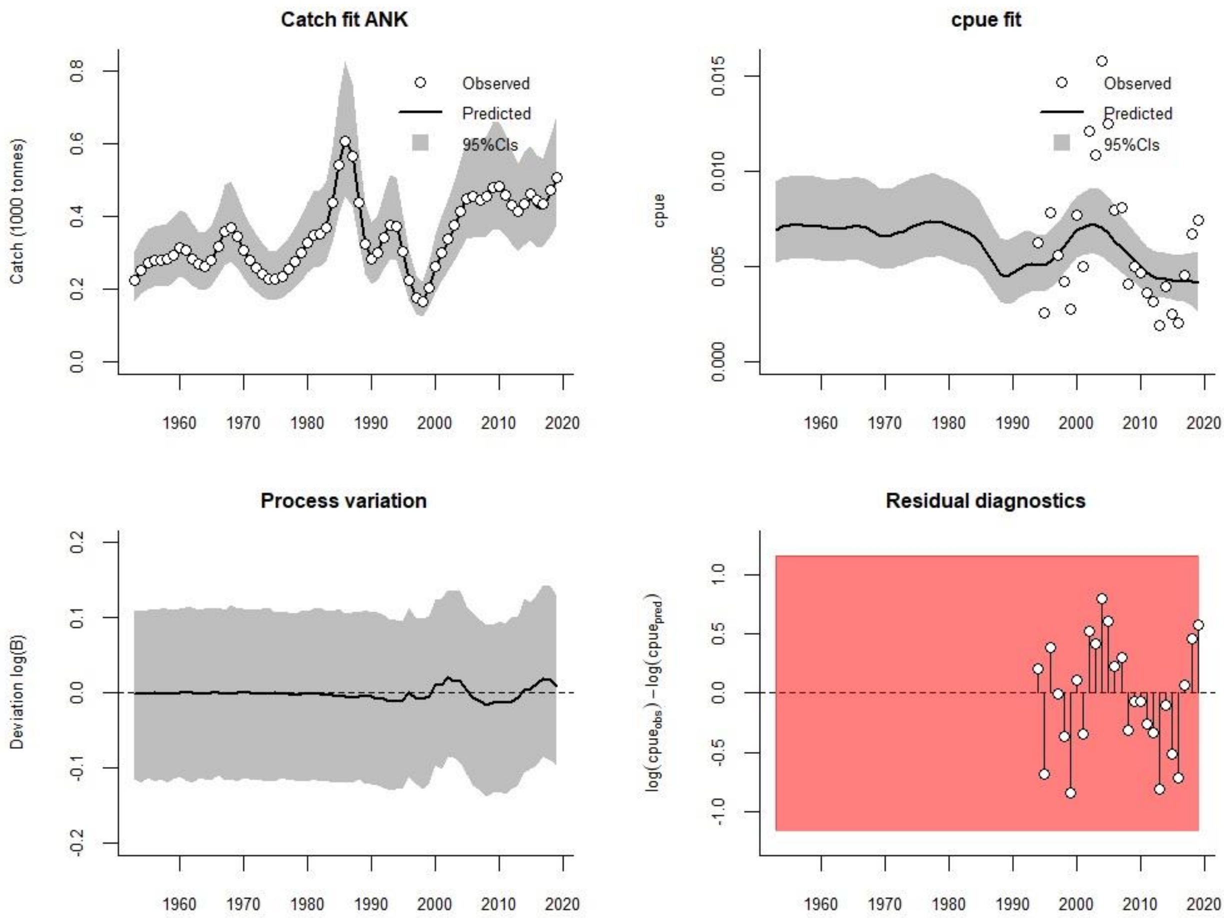

Figure 9: On the upper panels are compared the observed data to the trajectories estimated by the model for Catch (left) and CPUE (right). On the right lower panel are shown the residuals for the CPUE on a colored background, where red indicates some issues on the model fit. On the left lower panels is shown the variation of production given by the stochastic model in respect to the trajectory described by the Schaefer curve.

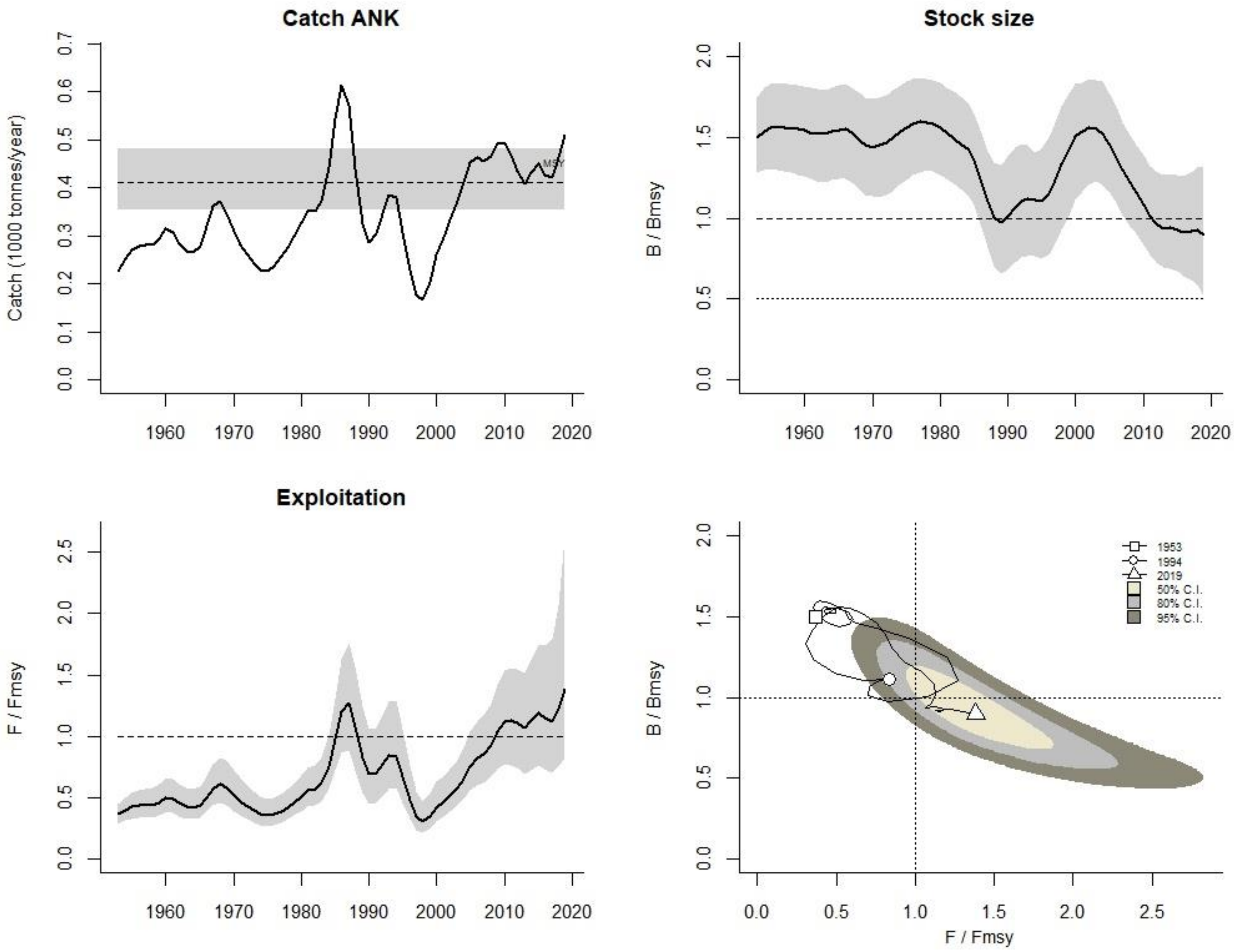

Figure ***10:*** Results of final C-MSY run. The upper left panel shows catches relative to the BSM estimate of MSY, with indication of 95% confidence limits in grey. The upper right panel shows the development of relative total biomass (B/B_{MSY}), with the grey area indicating uncertainty. The lower left graph shows relative exploitation (F/F_{MSY}), with F_{MSY} corrected for reduced recruitment below 0.5 B_{MSY}. The lower-right shows a not colored version of the Kobe plot, with the trajectory of relative stock size (B/B_{MSY}) over relative exploitation (F/F_{MSY}).

