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RESEARCH PAPER

Length Based Assessments for European Pilchard *Sardina pilchardus* and European Anchovy *Engraulis encrasicolus*, in the İzmir Bay, Aegean Sea

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Abstract

In the Mediterranean Sea, European pilchard *Sardina pilchardus* and European anchovy *Engraulis encrasicolus* are the most important small pelagic fish regarding their ecological role, and revenue. Here, we perform a comprehensive assessment of length-based methods for those small pelagics from İzmir Bay, Aegean Sea. Therefore, the Length-based Bayesian Estimator and Length-based Spawning Potential Ratio were used to evaluate the stock structure and status of two important small pelagic fish. The length range for *Sardina pilchardus* was from 7.1 cm to 17.3 cm in TL. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were over 1, suggesting truncated length structure and fishing of not too small individuals. The proportion of mature individuals in the catch was far less than half (36%) suggesting that in these fisheries catch consists mostly of immature individuals. The length range for *Engraulis encrasicolus* was from 5 cm to 15 cm in TL. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were over 1 (1.2 and 1.3, respectively), suggesting truncated length structure and fishing of large individuals. The proportion of mature individuals in the catch was over half (52%) suggesting that in these fisheries catch consists of adults. The estimated sizes at median 50% selectivity (SL_{50}) for *S. pilchardus* (11.1 cm) was ~0.6 cm shorter than its lengths at 50% maturity (L_{50}) of 11.7 cm, which indicates that a large proportion of the catch was immature. The median estimate of the spawning potential ratio was ~0.19 for *S. pilchardus* and ~0.48 for *E. encrasicolus*.

Introduction

A fundamental aspect of ecology and fisheries research is to improve knowledge on how fish grow (Mion et al., 2020). Fish shows a species-specific response to temperature increase even under similar abiotic conditions. For example, the demersal fish presents greater thermal plasticity than the pelagic fish (Kikuchi et al., 2019), but does not respond quickly as small pelagics which have characteristics such as rapid growth, short lifespan, and quick response to the environmental changes (Schreiber et al., 2011). Small pelagics have the highest catch rate in the world fisheries (FAO, 2020), as well as in the Turkish fisheries (Demirel et al., 2020; TurkStat, 2022). The purse seine is main fishing technique in pelagic fishery and it has been recognized the most productive fishing tool that approximately one-third of the global catch has been obtained for the last 50 years (FAO, 2020). In the Mediterranean Sea, European pilchard *Sardina pilchardus* and European anchovy *Engraulis encrasicolus* are the main small pelagic species regarding their ecological role, high abundance and revenue. Especially in the Aegean Sea, small pelagic species provide high revenue (Stergiou & Laskaratos, 1997).

The size composition or length-frequency distribution of a fish population has long been used as one of the data sources to assess stock status in fishery management (Pauly & Morgan, 1987; Gulland & Rosenberg, 1992; Costello et al., 2012; Froese et al., 2018). Length-based Bayesian estimator (LBB; Froese et al., 2018) is one of the methods used in data-limited stock assessment basis on length frequency data. LBB works for species that growth throughout their lives, such as most commercial fish and invertebrates, and requires no input in addition to length frequency data. It estimates asymptotic length (L_{inf}), length at first capture (L_c), relative natural mortality (M/K) and relative fishing mortality (F/M) over the age range represented in the length-frequency sample. Length-based spawning potential ratio (LBSPR, Hordyk et al., 2015) is defined as the proportion of the unfished reproductive potential left in the population at any given level of fishing pressure. It is based on the concept that without fishing a fish population can complete 100% of its natural potential for spawning, but that fishing reduces a population's SPR. Unlike fishing mortality-based approaches, which directly relate to some part of the population removed each year by fishing, SPR method reflects the cumulative effect of fishing and ecological impacts on the spawning potential of exploited stocks for a few previous years (a life span of period approximately). Recently, data-limited models were subjected to their performance metrics in real stocks, in order to evaluate accuracy of their outputs according to resilience of species/stocks based on life history characteristics (Chong et al., 2019; Bouch et al., 2020; Free et al., 2020; Pons et al., 2020). Commonly used three length-based assessment methods in the data-limited fisheries, length-based integrated mixed effects (LIME; Rudd & Thorson, 2018), LBSPR and the LBB were recently evaluated for their performance. It was concluded that, compared to the other two methods, LBB performed better in estimating the depletion levels of heavily- and moderately-fished stocks, especially for the short-lived species, while estimations using both the LBB and LIME for long-lived, slightly-fished species generally resulted in more biases (Pons et al., 2020).

