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Conserve immatures and rebound the potential: stock status and reproduction of whiting (*Merlangius merlangus* [Linnaeus, 1758]) in the Western Black Sea

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ABSTRACT

The stock structure and productivity components (growth, maturity and mortality) of the Black Sea whiting *Merlangius merlangus* were studied in the western Black Sea for a year. The results aim to improve fisheries management of whiting in the Black Sea. Fresh samples were collected from commercial bottom trawlers between October 2017 and September 2018. Using monthly length-frequency data set for the growth trajectories, a bootstrapped procedure was employed to improve parameter optimization. Duration and timing of the spawning season and size at sexual maturity were modelled using generalized additive models (GAMs). The presence of clear differences in oocyte size groups indicates that oocyte development of Black Sea whiting is a 'group synchronous' ovarian developmental process characterized by continuous reproduction. From the gonadosomatic index values, their spawning activity intensifies especially between October and April, captured also in the time component in the GAM modelling. The length at first maturity was 13.9 cm for females and 12.5 cm for males. The mortality rates, yield per recruit analyses, and length-based indicators suggest that whiting is heavily exploited with alarming signs of overexploitation. Undoubtedly, setting catch limits and re-establishing management plans will be the first two steps to ensure reproductive success and prevent overfishing ($F >$ Fmsy).

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Introduction

Whiting, *Merlangius merlangus* (Linnaeus, 1758) is an important commercial fish species distributed in the North-Eastern Atlantic and the Mediterranean and Black Seas (Froese and Pauly 2020). From a fisheries resource perspective, its global landings have mainly been taken from North-eastern Atlantic waters (mainly Bay of Biscay, North Sea, Irish Sea and Baltic Sea) and its adjacent seas in the Mediterranean, mainly the Black Sea and Adriatic Sea. Inherently, the Black Sea is one of the important fishing grounds after the North Sea and Celtic-Biscay Shelf for whiting fishery. Globally, Turkey is the second country with the highest whiting fisheries after the UK (Pauly et al. 2020). According to FAO statistics (FAO, 2020), the annual world catch of whiting increased sharply from ~100,000 tons in 1950, up to levels of 300,000 in 1976. Since then, landings have decreased steadily, with the exception of some years, to the lowest levels (around 50,000 tons) observed in the past 20 years.

According to Turkish national fisheries statistics, whiting dominates the main demersal catches in the Black Sea (TUIK 2021). Historically, whiting was the most abundant demersal species in the Black Sea, but, since 1990, its abundance and catch decreased dramatically (STECF 2014; Figure S1), patterning a classic 'boom and bust' cycle. In the Mediterranean and Black Sea, however, whiting has been categorized in the Least Concern level by the IUCN (Nedreaas et al. 2014). It has an important ecological role in the Black Sea ecosystem where adults are considered top predators feeding mainly on fish (e.g. sprat, anchovy, juvenile whiting, etc.) (İşmen 1995). Stock shows only bathymetric seasonal and ontogenic migrations from shallow waters to deeper and vice versa (Genç et al. 1998).

Whiting is a member of the Gadoid family and is caught commercially by the artisanal and industrial fisheries with assorted fishing gears (bottom trawls, gillnets, deep water cast nets) in the Black Sea. In particular, whiting has been heavily exploited inside the 100-m isobaths by the industrial fleet, which regularly operates along the Turkish coasts of Western Black Sea and is responsible for 85% of whiting landing (Zengin et al. 1998). The Turkish multi-species (red mullet,

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turbot and whiting) industrial fishery that operates on the whiting is composed of 197 and 147 bottom trawlers in the Western and Eastern Black Sea, respectively (TUIK 2021). For the other Black Sea riparian countries whiting is of little interest and is thus not targeted but generally caught as by-catch. The only two measures to help rebuild this stock in Turkish waters are a Minimum Landing Size (MLS) regulation and a seasonal 'summer ban' on all industrial fishing (BSGM 2020).

Biological and ecological research on whiting have been conducted in the Black Sea. However, many studies on the characteristics of whiting have primarily occurred in the 'Eastern Black Sea coast of Turkey', in most cases dealing with length-weight relationship (İşmen 1995; Kalaycı et al. 2007; Bilgin et al. 2012;), population parameters (İşmen 1995; Şahin and Akbulut 1997; Sağlam and Sağlam 2012), feeding (Mazlum and Bilgin 2014), habitat (Çiloğlu et al. 2001), reproduction and fecundity (Bilgin et al. 2012; Mazlum and Bilgin 2014; Taylan et al. 2018) and size selectivity (Kalaycı and Yeşilçiçek 2014). Some of these studies were conducted decades ago, but were also specific to certain seasons, which may provide a fragmentary picture of whiting fisheries. In addition, knowledge of the whiting life history traits in the 'Western Black Sea' remains inadequate for an accurate stock assessment. Moreover, genetic studies have found low, but significant genetic differentiation between the central Black Sea (Sinop) and Turkish Strait System region (Bektaş 2003). Therefore, regional stock studies of whiting are important for accurate fisheries management.

