Turk. J. Fish.& Aquat. Sci. 23(SI), TRJFAS22719
https://doi.org/10.4194/TRJFAS22719

RESEARCH PAPER

Turkish Journal of FISHERIES and AQUATIC SCIENCES

Stock Assessment of Red Mullet, *Mullus barbatus* Linnaeus, 1758 by Length-based and Catch-based Models in the Northeastern Mediterranean

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How to Cite

Kılıç, S., Öztürk, S., Sarıgöz, S., Erkan, S., Kanyılmaz, M., Tıraşın, E.M. Vasconcellos, M., Lelli, S., Demirel, N. (2023) Stock Assessment of Red Mullet, *Mullus barbatus* Linnaeus, 1758 by Length-based and Catch-based Models in the Northeastern Mediterranean *Turkish Journal of Fisheries and Aquatic Sciences*, *23(SI)*, *TRJFAS22719.* https://doi.org/10.4194/TRJFAS22719

Article History
Received 10 October 2022
Accepted 30 January 2023
First Online 06 February 2023

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Keywords
Data-poor fishery
Demersal fish
Fisheries management
GSA 24

Abstract

Stock assessment for *Mullus barbatus* using catch-based (CMSY) and length based (LBB, LBSPR and LIME) data limited models were performed by using official catch statistics and commercial length frequency data from northeastern Mediterranean. The CMSY model results showed that the catch amount did not exceed MSY, and the fisheries reference points (B/BMSY and F/FMSY) indicated a healthy stock status in 2020. The LBB model results indicated that the biomass ratio was above safe biological limits (B<0.5 BMSY) but fishing mortality was slightly higher than natural mortality. Likewise, LBSPR results showed that SL50 for red mullet was higher than its Lm50, while the estimated median SPR was above the limit of 20% set as the biological reference point. The LIME results were more optimistic than those from the LBB and LBSPR and the estimated SPR was found above 40% which is the target reference point for a sustainable stock. According to the results of different assessment models, the red mullet stock was deemed sustainable in terms of biomass but observation of fishing pressure is required

Introduction

The General Fisheries Commission for the Mediterranean (GFCM) divides the Mediterranean coast of Türkiye into two geographical subareas (GSA), with the number 22 denoting the Aegean Sea and 24 the northern Levant Sea (or northeastern Mediterranean) (GFCM, 2009). The fisheries resources in GSA 24 are multispecies and generally lack large monospecific stocks compared to the open ocean. According to recent studies, the exploitation rate has been steadily increasing and selectivity deteriorating, thus leading to overfishing of fish stocks (FAO, 2022). Total catches remained below 15,000 tonnes between 2000 and 2008, then increased gradually to a peak value of 30,000 tonnes in the mid-2010s and then fluctuated around the 10,000 tonnes level during the late 2010s (TURKSTAT, 2022). In the same period, the cumulative percentage of over-exploited and collapsed stocks increased linearly, suggesting that the fisheries resources are at risk from overexploitation (Demirel et al., 2020;).

The region's small-scale fisheries sector predominantly uses trammel nets, gill nets and longlines. Fishers often use two different size mesh

trammel nets to target a wider range of species, i.e., a small mesh for small species such as mullet, and a larger mesh net for other species. Many demersal species such as seabreams, seabass, red mullet and grouper are landed. Longlines are used to target swordfish and large tuna species; stingrays are often caught as by-catch and then discarded since there is no local consumption of these species (Ulman et al., 2013). Industrial operations include trawlers, purse seiners and beach seiners. The northeastern Mediterranean coast (GSA 24) has the lowest reported landings with respect to other regions in Türkiye and represented 4.6% of the country's total commercial landings in 2020 (TURKSTAT, 2022).

Red mullet, *Mullus barbatus* Linnaeus, 1758, is an important demersal fish for commercial fisheries, as it is one of the most landed demersal species in GSA 24. While 177 bottom trawls and 982 gillnets boats fished during 2020 in GSA 24, 90% of *M. barbatus* was fished by bottom trawls and most of the remaining part was caught by gillnets (TURKSTAT, 2021). The stock of *M. barbatus* in the eastern side of GSA 24 was mainly exploited by bottom trawls, whereas in the western side, it was exploited (a small amount) by gillnets and trammel nets due to very limited fishing grounds suitable for trawling.