Here, we perform data-limited stock assessment of length-based methods for the most important small pelagics, *E. encrasicolus* and *S. pilchardus* from İzmir Bay Aegean Sea. Therefore, the Length-based Bayesian estimator (LBB) and Length-based spawning potential ratio (LBSPR) were used to evaluate stock structure for three-years length-frequency data. Since, the ratio of older / larger fish in the population is one of the expected indicator of a healthy stock, length-based methods aim to provide an evidential basis for the protection and management of fishery resources in the İzmir Bay.

Materials and Methods

Samplings in İzmir Bay

Catch statistics show half of the small pelagic catch in the Aegean Sea constitute by Turkey (FishStat, 2022). The catch of *S. pilchardus* is slightly higher and more stable than *E. encrasicolus* in years (Figure 1).

The İzmir Bay is an important fishing ground in Turkish Aegean coast. There are 50 purse-seiners registered with the Association of Aegean Region Fishers and consequently fishing in Aegean Turkish waters. Approximately 1/5 of total purse-seine vessel operate in the İzmir Bay throughout the season, while the others are scattered in other gulfs and inlets of the Aegean.

Samplings were performed by commercial purse-seine vessel "Afala" during fishing season by monthly frequency from 2017 to 2019. The vessel was preferred as it was a typical purse-seine vessel operate in the İzmir Bay with 23.4 m in length and 313.3 kW in engine power. According to Turkish fishery law, purse-seine fishery is prohibited between 15 April -1 September annually to protect many commercial species' spawning season (BSGM, 2020). Therefore, purse-seiners are active 225 days with duration of 60-120 min. operation daily. All specimens obtained during each fishing haul were measured in length to the nearest 0.5 cm. Length frequency (0.5 cm) were used for analysis.

Length-based Assessments

Growth parameters for marine fish species were collected from a literature review of peer-reviewed articles, unpublished thesis and project reports (Table 1). Literature review were principally collected for İzmir Bay as much as possible. If sources for the region were unavailable, data from neighboring waters were used.

We used length-based Bayesian biomass estimation method (LBB) by Froese et al. (2018; 2019) for the analysis of size composition, such as length-frequency (LF) data from commercial catches, where all relevant parameters are estimated simultaneously with a Bayesian Monte Carlo Markov Chain (MCMC) approach.

It is assumed that the growth in length follows von Bertalanffy's (1938) growth equation:

$$L_t = L_{inf}\left(1 - e^{-K(t-t_0)}\right)$$

When the fish are fully selected by the gear, the curvature of the right side of catch samples is a function of total mortality (Z=*M*+*F*) relative to K. the following equation describes the framework for approximating stock status from L_{inf}, *M/K*, *F/K*, and L_c (Froese et al., 2016). First, given the estimates of L_{inf} and M/K, L_{opt}, i.e., the size at which cohort biomass is maximum can be obtained. A given fishing pressure (F/M), the mean length at first capture which maximizes catch and biomass (L_{c_opt}) can be obtained from:

$$L_{c_{opt}} = \frac{L_{inf}\left(2+3\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)}$$

A proxy for the relative biomass that can produce MSY (B_{MSY}/B_0) with *F/M*=1 and L_c=L_{c_opt} (Froese et al., 2018). The relative biomass and the length at first capture estimated by LBB can then be used directly for management of data-poor stocks. If relative stock size B/B_0 is smaller than B_{MSY}/B_0, reduce catches. If the mean length at first capture L_c is smaller than L_{c_opt}, start fishing at larger sizes.

We also used other length-based method, the LBSPR which utilizes the size structure of an exploited population. SPR is a function of relative fishing pressure (*F/M*), the ratio of fishing (*F*) to natural (*M*) mortality, and the two main life history ratios, *M/K* and L_m /L_{inf} (Hordyk et al., 2015). *K* is the von Bertalanffy growth co-efficient, L_m is the size of maturity at which 50% of a size class is mature and L_{inf} is asymptotic size. The inputs to the LBSPR model are: (i) the *M/K* ratio, (ii) the mean asymptotic length (L_{inf}), (iii) the variability of length-at-age (CV L_{inf}), which is difficult to estimate directly without reliable length and age data, and normally assumed to be around 10%; and (iv) an estimated size of maturity (L_m) specified in terms of the length at which 50% (L_{50}) and 95% (L_{95}) of a population is mature. In practice the L_{inf} of a stock is unlikely to be known and practically impossible to estimate in a data poor fishery.