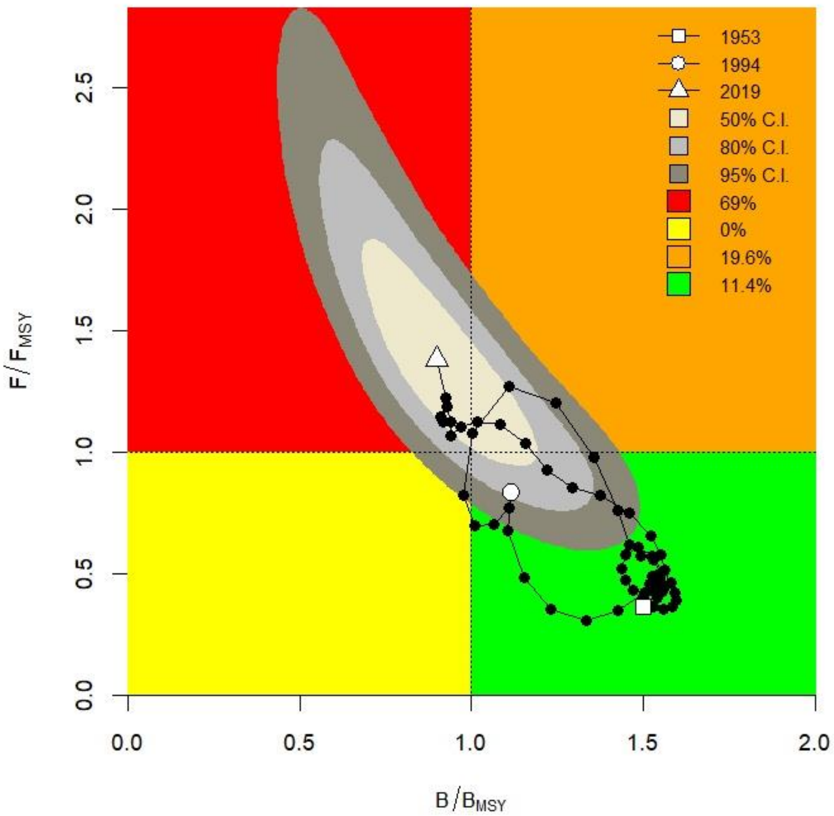

Figure 11: Kobe plot representing the time series of pressure (F/F_{MSY}) on the Y-axis and of state of the Biomass (B/B_{MSY}) on the X-axis. The brown area indicates healthy stock sizes that are about to be depleted by overfishing. The red area indicates ongoing overfishing while the stock is too small to produce maximum sustainable yields. The yellow area indicates reduced fishing pressure on stocks recovering from still too small biomass. The green area is the target area for management, indicating sustainable fishing pressure and healthy stock size capable of producing high yields close to MSY.

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

$F_{current}$ (2019)	0.305
Lower limit (95% c.i.)	0.207
Upper limit (95% c.i.)	0.529
F_{msy} (2019)	0.221
$F_{current}/F_{msy}$	1.383
Lower limit F_{curr}/F_{msy} (95% c.i.)	0.829
Upper limit F_{curr}/F_{msy} (95% c.i.)	2.635
Current Biomass (thousand tonnes)	1.672
B_{msy}(thousand tonnes)	1.864
Current Biomass / B_{msy}	0.897
L. limit Current Biomass/B_{msy}(95% c.i.)	0.516
U.limit Current Biomass/B_{msy}(95% c.i.)	1.321
MSY (thousand tonnes)	0.412
Catches 2019 (thousand tonnes)	0.524

State of exploitation: Exploitation pattern remained s**Table** until the beginning of the '80s, then it sharply rose and spiked in 1987 at F/F_{MSY} = 1.25. In following years, the F trend declined until 1998, when it returned to values comparable to the first part of the series. From 1999 onward, the F trend restarted to rose and continued almost linearly until 2019, which registered the highest value of the timeseries.

State of the biomass: biomass trend remained s**Table** until the mid of the '80s, then it faced a steep decline resulting in B< B_{MSY} in 1989. In following years, the B trend raised again until 2002, when it started to decline and went below the B_{MSY} in 2011. During the last years the B trend stabilized around 0.9 B_{MSY}.

6.1.5 Retrospective analysis, comparison between model runs, sensitivity analysis

6.1.5.1: Retrospective analysis

The retrospective analysis (**Figure 12**) was conducted by removing up to three years of data. The model was not very s**Table** and the trajectories were diverging in the more recent years.

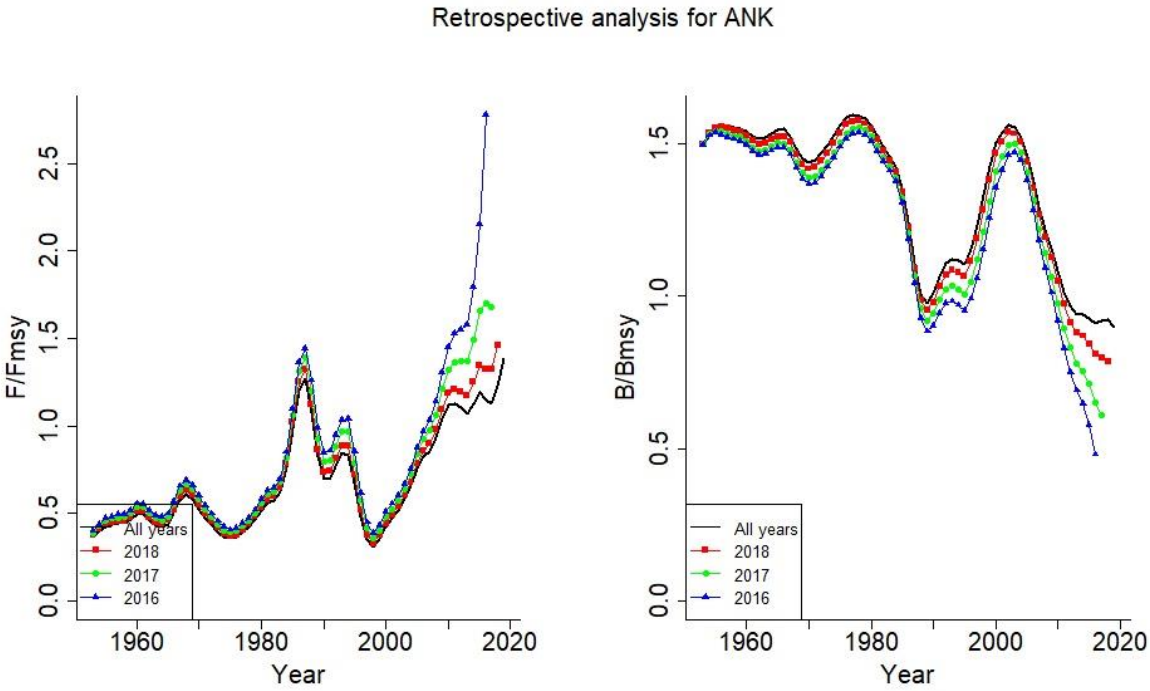

Figure 12: retrospective analysis of the best CMSY model

6.1.5.2: Sensitivity analysis

A sensitivity analysis was carried to test the effect of input data and model parameters. In particular, were tested: (1) the effect of using input data of *Lophius spp.*, instead of using data for *Lophius budegassa* (author reconstruction based on MEDITS survey data); (2) the effect of the prior for final depletion; (3) the effect of Historical data reconstruction for Croatian landings.