Fishery management in the Black Sea shows the absence of long time-series of abundance indices; availability of this type of data enhances a key indicator to categorize the stock status uncertainty. Thus, from the stock assessment point of view, whiting might be considered as a data-limited fishery resource. Currently, the data-limited stock assessment methods used to define the stock status in developed countries may greatly contribute to improving the knowledge of the status of fisheries (Pérez 2019). Moreover, detailed knowledge of exploitation states is vital for management plans.

The number of scientific studies on the reproduction and stock status of whiting, which is a very important finfish resource for Turkey's Black Sea fisheries, is insufficient considering the size of Turkey's coastline on the Black Sea. The ecological and also economic impacts of the decline in whiting landings over the last 20 years show the need for more extensive research toward better management. To close this data gap, the objectives addressed in this first detailed study are (i) to assess stock assessment indicators (growth parameters, mortality rates and exploitation status, yield per recruit); (ii) to define the spawning cycle and peaks; and (iii) to estimate length at maturity (L_{mat}) by sex in the Western Black Sea. The main aim of this study to provide details of the reproductive aspects of whiting in the Western Black Sea, which can contribute to improvement of stock assessment and effective management of this species in the region.

Materials and methods

Sampling

Whiting specimens were collected monthly between October 2017 and September 2018 from the western Black Sea coast of Turkey by commercial bottom trawl vessels. During the industrial summer ban period, the samples were collected by a commercial vessel with the permission of the Ministry. Altogether 1040 females, 833 males and 115 unsexed immature individuals were collected for biological analysis in this study. Apart from these 1988 samples, only total length (TL) measurements of 1598 samples were made to be used in the calculations of growth parameters. Measurements performed in the laboratory included total length (TL, at the nearest 0.1 cm), body weight (TW, at the nearest 0.1 g), sex, gonad weight (GW, with an accuracy of 0.01 g), and liver weight (LW, with an accuracy of 0.01 g). Male and female whiting are sexually dimorphic and easily identifiable based on gonadal characteristics. The sex ratio was expressed as a percentage and determined by the following equation 'n_{sex}/total number of fish" $\times 100$'. The sex ratio was tested by the χ^2 test for significance.

Growth analysis

The length-weight relationship (LWR), $W = aTL^b$ was converted into its logarithmic expression: $Loga + bLogTL$. The parameters *a* and *b* were calculated by least-squares regression, as was the coefficient of determination (R^2). The b value of the species was tested by a t-test ($\alpha = 0.05$) in order to verify whether it was significantly different from 3. Length frequency analysis (LFA) was used to obtain the growth parameters. In total, 3586 individuals were grouped into size class intervals of 1 cm to obtain monthly length frequency distributions (LFDs), assuming that the sample adequately represents the length distribution of the total catch from the bottom trawl fishery. LFA has been deployed successfully for some gadoid species (Aldebert and Morales-Nin 1992). For this analysis, Pauly's most popular technique of Electronic

Length-Frequency Analysis (ELEFAN I) was implemented by use of TropFishR package (Mildenberger et al. 2017) applying the R software program (R Core Team 2018). By using this package one can do an arrangement for choosing an appropriate bin width to maximize the Rn score of non-parametric scoring from the goodness of fit index (Taylor and Mildenberger 2017). For optimum search and improvement in the accuracy of the growth parameters, the LFD was binned according to the formula of Wang et al. (2020); Optimum Bin Size (OBS) = 0.23 × Lmax 0.6. Figure S2 shows the raw LFD data and after restructuring with a moving average of 5. The TropFishR package provides two novel optimization routines for the fitting of von Bertalanffy growth function (VBGF) or seasonally oscillating VBGF (soVBGF) parameters: (i) the 'ELEFAN_SA' function uses the Simulated Annealing algorithm in the package 'GenSA', and (ii) the 'ELEFAN_GA' function using the Genetic Algorithm package 'GA' (Scrucca 2013). After determining the best method by best goodness of fit (max Rn score), the bootstrapped ELEFAN_ GA function was also rerun for allowing assessment of the uncertainties around the growth estimates according to Schwamborn et al. (2018). Bootstrapped ELEFAN provided a holistic and robust assessment of the fisheries with sequential estimation of growth (Abobi et al. 2019). soVBGF formulated as: Lt = Linf (1 − exp(−(Lt L_∞ k(t − t0) + S(t) − S(t0)))), where S(t) = (CK/2π) sin 2π(t − ts), C is a constant indicating the amplitude of the oscillation, typically ranging from 0 to 1, and ts is the fraction of a year (relative to the age of recruitment) where the sine wave oscillation begins (Taylor and Mildenberger 2017), L_t is the fish length (cm) at time t (years), L_∞ is the asymptotic length (cm), k is the growth coefficient (years^{-1}), and t0 (years) is the hypothetical time at which the length is equal to zero. Winter Point (WP) designates the period of the year expressed as a fraction of a year when growth is slowest. In the northern hemisphere, WP is often found in the neighbourhood of 0.2, i.e. in February, while WP often has a value of 0.7 in the southern hemisphere. The WP is related to ts through: ts + 0.5 = WP (Pauly 1987). Munro's growth performance index $\varphi' = \log(k) + 2\log(L_\infty)$ and t-test (Pauly and Munro 1984) were used to test the accuracy of the growth parameters.