SPR index can be calculated as the ratio of the equilibrium reproductive output per recruit that would occur with the current year's fishing intensity and biological parameters of fish, to the equilibrium reproductive output per recruit that would occur with the same biological parameters without fishing activity. It ranges between 0 and 1, with a value of 1 representing an unexploited stock. Therefore, the status of stock can be classified into three different groups, which are under (SPR>0.4), moderate (0.2<SPR<0.4) and over (SPR<0.2) exploited. SPR can be used to set targets and limit reference points for monitoring of stock status.

Results

In this study, length measurements were performed on 29,836 and 25,797 individuals for *Sardina pilchardus* and for *Engraulis encrasicolus* respectively.

Length range for *S. pilchardus* was from 7.1 cm to 17.3 cm in TL. Estimated relative fishing mortality *F/M* was found 5.8, while estimated relative biomass (B/B_{MSY}) was found 0.30 for the year 2019. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were 1.1 for both (Table 2, Figure 2a). The ratio of L_{95th}/L_{inf} was 0.92. The proportion of mature individuals in the catch was 36%.

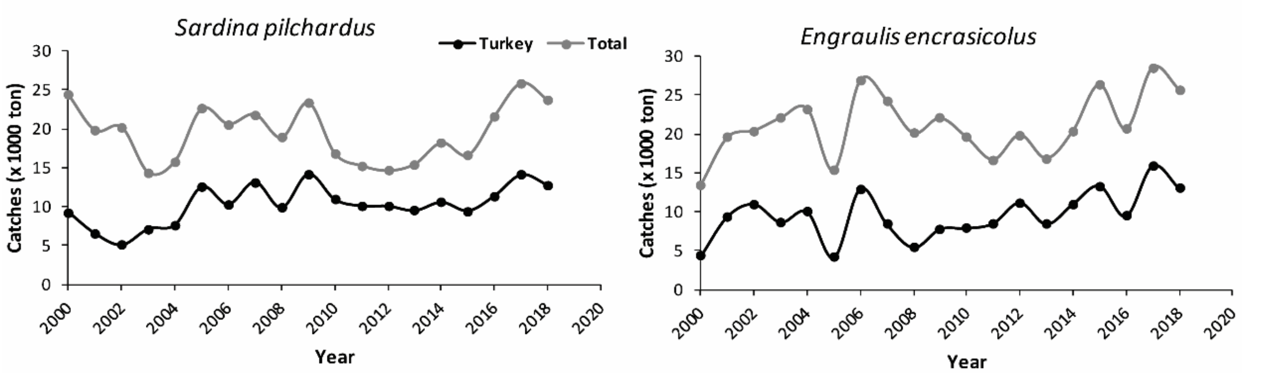

Figure 1. Total catch of *Sardina pilchardus* and *Engraulis encrasicolus* in the Aegean Sea with Turkish portion between 2000 and 2020.

Table 1. Literature review for size-at-maturity (L_m) and von Bertalanffy growth parameters for *Sardina pilchardus* and *Engraulis encrasicolus* in the Aegean Sea

Species	L_m (cm)	L_{inf} (cm)	t_0	*k* (1/y)	L_{max} (cm)	Area	References
	12.0	20.7	-3.58	0.18	19.5	İzmir Bay	Cihangir, 1996
Sardina pilchardus	11.7	17.2	-1.28	0.53	17.3	NW Med.	Tsikliras & Koutrakis, 2013
	11.5					NW Med.	Gucu et al., 2013
Engraulis encrasicolus	10.5	-				Aegean Sea	Somarakis et al., 2004
	8.8					NW Med.	Gucu et al., 2013

Table 2. Outputs of LBB and LBSPR analysis

Species	Years	L_{inf} (cm)	L_{opt} (cm)	SL_{50} (cm)	SL_{95} (cm)	*F/M*	B/B_{MSY}	Y/R'	SPR (%)
Sardina pilchardus	2017-2019	17.0	11.0	11.1	12.1	5.80	0.30	0.02	0.19
Engraulis encrasicolus	2017-2019	12.7	8.4	9.3	10.4	1.20	1.40	0.02	0.48