The aim of the present work was to assess the state of the stock and the exploitation rate of red mullet in the northeastern Mediterranean Sea (GSA 24). Due to the lack of historical fisheries-dependent and independent data, which excludes the use of conventional stock assessment methods, two types of assessment methods applicable to data-limited situations were used here to evaluate the stock status of red mullet: catch-based methods and length-based methods. The results form the basis for management recommendations for maintaining the data-poor red mullet stock at sustainable levels of exploitation.

Materials and Methods

In this study, the catch-based 'CMSY' method (Froese et al., 2017) was used with 20 years of national catch statistics. The 'CMSY' method enables estimation of fisheries reference points by time series of catch data only, namely data-poor stocks. In addition, three different length-based assessment models; i) Length-Based Bayesian (LBB) estimator, ii) Length-based Spawning Potential Ratio (LBSPR) and iii) Length-based Integrated Mixed Effects (LIME), were employed to obtain a detailed assessment of red mullet stock. The input data for the length-based models were the length frequency data collected from the commercial fisheries in the northeast Mediterranean (GSA 24) between 2018 and 2021 (Figure 1).

Catch-based Assessment

The Turkish Statistical Institute (TURKSTAT) collects catch data for commercial fish species from all Turkish waters. The national catch data between 2000 and 2020 were used for catch-based assessment (Figure 2).

In the CMSY model (Froese et al., 2017), probable ranges for the maximum intrinsic rate of population increase (r), and for unexploited population size (or carrying capacity, k) are filtered using a Monte Carlo approach to detect "viable" *r-k* pairs. Prior estimates of r were obtained from the life-history traits of red mullet from FishBase (www.fishbase.org). Therefore, prior range for r and k were set to 0.42–1.00 and 3.48–10.40 respectively, while prior initial relative biomass was set to moderately exploited stock level (0.4-0.8; Froese et al., 2017). The Schaefer function for biomass dynamics (SPM) was estimated by CMSY:

$$B_{t+1} = B_t + r\left(1 - \frac{B_t}{k}\right)B_t - C_t$$

where B is biomass (tonnes), C is catch (tonnes), r is the intrinsic rate of population growth, k is the carrying capacity, and t is time (years).

According to FAO (1999) guidelines of indicators and reference points for fisheries, "*Where MSY estimates are available, it should be possible to determine whether the fishing effort level corresponding fishing mortality rate (F_{MSY}), is currently being exceeded or not*". Therefore, the present study used indicators such as ratio of current fishing mortality rate to that at MSY (F/F_{MSY}) and ratio of current population biomass to that at *MSY* (B/B_{MSY}) (FAO; 1999; Froese et al., 2015). For a sustainable stock, expected criteria were $F/F_{MSY} \leq 1$ and $B/B_{MSY} \geq 1$.

Length-based Assessments (LBB, LBSPR, LIME Models)

Length-frequency data (Figure 3) were obtained from a total of 13,552 fish sampled from commercial trawlers and gillnetters in the regions of Antalya Bay, Mersin Bay and Iskenderun Bay from 2018 to 2021 (Figure 4). Length-frequency data were weighted by regions and gears according to landing data (TURKSTAT, 2021). Estimates of growth parameters for red mullet were collected from a literature review (Table 1) and the most recent estimates (Ok and Gücü, 2013) were used as a prior. Length-at-first maturity for red mullet was determined as 11.3 cm for Lm_{50} and 14.2 cm for Lm_{95}; these were estimated from the collected individual length and maturity data (Unpublished data). Natural mortality (M) was estimated as 0.69 with the method suggested by Gislason et al. (2010).

Three different length-based assessment models, LBB, LBSPR and LIME were used. LBB is a method for analyzing length-frequency data from exploited fish or invertebrate populations, in which all relevant parameters are estimated synchronously using the Bayesian Monte Carlo Markov Chain (MCMC) approach (Froese et al., 2018). LBB estimates several parameters for one or several length-frequency samples

representing the population in question, including asymptotic length (L_∞), mean length at first capture (L_c), relative natural mortality (M/K), and relative fishing mortality (F/M) (Froese et al., 2018b; see also Froese et al., 2019). The method describes the framework for approximating stock status from L_∞, M/K, F/K, and L_c (Froese et al., 2018; 2019a; 2019b). In addition, these parameters allow the estimation of the length at first capture that would maximize catch and biomass for the given fishing effort (L_{c_opt}), and estimation of a proxy for the relative biomass capable of producing maximum sustainable yields (B_{MSY}/B_0) (Froese et al., 2018).