Macroscopic and histological classification of gonads

Each specimen was macroscopically assigned to a gonadal stage on the basis of a scale consisting of five maturity phases where: Phase I = immature; Phase II = developing or regenerating; Phase III = spawning capable; Phase IV = actively spawning; and Phase V = regressing (Brown-Peterson Nancy et al. 2011). To corroborate the macroscopic classification of females, a subsample of female gonads was histologically examined. Sub-sampled female gonads were fixed in formalin solution before dehydration and embedding in paraffin. After this processing step, sections of 5-µm thickness were cut, placed in glass slides, stained using a haematoxylin-eosin staining procedure and examined using a light microscope (Galimany et al. 2015). The immature ovaries (maturity stage 1) comprised oocytes in the primary growth phase and thin ovarian wall (PG; Figure 1-I). The oocytes of developing ovaries (maturity stage 2) had initiated the secondary growth phase with the formation of cortical alveoli (CA; Figure 1-II). Entry into the spawning capable phase was characterized by the appearance of tertiary vitellogenic (Vtg3) oocytes (Figure 1-III) and active spawning can be used to identify those fish that are progressing through germinal vesicle breakdown (GVBD), or hydration. The regressing phase was recognized by the presence of oocyte atresia, a reduced number of vitellogenic oocytes, and, in some species, Post Ovulatory Follicles (POFs) (POF; Figure 1-IV). The regenerating phase was differentiated from the immature phase by (i) a thicker ovarian wall (OW; Figure 1-V); (ii) the presence of more space, interstitial tissue and capillaries around PG oocytes, (iii) the presence of muscle bundles (Brown-Peterson Nancy et al. 2011).

Spawning season and size at first maturity

The spawning season was identified by analysis of the monthly variation of the changes in gonadosomatic (GSI), hepatosomatic (HSI) and condition factor (K) indices for each sex. The GSI, HSI and K were calculated according the following equations: GSI = (GW/TW) × 100; HSI = (LW / TW) × 100; K = (TW/L^3) × 100. Length at first maturity (L_{mat}) was defined as the length at which 50% of individuals had already spawned at least once, and was calculated by incorporating individuals with gonadal stages higher than stage II. L_{mat} was estimated for both sexes using a logistic function that was fitted to the proportion of sexually mature individuals by each size class using a non-linear regression following King's (1995) formula; $P = 1/\{1 + \exp[-r(L - L_{mat})]\}$, where P is the proportion mature in each size class, r (−b slope) is a parameter controlling the slope of the curve and L_{mat} is the size at 50% maturity. For this analysis, the sizeMat package (Torrejon-Magallanes 2019) was used by R programming. Markov Chain