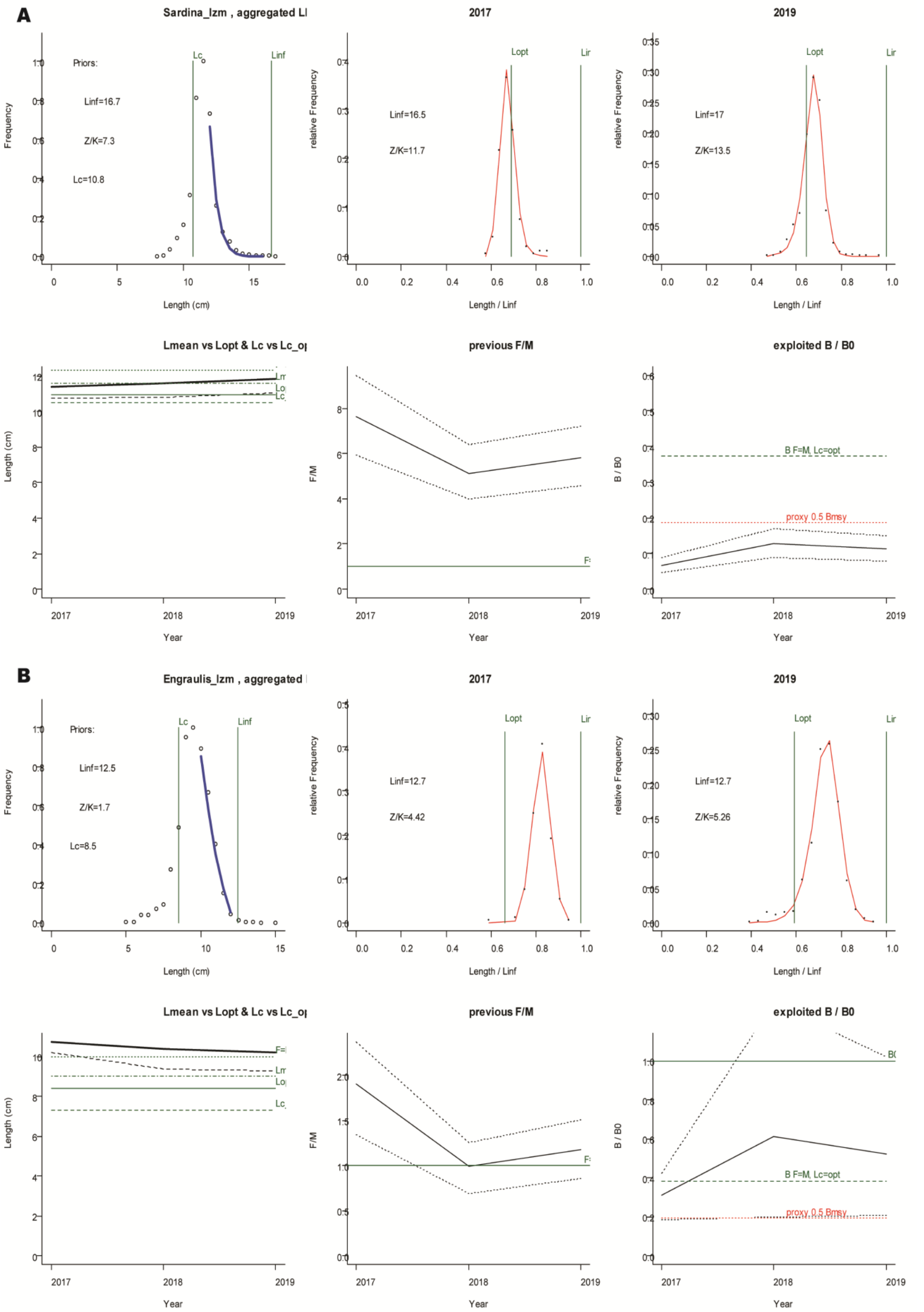

Figure 2. Graphical output produced via LBB model for a) *Sardina pilchardus* (Sardina_Izm) and b) *Engraulis encrasicolus* (Engraulis_Izm) in the Izmir Bay for the years 2017–2019. The left panels show the accumulated length frequency (LF) data, and the right panels show changes in L_{mean}.

Length range for *E. encrasicolus* was from 5 cm to 15 cm in TL. Estimated relative fishing mortality *F/M* was found 1.2, while estimated relative biomass (B/ B_{MSY}) was found 1.40 for the year 2019. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were 1.2 and 1.3 respectively (Table 2, Figure 2b). The ratio of L_{95th}/L_{inf} was 0.95. The proportion of mature individuals in the catch was 52%.