Run S1/S2/S3: effect of landing data for *Lophius spp.* instead of *Lophius budegassa* and sensitivity on final depletion

A first sensitivity analysis was carried out by changing the priors for final depletion in CMSY model (**Table** 6.1.5.1) and by testing the alternatives catch timeseries: aggregated at *Lophius spp.*, or reconstructed for *L. budegassa*. As reported in section 3.2, landing data for *Lophius budegassa* were confounded with those of *Lophius piscatorius*, so landing by species was considered not reliable. We tried a data reconstruction to obtain data for *L. budegassa* by using the information contained in the Scientific survey. In particular, we calculated the ratio $L.\ budegassa/Lophius\ spp.$ in the MEDITS biomass index (years 1994-2019), and we applied a moving average linear filter (λ=1/9), thus obtaining a smoothed proportion of L. *budegassa* over L. *spp*. (**ANKprop, Figure 13**). The value of ANKprop was used to obtain *Lophius budegassa* catches as *Lophius spp* $_{Year\ I}$ * ANKprop $_{Year\ I}$ (**Figure** 14).

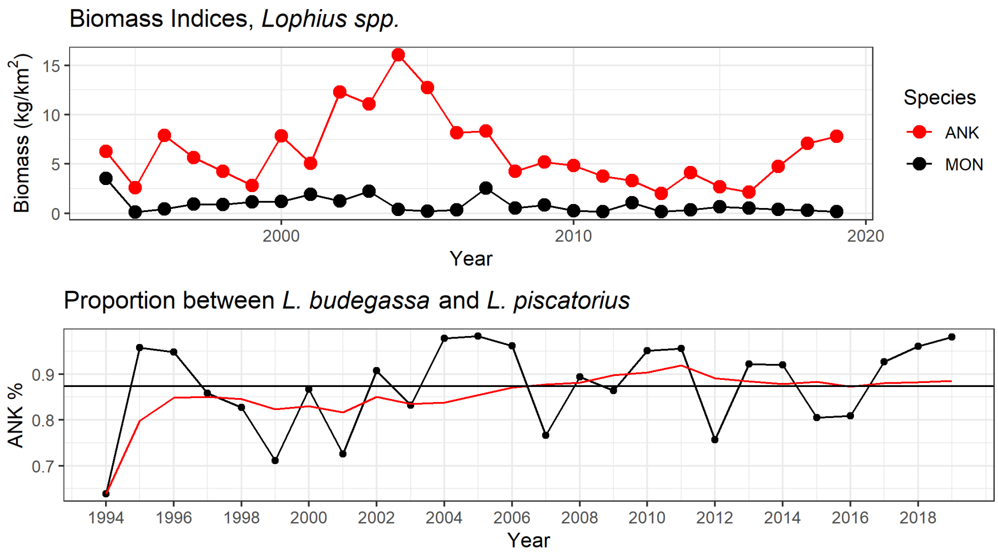

Figure 13: reconstruction of the proportion between *Lophius budegassa* and *Lophius spp*. indices.

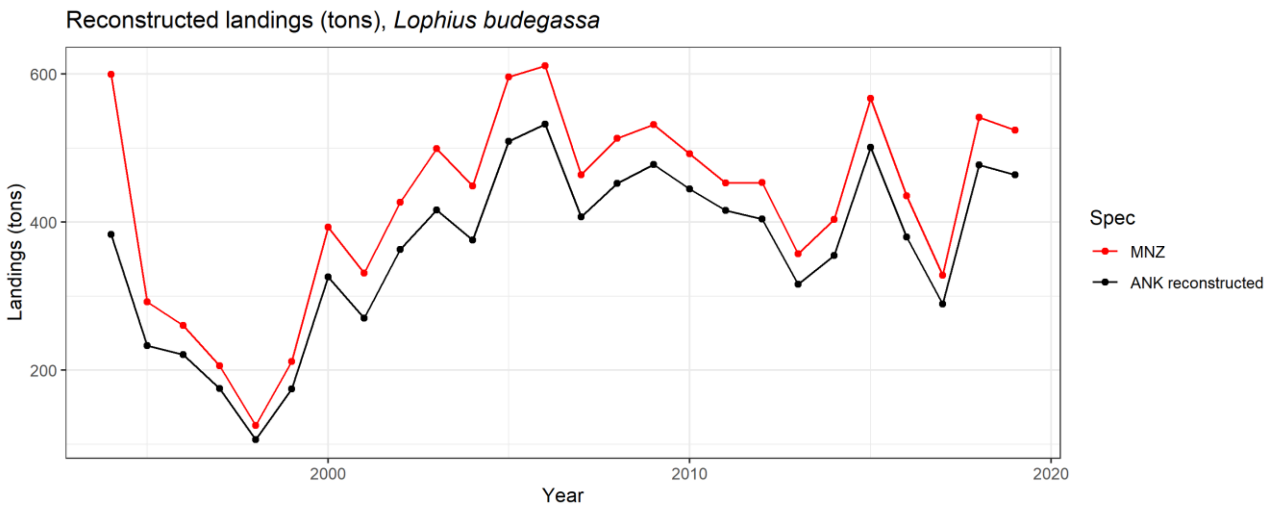

Figure 14: comparison between catch timeseries of *Lophius spp*. (official data) and *Lophius budegassa* (author reconstruction).

First two runs (S1 and S2) base on *L. budegassa* timeseries, using as final depletion prior the output coming from alternative runs of the AMSY model (see 6.1.2). The third run and the fourth runs (S3 and S4) were done on the *Lophius spp.* catch timeseries, using as final depletion prior the output coming from alternative runs of the AMSY model. Models parameters are summarized in **Table** 6.1.5.1. The sensitivity analyses showed an improvement of diagnostic using the timeseries for *Lophius spp.* (1953-2019), which length was more than the double than the reconstructed time series for *Lophius budegassa* (1994-2019).

Irrespectively to the time series used, the prior for final depletion slightly influenced the final result, however setting a more pessimistic prior caused a degradation of model diagnostics.

In the run S1 (**Figure** 15 and 16), the trajectory for the biomass drawn by the CMSY and by the the BSM model were well overlapped, however the posterior for the final depletion was above the priors boundaries.

In the run S2 (**Figure** 17 and 18), the trajectory for the biomass drawn by the CMSY model tends to diverge from the BSM model, however the concordance between priors and posterior distribution was better in respect to S1.

In the run S3 (**Figure** 19 and 20) the BSM and CMSY analysis are almost overlapped, however the posterior for the final depletion was above the prior's boundaries.

In the run S4 (**Figure** 21 and 22) the BSM and CMSY analysis are almost overlapped, and the prior and posterior distribution for final depletion were in good agreement.