LBSPR is based on size structure of an exploited population. Spawning potential ratio (*SPR*) is considered as the function of i) relative Lm_{50}/L_∞ where Lm_{50} is the size of maturity at which 50% of a size class is mature and L_∞ is asymptotic size that are basis of life history characteristics, ii) relative mortality (F/M), and iii) relative M/K where K is the von Bertalanffy growth coefficient (Beverton, 1963; Hordyk et al., 2015a). The *SPR* index can be calculated as the ratio of the equilibrium between spawning biomass and recruitment under current fishing pressure to the same equilibrium without fishing pressure.

LIME is based on the length composition of the catch from a single year as well as assumed life history information, including the length-at-age relationship, an assumed natural mortality rate (M) and Lm_{50}. The method has the ability to account for variable fishing mortality and recruitment when only length data are available (Rudd and Thorson, 2017).

Results

The catch statistics indicated a gradual increase until 2012 when a sharp decline occurred (Figure 2). According to the stock assessment results of the CMSY analysis, red mullet catch was below the estimated *MSY*=922 tonnes for GSA 24 (Table 2). Estimated relative biomass showed a sharp decrease in 2012, and since then biomass was gradually recovered and found as 2430 tonnes in 2020 (Table 2, Figure 5). The ratio of estimated fishing mortality (F) to F_{MSY}, was below 1 in most years except in 2012 and 2013, which implies sustainability. Relative biomass estimations were above estimated B_{MSY} between 2000 and 2011, but was lower than the threshold from 2011 until 2019 (Figure 5; Table 2).

The length range for *M. barbatus* was between 6 cm and 26 cm in TL. The estimated relative fishing mortality F/M was found to be 1.3, while the estimated relative biomass (B/B_{MSY}) was 0.88 for 2021. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were 1.1 for both (Figure 6). The ratio of Lm_{95}/L_∞ was 0.93. The proportion of juveniles in the catch was 37%.

The estimated sizes at median 50% selectivity (SL_{50}) for red mullet was 11.8 cm. (Figure 6), which indicates that a large proportion of the catch was made up by adults. The median estimates of the spawning potential ratio (*SPR*) was ~0.28 (Figure 7). According to LIME outputs, the estimated *SPR* was above the target 40% set as the sustainable reference point (Figure 8).

Discussion

In this study, the stock status of a commercially important demersal fish species, red mullet, was analyzed using two types of data limited methods (catch-based and length-based models) applied to national catch statistics and length-frequency data obtained from the commercial fishers in the northeastern Mediterranean (GSA 24). The *M. barbatus* stock was deemed sustainable. The CMSY model results showed that the catch amount did not exceed the *MSY*, and the fisheries reference points (B/B_{MSY} and F/F_{MSY}) indicated a healthy stock status in 2020. In order to reduce the pressure of overfishing and overexploitation on fish stocks, Türkiye started to implement the first of the buyback programs for fishing vessels of 12 m and above in 2012 (GTHB, 2012). Afterwards, four more buy-back programs were put into practice by 2018 (Göktay et al, 2018). After the implementation of the buyback program in 2012, the number of trawlers, which was 205, plummeted dramatically to 136 in 2015, then

Table 1. Input parameters for length-based analysis used as priors.

L_∞ (cm)	K (y^{-1})	t_0 (y)	Reference
24.8	0.52	-0.33	Bingel (1987)
24.4	0.716	-0.45	Bingel et al. (1993)
24.26	0.565	-0.305	Özbilgin et al. (2004)
26.0	0.56	-0.30	Ok and Gücü (2013)

Table 2. Outputs of the CMSY model for red mullet.

Year	*MSY* (t) (95% CL)	B_{MSY}(t) (95% CL)	F_{MSY} (y^{-1}) (95% CL)	*B* (t)	*F* (y^{-1})	B/B_{MSY}	F/F_{MSY}	Stock Status
2019	922	2420	0.378	2337	0.362	0.97	0.96	Sustainable
2020	(714-1160)	(1740-3420)	(0.265-0.536)	2430	0.315	1.04	0.84	

increased slightly over the next four years to 173 in 2020 (Figure 2). At the same time, similar to the change in the number of trawler boats, the red mullet landing which was 1614.4 tonnes in 2012, decreased significantly to 506 tonnes in 2015. Then, with slight fluctuations, it increased to 767.6 tonnes in 2020 (TURKSTAT, 2021). With this reduction in the number of trawler boats, it can be seen that the fishing effort on the red mullet stock also decreased, resulting in a recovery in biomass (Figure 4). The proportional variation between the number of ships and the amount of landings indicates that the buyback program was partially successful in reducing the pressure on fish stocks for a certain period of time. Additional management measures should be taken in order to further reduce or limit the number of fishing boats and the amount of catch to a certain level.