The estimated sizes at median 50% selectivity (SL_{50}) for *S. pilchardus* was 11.1 cm. (Figure 3a, Table 2), which indicates that a large proportion of the catch is immature. For *E. encrasicolus*, SL_{50} was found 9.3 cm which is similar to its maturity size. The median estimates of the spawning potential ratio (SPR) was ~0.19 for *S. pilchardus* and ~0.48 for *E. encrasicolus*. The estimated median SPR was constrained to a relatively low range of values for *S. pilchardus* (~0.19), except *E. encrasicolus*, where the 25th to 75th percentiles ranged from ~0.35 to 0.63 (Figure 3b).

Discussion

In this study, we analyzed stock status of two important small pelagic fish by length-based data limited models using length-frequency data obtained from commercial purse seine fishery in İzmir Bay. We found that *S. pilchardus* stock was overfished, its fishery was not sustainable and this stock needs better management measures, while *E. encrasicolus* stock was healthy and its fishery was found sustainable. LBB model results showed that almost 64% of *S. pilchardus* catch constitutes juveniles and immature adults in İzmir Bay. The proportion of mature individuals in the catch was far less than half, suggesting that in these fisheries catch consists mostly of immatures. Biomass ratio was found outside of safe biological limits (B<0.5 B_{MSY}), while fishing mortality was 5 times higher than natural mortality. Average length, catch length and optimal length ratios was over 1, suggesting 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 SL_{50} for *S. pilchardus* was ~0.6 cm shorter than its L_{50}, while the estimated median SPR for *S. pilchardus* was below limit 20% as the biological reference point. For *E. encrasicolus* stock, LBB outputs indicated high biomass ratio (B ≥ B_{MSY}) and LBSPR model found SPR was over 40% which is the target sustainable reference point. Average length, catch length and optimal length ratios were over 1, suggesting truncated length structure and fishing of large individuals. The ratio of the 95th percentile length to asymptotic length was slightly lower than 1, suggesting that large fish were properly present in the catch. The proportion of mature individuals in the catch was slightly over than half suggesting that in this fisheries catch consists of adults.