Considering the coherence between CMSY and BSM model and the comparison between priors and posterior distribution as the major diagnostic, the best run obtained was S4. Nevertheless, the final result is consistent along the four combinations (**Figure** 23)

Table 6.1.5.1: setting of sensitivity analysis runs

Run	**Timeframe**	**Tuning index**	**Resilience**	**B/k Initial**	**B/k Int**	**B/k Final**
S1	1994-2019	MEDITS	0.25-0.66	0.2-0.6	NA	0.15-0.48
S2	1994-2019	MEDITS	0.25-0.66	0.2-0.6	NA	0.2-0.68
S3	1953-2019	MEDITS	0.25-0.66	0.6-0.9	1994; 0.2-0.6	0.15-0.48
S4	1953-2019	MEDITS	0.25-0.66	0.6-0.9	1994; 0.2-0.6	0.2-0.68

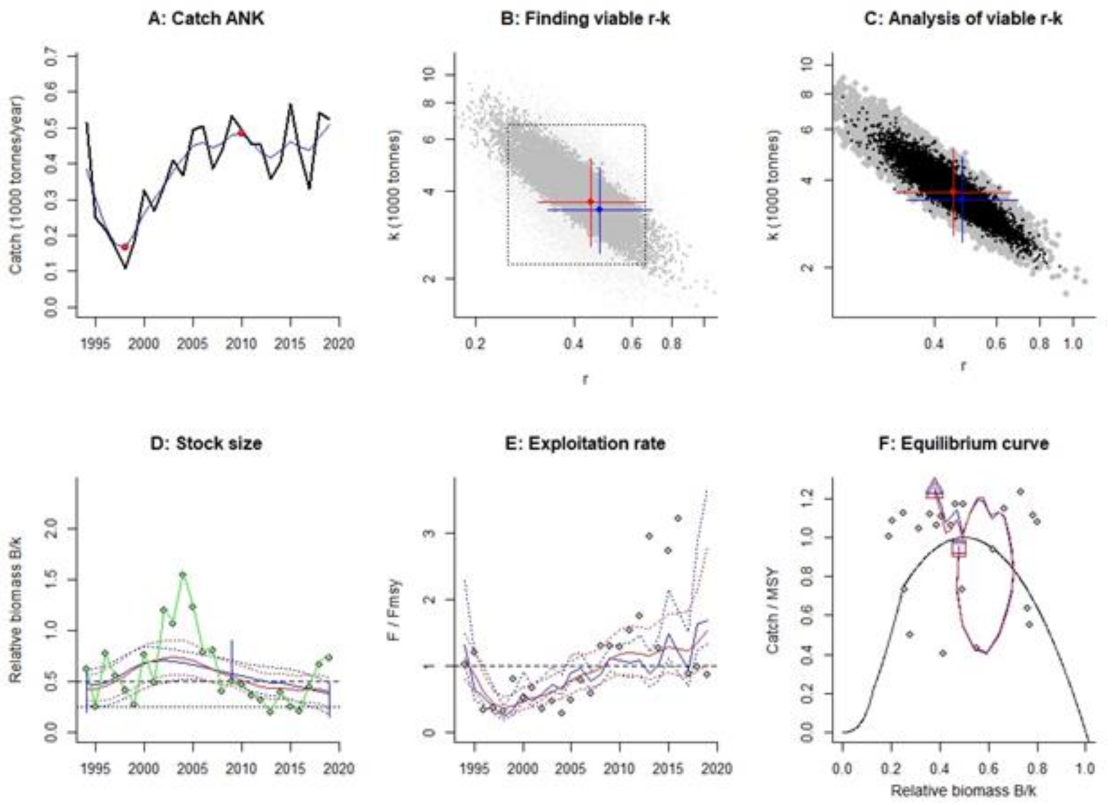

Figure 15: diagnostics and trends for run S1

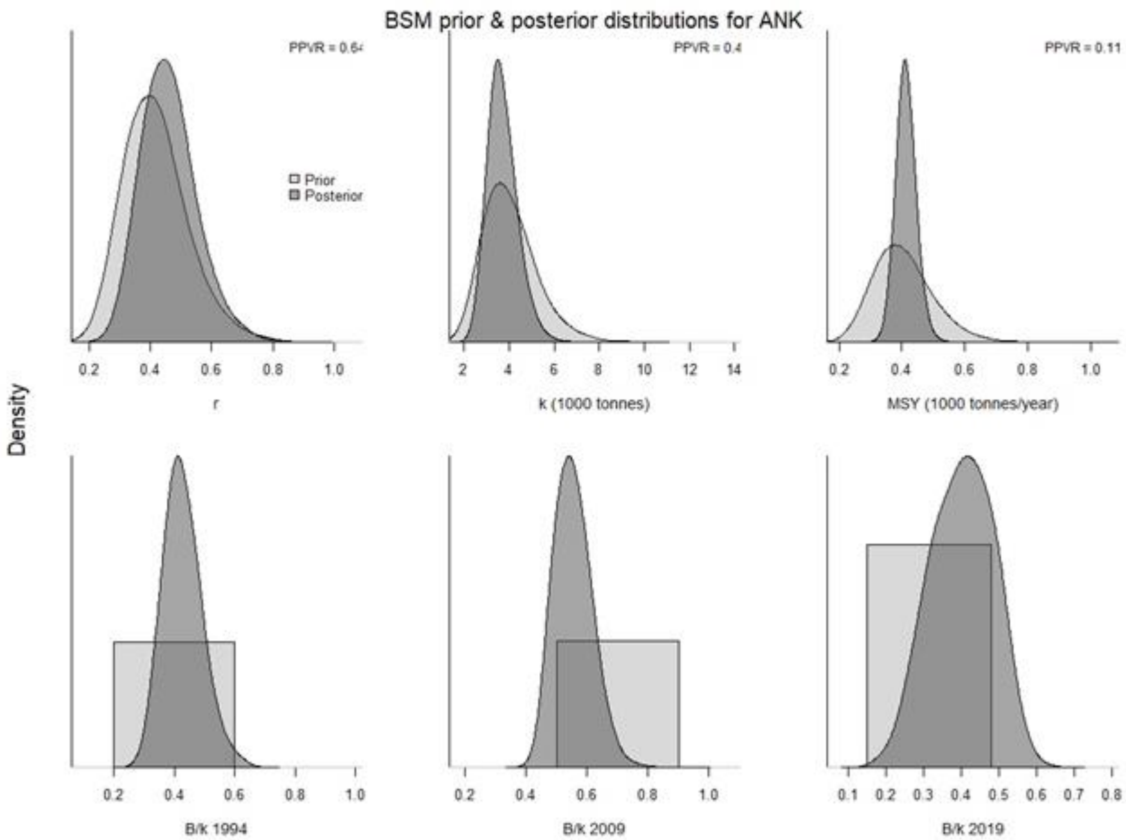

Figure 16: prior and posteriors distribution for run S1

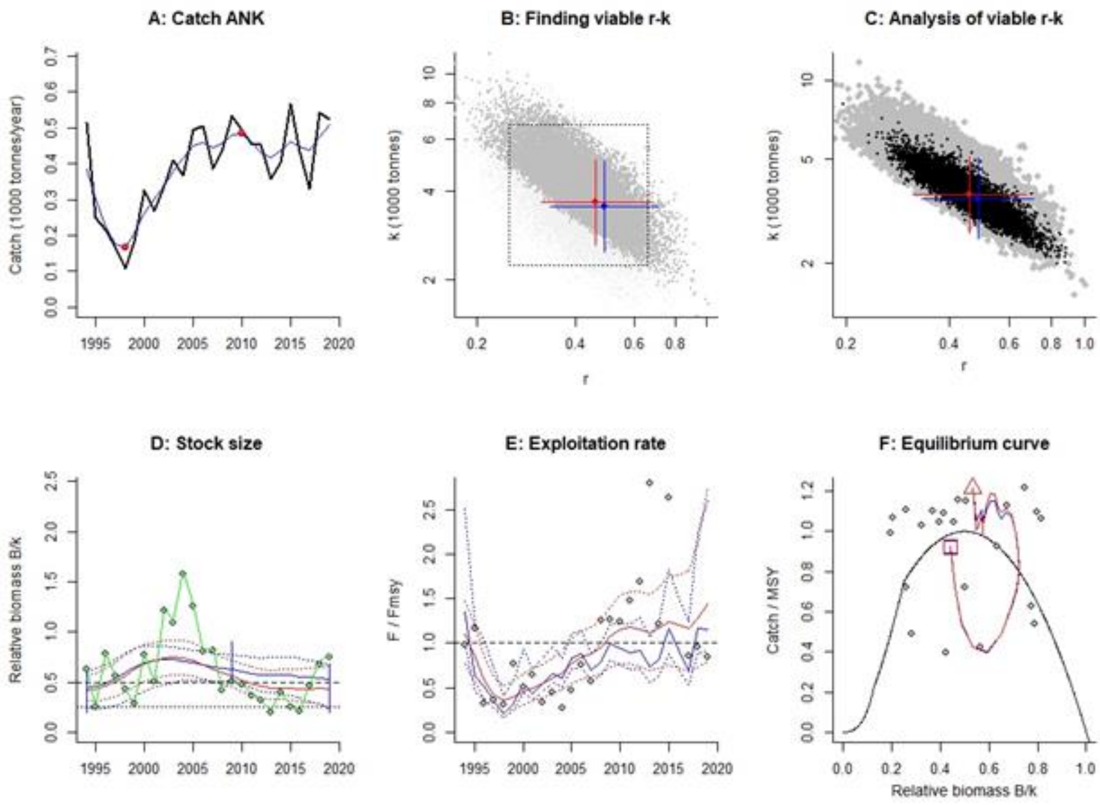

Figure 17: diagnostics and trends for run S2

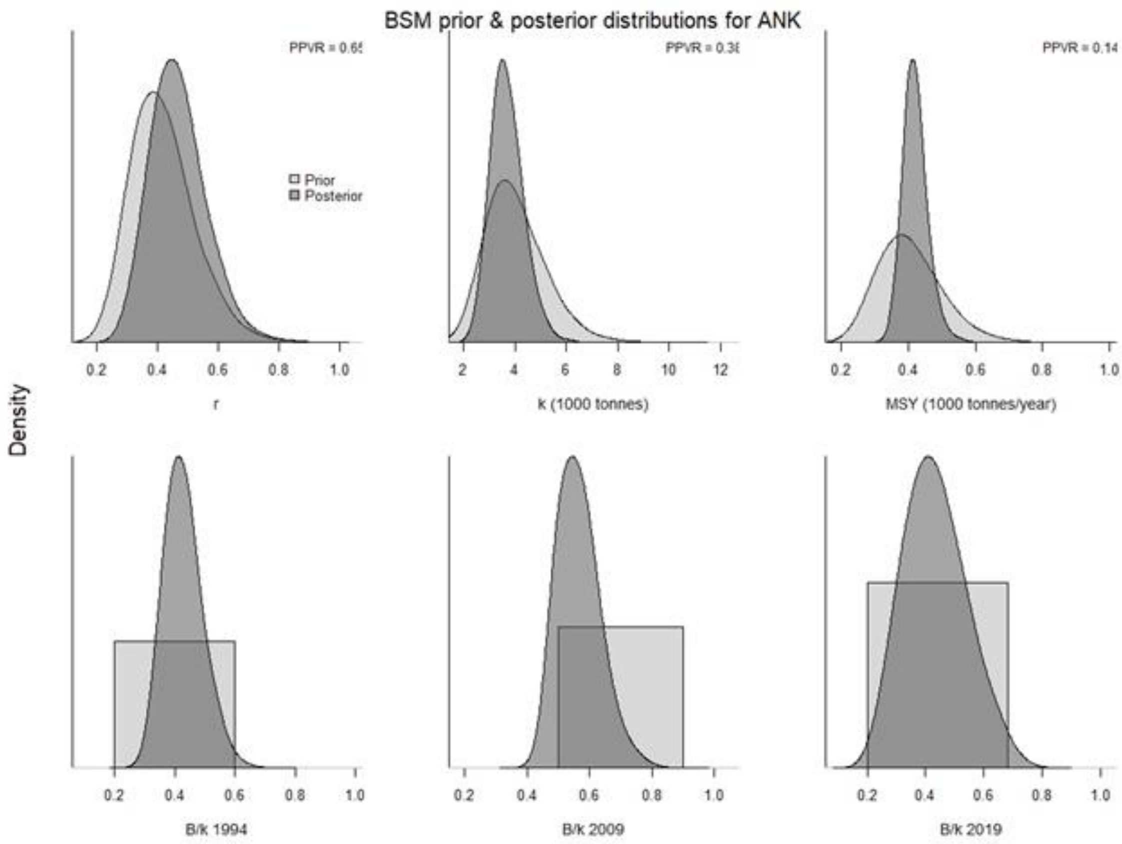