The LBB model results showed that almost 63% of the red mullet catch were adult specimens. The proportion of mature fish in the catch was more than half, suggesting that in these fisheries, the catches consist mostly of adults. However, it should be noted that the model assumes knife-edge selectivity while gillnets have a typical dome-shaped selectivity which indicates a necessity of careful evaluation of the results. For instance, if most of the catch had come from trammel nets, results would doubtlessly be acceptable

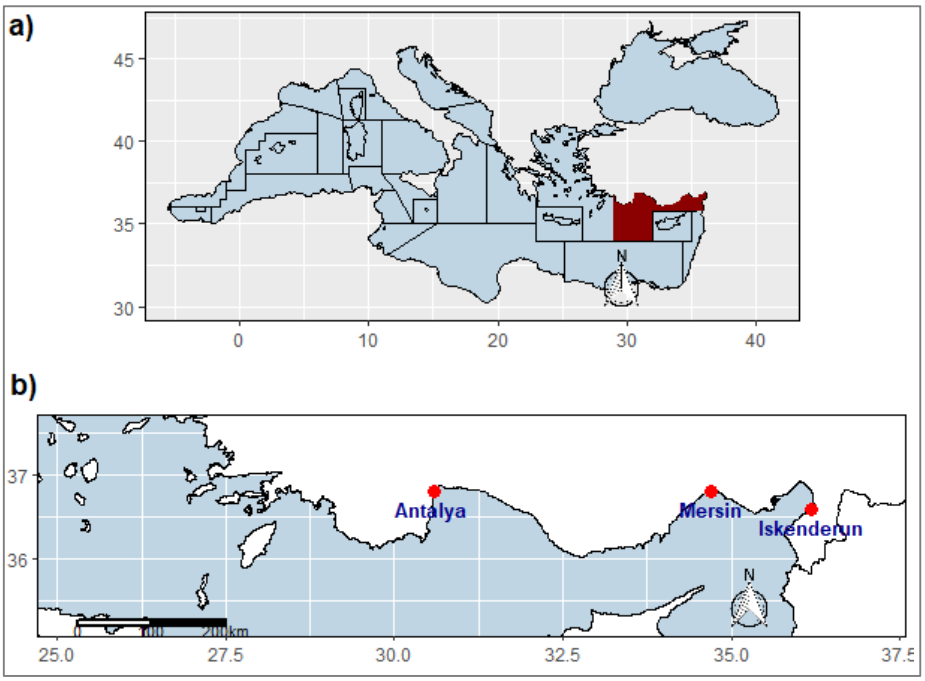

Figure 1. Maps show (a) the borders of the GFCM geographical subareas (GSAs) in the entire Mediterranean Sea and the location of the northeastern Mediterranean (GSA 24) covered in red, and (b) the locations of the fishing areas where the commercial length frequency data were collected.

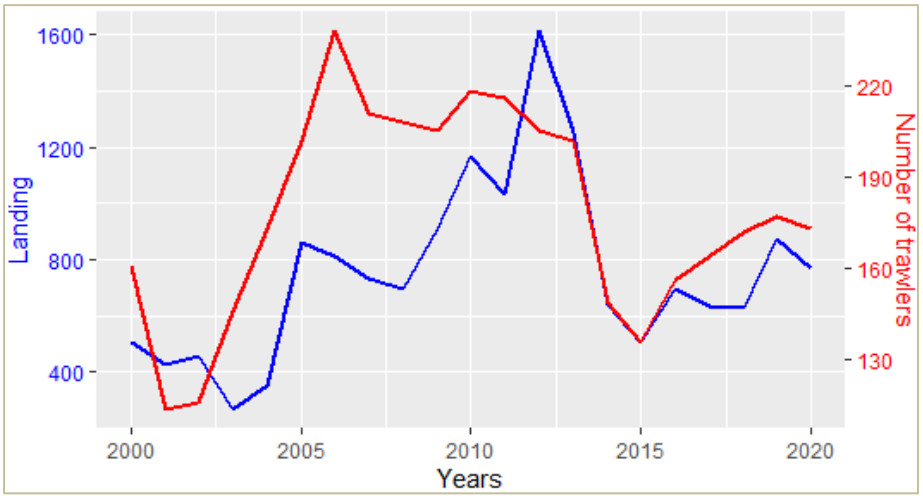

Figure 2. Landings (tonnes) of *Mullus barbatus* as an input in CMSY analysis, and numbers of trawler boats between 2000 and 2020 in the Turkish Mediterranean Sea (TURKSTAT, 2022).