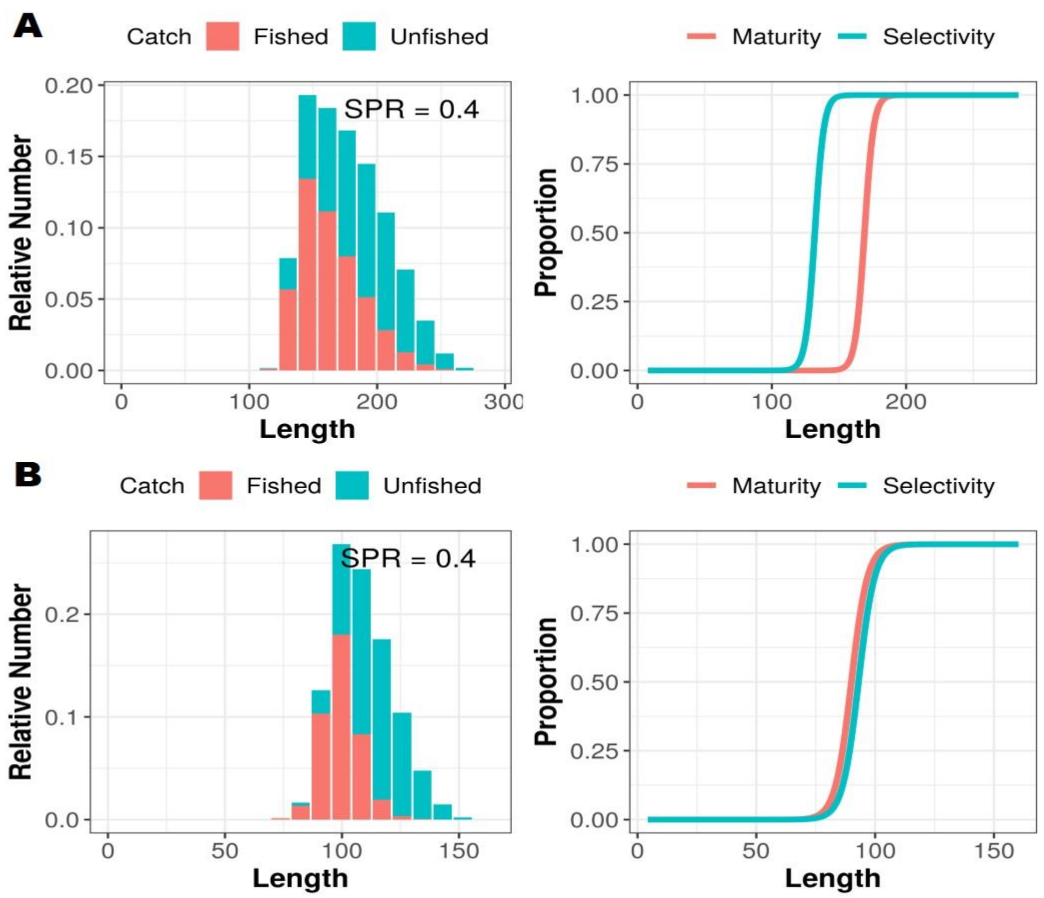

Figure 3. Graphical output produced via LBSPR estimation for a) *Sardina pilchardus* (Sardina_Izm) and b) *Engraulis encrasicolus* (Engraulis_Izm) in the Izmir Bay for the years 2017–2019. The left panels show population structure according to 40% SPR, and the right panels show selectivity and maturity curves.

Fisheries has serious effect on the changes in size distribution of fish population (Leitão, 2019). Some recent work on Mediterranean fisheries stocks shows that the mean catch sizes of many taxa are shrinking (Pauly et al., 1998; Damalas et al., 2015), from very high fishing pressure, the length of maturity decreases as an evolutionary response (de Roos et al., 2006). Because, the nature of fisheries is size selective, its first aim targeting the valuable large fish which cause alteration in reproductive capacity, recruitment, and further community structure (Shin et al., 2005; Tu et al., 2018). Young individuals which have a better chance of food competition can reach the condition required for sexual maturity at an earlier age. In studies investigating the effects of fishing pressure on populations, in accordance with the findings in this study, it was reported that the average catch length decreased in the exploited stocks. (Jennings et al., 1999; Götz et al., 2008). Maturity length (L_m) signifies the length at which 50% of individuals in a population reached sexual maturity, is a very useful tool towards understanding the sustainable potential of a stock (Froese et al., 2019). Since larger matured fish have much higher fecundities, some suggest to shift size at first capture towards a larger optimal length or at least by limiting juvenile exploitation so that recruitment can occur (Vasilakopoulos et al., 2014; Froese et al., 2016).

In fisheries management there are indirect control regulations on harvesting fish stocks such as minimum landing size (MLS), seasonal and temporal closures, gear restrictions (Maynou, 2020). MLS implementation is a very common regulations and in Turkey many commercial species have their own MLS. For *S. pilchardus* MLS is set at 11 cm in TL (Soykan, 2019), which is below the size of maturity for this species as L_m=11.7 cm. For *E. encrasicolus*, MLS is set to 9 cm in TL which is suitable for this species maturity size. According to our length-based assessment results, it is clear that MLS regulation should be immediately rearranged and raised up to 12 cm in TL for *S. pilchardus* in order to recover its stock. Another indirect control regulation in Turkey, seasonal closure in industrial fisheries which has been implemented since 1970s and it is the longest one (from 15 April – 1 September) in the entire Mediterranean Sea. Seasonal fisheries closures were found effective for summer spawning species (Yıldız et al., 2020), and as a summer spawner *E. encrasicolus* (Somarakis et al., 2006) benefitted from seasonal closure. However, *S. pilchardus* is known that its reproductive period in the Aegean Sea is quite long and they lay eggs in the winter and spring months (Ganias et al., 2007). Therefore, this species has almost no benefit from seasonal closure period and it is not protected during its spawning season. We highly recommend that species-specific regulations regarding fishing ban during spawning period should be rearranged.

In our study, main limitation is shortness of time series data, still as it is the first attempt to understand stock status of two important small pelagic fish, we believe our study will serve a baseline for better fisheries management. Although indirect control measures in fisheries are important, direct control measure of quota application is requested by both fishers from the region and fisheries scientist.

Ethical Statement

Not applicable.

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Author Contribution

ZT and AMŞ performed samplings and length measurements. ND run analysis and evaluate outputs. ND and AMŞ reviewed literature data, ZT provided management information. ND wrote the first draft, all authors contributed to the final versions.

Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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