Figure 18: prior and posteriors distribution for run S2

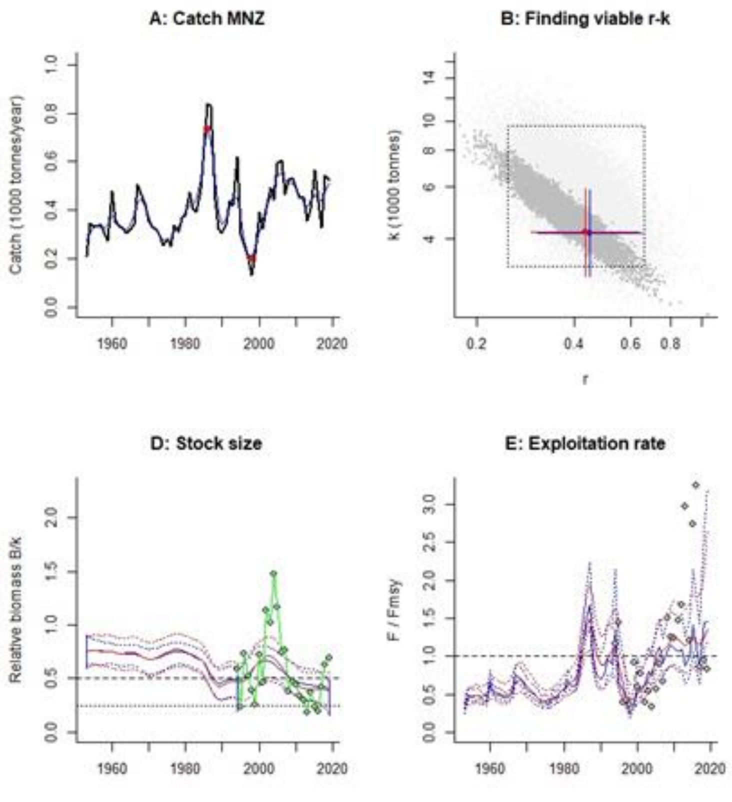

Figure 19: diagnostics and trends for run S3

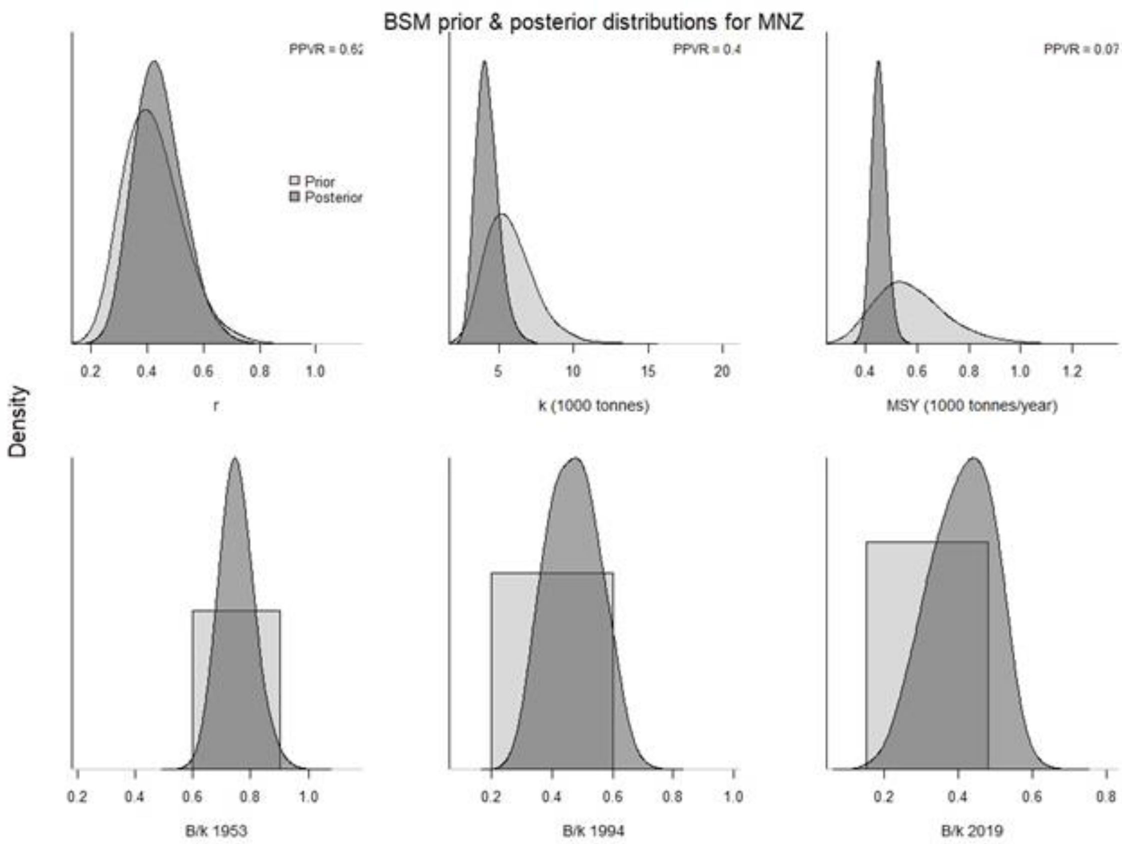

Figure 20: prior and posteriors distribution for run S3

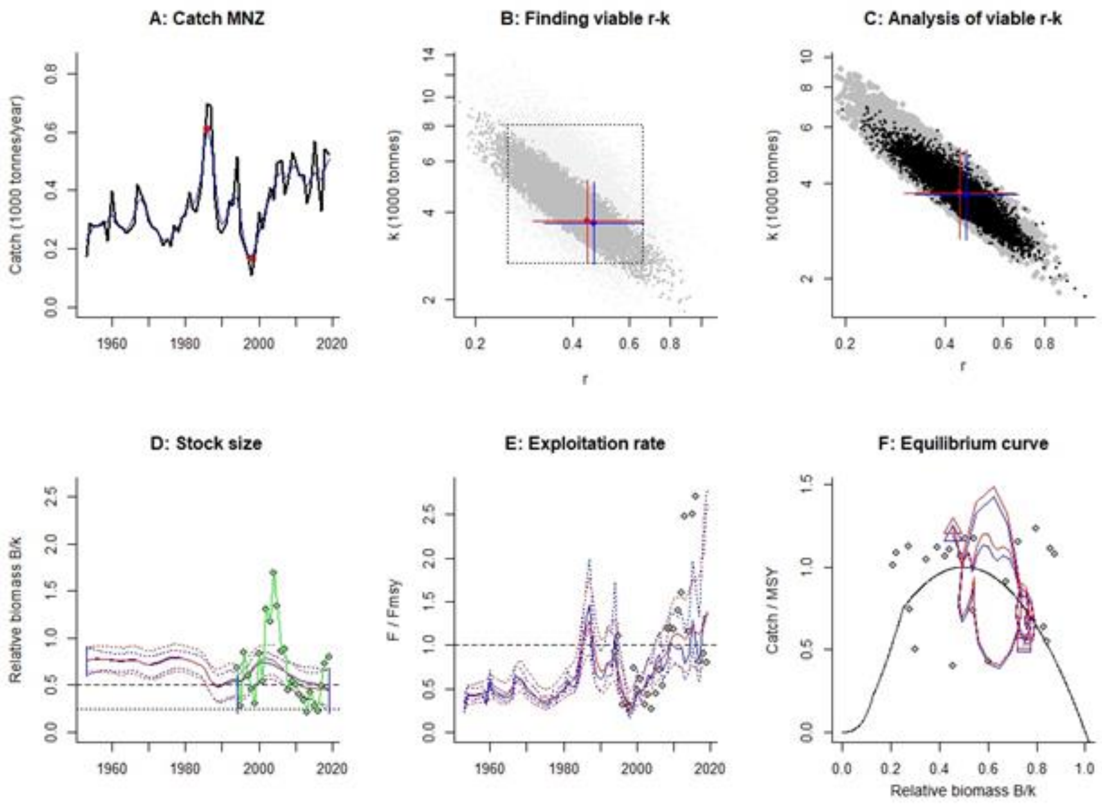

Figure 21: diagnostics and trends for run S4

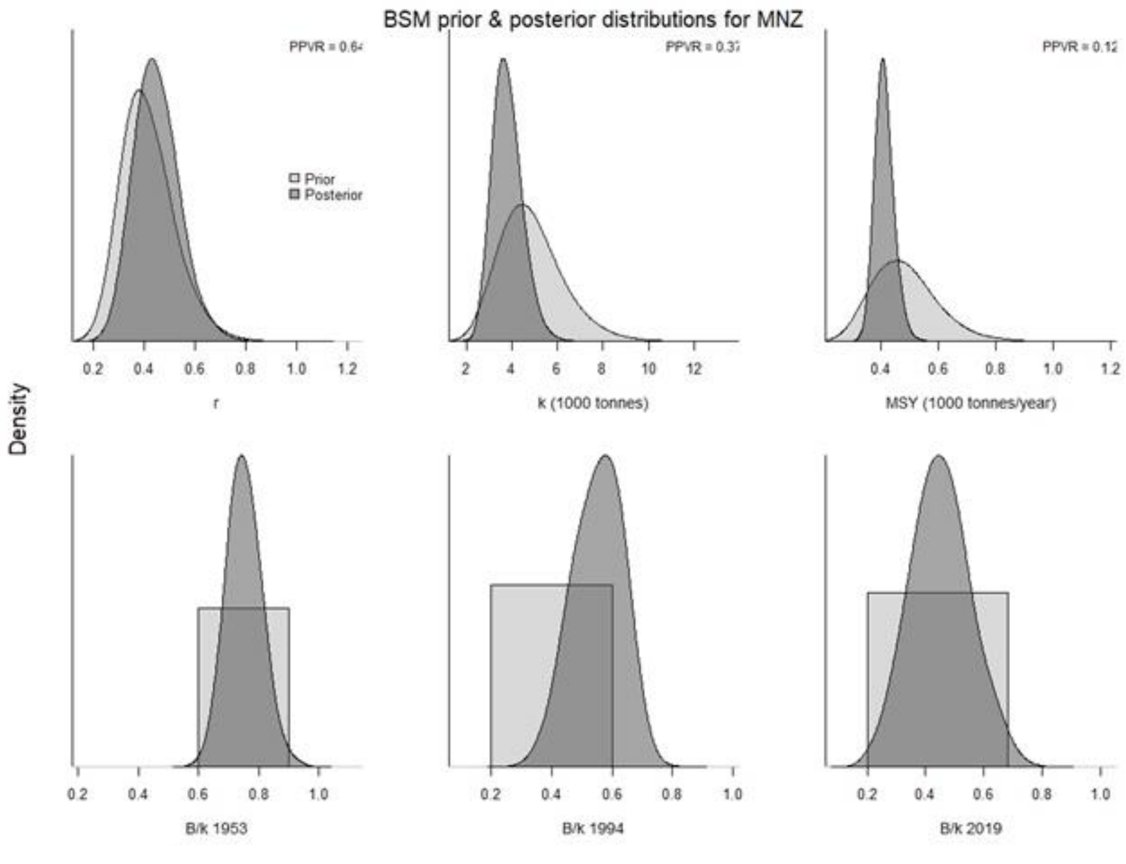

Figure 22: prior and posteriors distribution for run S4

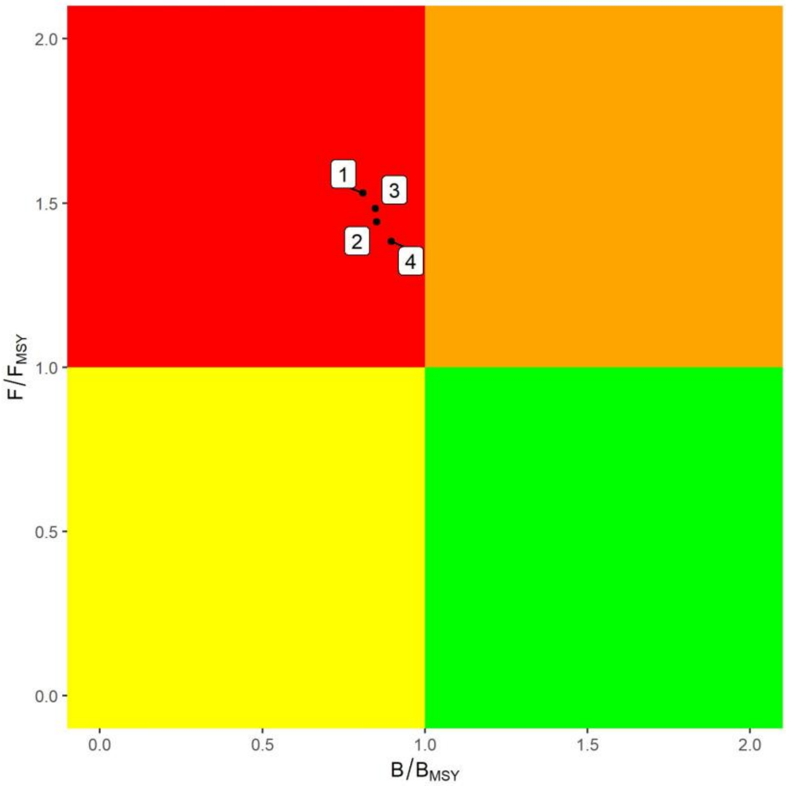

Figure 23: Kobe plot summarizing the final results for the four runs

Run H1/H10: the effect of Historical data reconstruction for Croatian landings

As reported in section 3.2, to obtain the data for a sensitivity analysis ten different timeseries for Croatian landings of *Lophius spp*. were simulated as random walks catch trajectories. In particular, the observed catches for Croatia in 2009 were taken as starting value (x_t). Time series were simulated