for such a selectivity pattern. The biomass ratio was found above safe biological limits (B<0.5 B_{MSY}) but fishing mortality was slightly higher than natural mortality. Average length, catch length and optimal length ratios were above 1, suggesting a truncated length structure. The ratio of the 95th percentile length to asymptotic length was slightly lower than 1, suggesting that large fish were less present. Likewise, LBSPR results showed that SL_{50} for red mullet was higher than its Lm_{50}, while the estimated median *SPR* was above the limit of 20% set as the biological reference point. The LIME results were more optimistic than those from the LBB and LBSPR and the estimated *SPR* was found above 40% which is the target reference point for

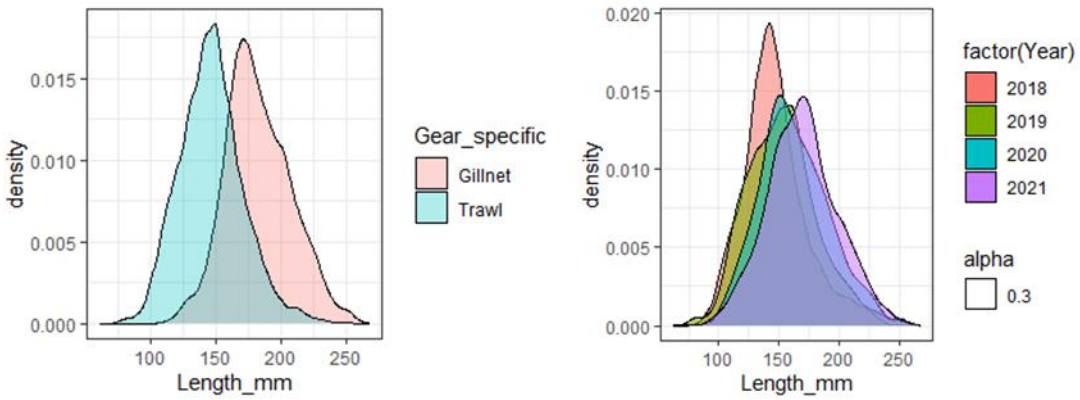

Figure 3. Input length-frequency data obtained from the region by fishing gear and year.

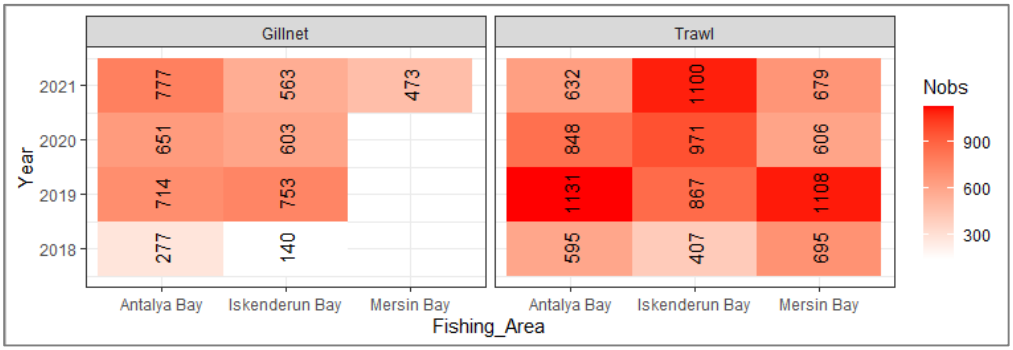

Figure 4. Sampled fish numbers from commercial trawlers and gillnetters by region and year.

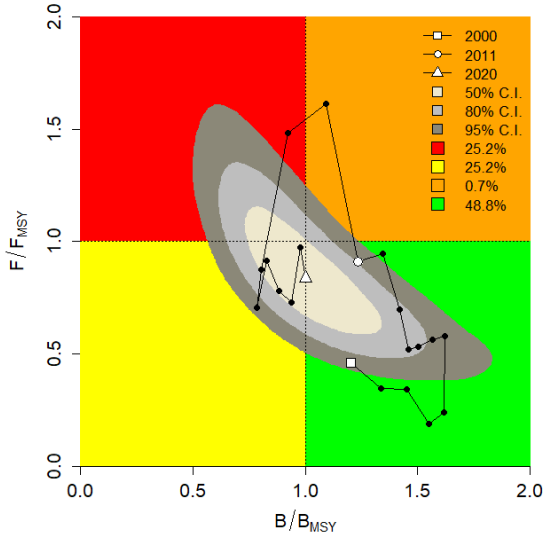

Figure 5. Output of the CMSY algorithm. The KOBE plot shows changes in the stock status of red mullet over the years. The color classification is based on the EU - Good Environmental Condition criteria. The red area is considered "very bad", the orange area is "bad", the yellow area is "moderate", and the green area is considered a "good" status.

a sustainable stock. The minimum landing size for red mullet in Türkiye is 13 cm. The minimum mesh size of bottom trawl nets for the Aegean and northeastern Mediterranean coasts of Türkiye apply as 40 mm in square shape cod-end and 44 mm in diamond shape cod-end (MoAF, 2020). However, minimum conservation reference size applied by the European Union (EU) Countries for red mullet. is 11 cm, whereas the square mesh cod-end is 40 mm i.e. the same as in Türkiye (EU, 2019). The selectivity (SL_{50}) of commercial bottom trawl net having 44 mm diamond shape mesh size were reported as 12.98 cm for red mullet by Kınacıgil et al. (2001) in Izmir Bay (the Aegean Sea) and the net was found as unselective. Ateş et al. (2010) reported that changing the mesh from a 44 mm nominal polyamide diamond mesh cod-end to a 40 mm nominal polyethylene square mesh cod-end increased the mean retention lengths (SL_{50}) from 10.7 to 14.2 cm under commercial conditions in the demersal trawl fishery for the red mullet in Antalya Bay, northeastern Mediterranean, Tokaç et al. (1998) reported that a 40 mm square mesh cod-end and a 44 mm diamond mesh cod-end had similar selectivity for red mullet, respectively 13.73 cm and 13.49 cm. However, the Lm_{50}