by modelling x_{t-1} as x_t+ w_t , where *t* indicate the time index and w_t was white noise obtained from a normal distribution with mean = 0 and standard deviation = standard deviation in Croatian catches in the available data (**Figure** 4). As a result, ten different catches timeseries for Croatian landing were obtained and summed to the Italian available data. Data as such obtained used as a sensitivity analysis (**Figure** 24). Large variability was observed among the reconstructed time-series, there were cases where simulated data for the 1960's were comparable to the most recent years (runs 6 and 10), and cases where simulated data for the 1960's where some of the lowest of the timeseries (runs 7 and 9). Each of the timeseries were used to fit a CMSY model based on the parameters obtained from run S4, which resulted the best model among S1-S4. Input parameters used in each of the ten runs are, indeed, those of run S4 (**Table** 6.1.5.1).

In **Figure** 25 are shown the F/F_{MSY} and the B/B_{MSY} trajectories as coming from all the models run. The stock trajectories are reasonably consistent along the ten models, being slightly more pessimistic on the final **Figure**s in the case were landings data were higher at the beginning of the timeseries (run 6 in particular). In any case, the final result was largely comparable along the runs. In addition, the indication of biomass and exploitation status was coherent with runs S1-S4, indicating a small influence of the historical data reconstruction on the final result. Hence, sensitivity runs H1-H10 confirms the goodness of the result obtained from run S4.

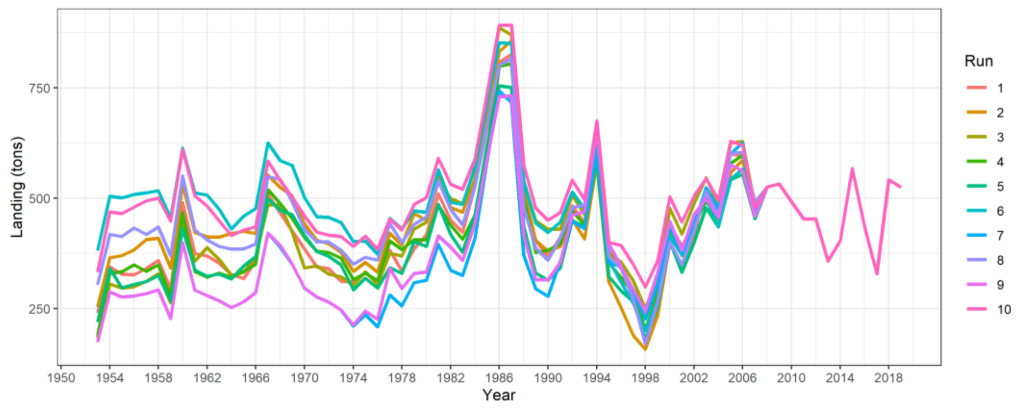

Figure 24: all the catch data timeseries coming from available Historical data combined with reconstruction of Croatian historical data (prior to 2009) as from ten different Random Walk models.