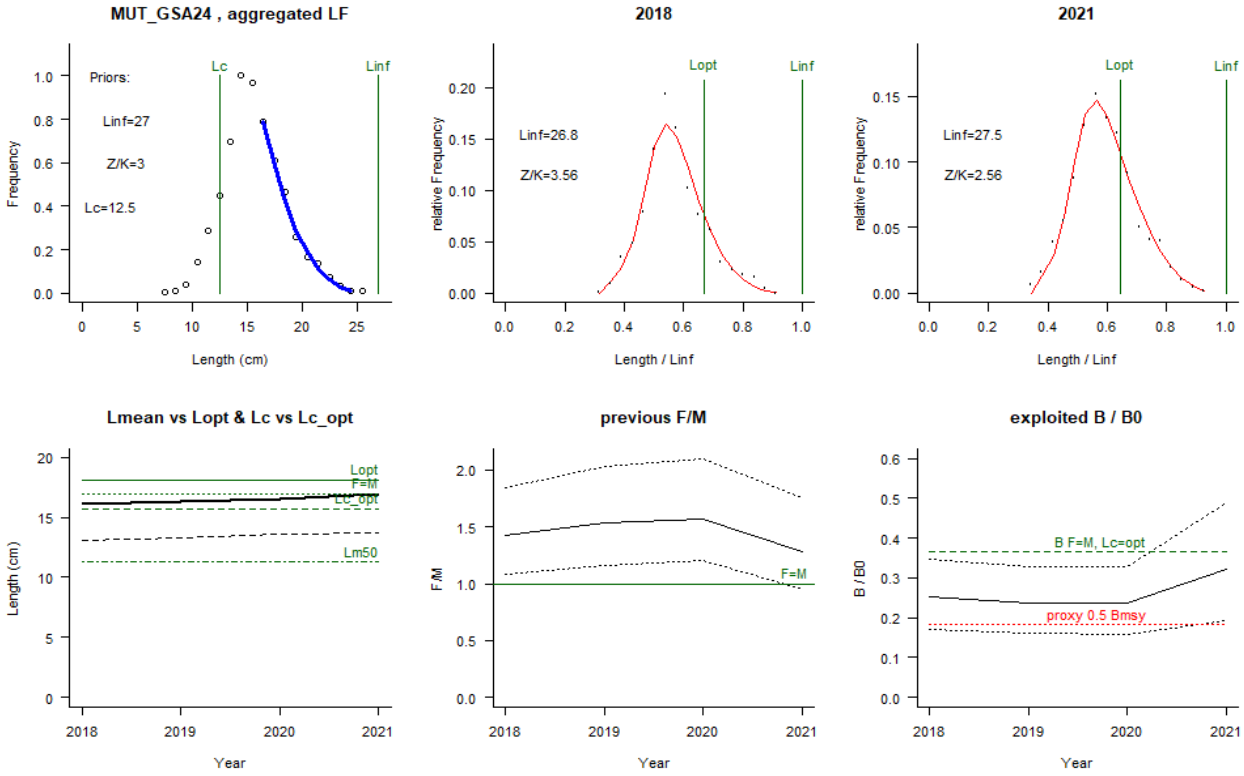

Figure 6. Graphical output produced through length-based Bayesian (LBB) estimation for red mullet.

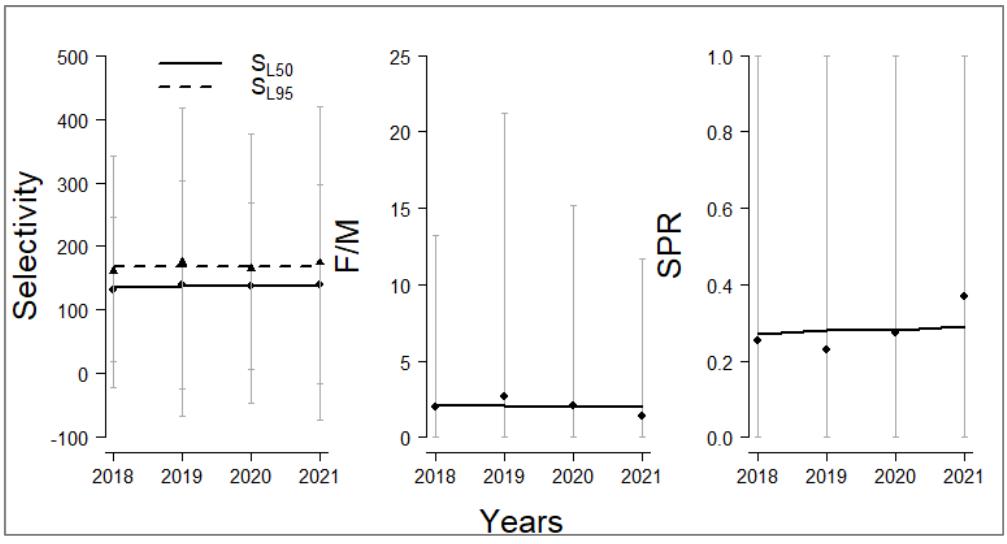

Figure 7. Graphical output produced through LBSPR estimation for red mullet.

for red mullet was reported as 11.6 cm for males and 12.6 cm for females by Ok and Gücü (2013). When considering the sexual maturity and minimum landing size, using 40 mm square mesh cod-end, which is more selective compared to 44 mm diamond mesh cod-end used by commercial trawl fisheries in the northeastern Mediterranean in Türkiye, should be encouraged.

Red mullet is landed predominantly from GSA 24 in Türkiye. It is also the most fished demersal fish species in this GSA (TURKSTAT, 2022). The GFCM classifies red mullet as group 1 among the priority species that drive the fishery and for which assessment is regularly carried out (GFCM, 2018). In this respect, an annual assessment of the red mullet stock is essential to reveal the current situation, sustainably exploit the stock, and manage (adjust) the fishing fleet and provide management recommendations. According to the GFCM stock assessment results of 2021, the status of the red mullet stocks was considered as sustainably exploited in GSAs 15, 22 and GSA 24 in the entire Mediterranean Sea (FAO, 2021).

The spawning season for red mullet in the northeastern Mediterranean and the Aegean Sea is generally considered to be between April and August (Akyol et al. 2000; Becer Özvarol et al. 2005; Kokokiris et al. 2013; Ok and Gücü, 2013). This coincides with the 15 April to 15 September temporal closure for trawlers in the territorial waters of GSA 24. Most of the red mullet stock in Türkiye is caught by trawlers and therefore, even though there is no temporal restriction for the use of gillnets in the Turkish Fishery Regulations (MoAF, 2020), spawners of red mullet still enjoy a level of protection.

The MoAF (2020) also apply some spatial restrictions concerning the bottom trawl fisheries between 1 to 3 nautical miles from the shore to protect fisheries resources on the Mediterranean coast of Türkiye. However, because sensitive habitats, such as spawning and nursery grounds, have yet to be identified, no special protective measures have been taken to date. In 1983-1984, Gücü and Bingel (2022) reported that red mullet stocks were distributed along the basin on an offshore band around 50 – 80 m depth during the spawning season, and after the spawning season aggregated on the shallow waters (5-15 m) near the rivers, which were therefore suspected to be the most important nursery sites. However, more research should be carried out to update the knowledge on red mullet spawning and nursery grounds, so that these areas can be protected.

Ethical Statement

This research followed all applicable guidelines for the care and use of fish.

Funding Information

This study was funded by the EastMed project of the Food and Agriculture Organization of the United Nations (FAO).

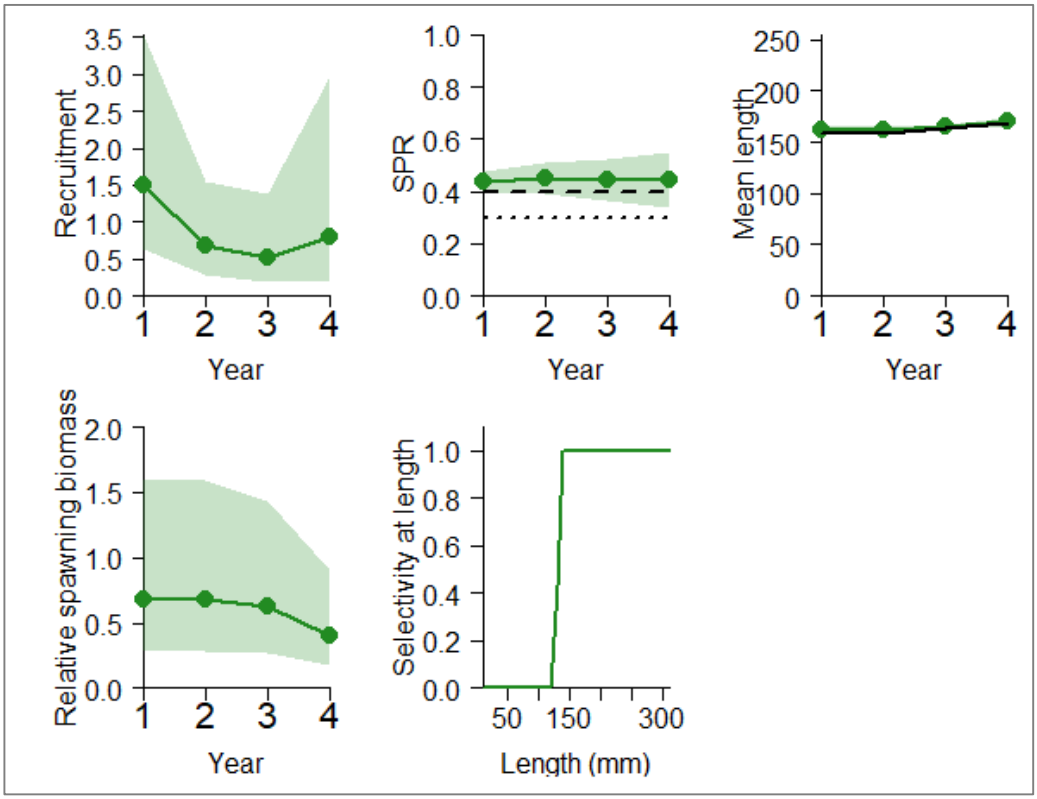

Figure 6. Graphical output produced through length-based Bayesian (LBB) estimation for red mullet.

Author Contribution

Data analysing by Savaş Kılıç, conceptualization and writing draft by Savaş Kılıç and Nazlı Demirel, review and editing by Savaş Kılıç, Nazlı Demirel, Mümtaz Tıraşın, Marcelo Vasconcellos and Stefano Lelli, data collection by Savaş Kılıç, Süleyman Öztürk and Süleyman Sarıgöz, funding acquisition and project administration by Serkan Erkan, Mahir Kanyılmaz, Marcelo Vasconcellos and Stefano Lelli were performed. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest**.**

Acknowledgements

The authors thank the data collectors Deniz Hasbek, Sinan Gelen, Hakan Dağhan, Hüseyin Hilmi Öter, Mehmet Kaya, Fatih Kızılyamaç and Ömer Toklu, from the Hatay, Adana and Mersin Province Directorate of Agriculture and Forestry for contributing to the sampling.

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