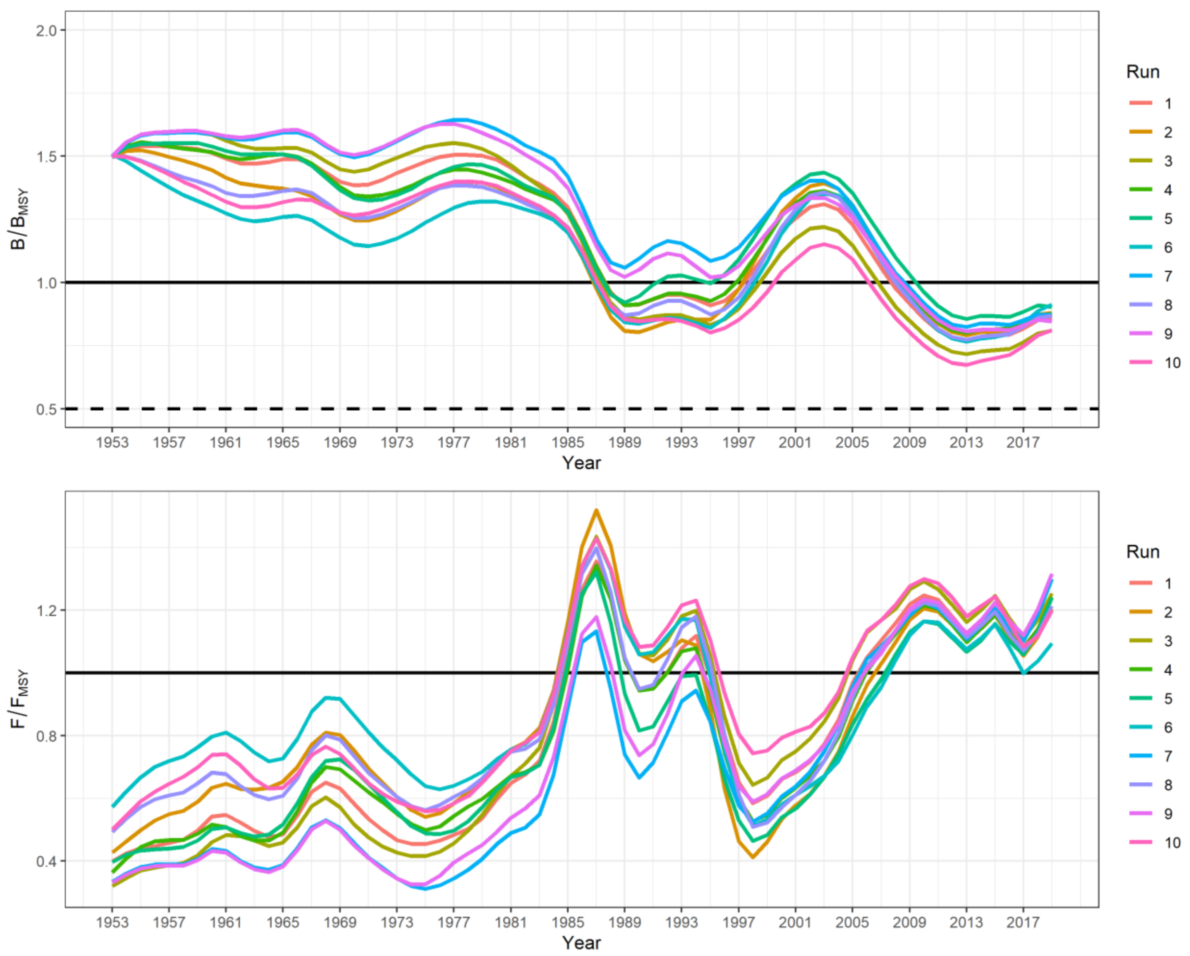

Figure 25: F/F_{MSY} and B/B_{MSY} trajectories estimated by the CMSY model fitted on the catch timeseries shown in **Figure** 24.

6.1.6 *Assessment quality*

The result given in the advice are coherent with the output of the sensitivity analysis, which shown a deterioration of model diagnostic by using a shorter time series and by changing the priors for final depletion. The biomass and exploitation trajectories are generally in line among all the sensitivity runs, and the final result were largely comparable. Nonetheless, due to large data uncertainties, the results of the assessment should be taken as qualitative.

7 Stock predictions

No information available.

Draft scientific advice

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

Table 7-1 Draft scientific advice

Based on	Indicator	Analytic al reference point (name and value)	Current value from the analysis (name and value)	Empirical reference value (name and value)	Trend (2015-2018)	Stock Status
Fishing mortality	Fishing mortality	F_{MSY}: 0.221	Fcurr: 0.305		I	IO
Stock abundance	Biomass (thousand tonnes)	B_{MSY}: 1.864	Bcurr: 1.672		D	O
Recruitment						
Final Diagnosis		**Due to large data uncertainties, these results should be taken as qualitative. The stock is possibly in overexploitation and the advice is to reduce the fishing mortality.**				

8 Explanation of codes

Trend categories

1) N - No trend
2) I - Increasing
3) D – Decreasing
4) C - Cyclic

Stock Status

Based on Fishing mortality related indicators

1) **N - Not known or uncertain** – Not much information is available to make a judgment;
2) **U - undeveloped or new fishery** - Believed to have a significant potential for expansion in total production;
3) **S - Sustainable exploitation**- fishing mortality or effort below an agreed fishing mortality or effort based Reference Point;
4) **IO –In Overfishing status**– fishing mortality or effort above the value of the agreed fishing mortality or effort based Reference Point. An agreed range of overfishing levels is provided;

Range of Overfishing levels based on fishery reference points

In order to assess the level of overfishing status when $F_{0.1}$ from a Y/R model is used as LRP, the following operational approach is proposed:

- If $Fc^*/F_{0.1}$ is below or equal to 1.33 the stock is in **(O_L): Low overfishing**
- If the $Fc/F_{0.1}$ is between 1.33 and 1.66 the stock is in **(O_I): Intermediate overfishing**
- If the $Fc/F_{0.1}$ is equal or above to 1.66 the stock is in **(O_H): High overfishing**

*Fc is current level of F

5) **C- Collapsed**- no or very few catches;

Based on Stock related indicators

1) **N - Not known or uncertain:** Not much information is available to make a judgment
2) **S - Sustainably exploited:** Standing stock above an agreed biomass based Reference Point;
3) **O - Overexploited**: Standing stock below the value of the agreed biomass based Reference Point. An agreed range of overexploited status is provided;

Empirical Reference framework for the relative level of stock biomass index

- **Relative low biomass:** Values lower than or equal to 33rd percentile of biomass index in the time series **(O_L)**
- **Relative intermediate biomass:** Values falling within this limit and 66th percentile **(O_I)**
- **Relative high biomass:** Values higher than the 66th percentile **(O_H)**

4) **D – Depleted**: Standing stock is at lowest historical levels, irrespective of the amount of fishing effort exerted;
5) **R –Recovering:** Biomass are increasing after having been depleted from a previous period;

Agreed definitions as per SAC Glossary

Overfished (or overexploited) *- A stock is considered to be overfished when its abundance is below an agreed biomass based reference target point, like B0.1 or BMSY. To apply this denomination, it should be assumed that the current state of the stock (in biomass) arises from the application of* *excessive fishing pressure in previous years. This classification is independent of the current level of fishing mortality.*

Stock subjected to overfishing (or overexploitation) *- A stock is subjected to overfishing if the fishing mortality applied to it exceeds the one it can sustainably stand, for a longer period. In other words, the current fishing mortality exceeds the fishing mortality that, if applied during a long period, under s***Table*** *conditions, would lead the stock abundance to the reference point of the target abundance (either in terms of biomass or numbers)*

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