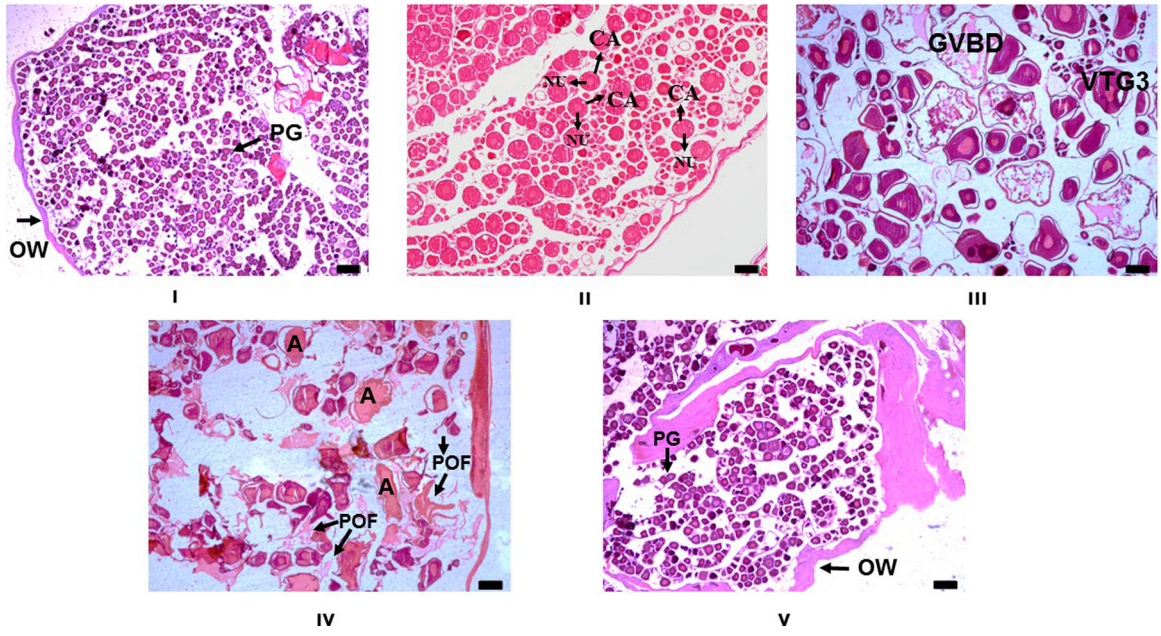


Figure 1. Five microscopic maturity stages of ovary. I: Immature (never spawned). II: Developing (ovaries beginning to develop, but not ready to spawn). III: Spawning capable (fish are developmentally and physiologically able to spawn). IV: Regressing (cessation of spawning) with hydrated oocytes (HYD). V: Regenerating. (A = Atresia; CA = cortical alveolar; GVBD = germinal vesicle breakdown; NU: Nucleus, OW: Ovarian wall; PG = primary growth; POF = postovulatory follicle complex; Vtg3 = tertiary vitellogenic). Scale bar indicates 200 µm for all stages.

Monte Carlo was used for logistic regression (Bayes GLM) that generates a sample from the posterior distribution of a logistic regression model using a random walk Metropolis algorithm.

GAM modelling for spawning activity

Individual GSI results from the biological data were modelled using the generalized additive model (GAM). An additive model is an extension of the classic linear model, allowing linear functions of the response variable (GSI) and the predictors to be replaced by smooth functions, and does not require functional assumptions (Agenbag et al. 2003). GAM modelling was applied to find the maximum GSI output related to other biological predictors. The explanatory variables used in model were: (a) TL, (b) days of year (used as a continuous variable), (c) mean seawater temperature and (d) gonadal stages. The 'mgcv' package (version 1.30-27) of the R program was used for this modelling. Mean seawater temperature values were taken monthly from the Turkish State Meteorological Service (https://mgm.gov.tr/deniz/deniz-suyu-sicakligi.aspx).

Mortality rates and Yield per Recruit analysis

The total mortality rate (Z) was estimated using the pooled length frequency data through the linearized length-converted catch curve analysis (Pauly 1983). The natural mortality rate (M) was estimated through the most recent empirical formula which requires the VBGF growth parameters (L_∞ and k) (Then et al. 2015); $M = 4.118k^{0.73}Linf^{-0.33}$. The fishing mortality rate, F, was deduced from the expression F = Z-M, and the exploitation ratio (E) from E = F/Z. The parameter E expressed the proportion of a given population that ultimately dies due to fishing under an existing exploitation pressure.

Here, the length-based yield per recruit model by Thompson and Bell (1934) was used to evaluate the exploitation levels used to provide biological reference levels and to deduce input control measures. The fishing mortality for which to estimate the yield trajectory was obtained by varying the parameter F in the Thompson and Bell model. In a length–frequency curve, Lc can be determined as the length at half of the maximum frequency in the ascending part of the curve (ICES 2012). a and b values of LWR equation of this study was used for this analysis. Calculated F values were compared against reference points derived from the YPR prediction model of Beverton and Holt (1957): (i) the highest biomass per recruit (F_{max}); (ii) a 50% reduction of the biomass of unexploited population (F0.5); and (iii) a fishing mortality which corresponds to 10% of the slope of the yield per recruit curve in the origin (F0.1). All analyses

were conducted using the TropFishR package in the statistical computing software 'R' (version 3.4.2).

Length-based reference points

The length-based reference points can be used as proxies when biomass are unknown (ICES 2012): length at 50% maturity (L_{mat}), length at first capture (Lc), length where growth rate in weight is maximum ($L_{opt} = (3/(3 + M/k))*L_{\infty}$), and the theoretical length resulting from fishing with F = M ($L_{m=f} = (3 * Lc + L_{\infty})/4$). Lc is the length class where 50% of the individuals are vulnerable to, and retained by, the gear, where N = Nmax/2 or half way up the ascending limb of the curve. P_{mega} is defined as those fish which are mega-spawners ($L_{opt} + 10\%$). LB-SPR requires as input the length composition data and the ratio of natural mortality to the von Bertalanffy growth coefficient (M/k), L_{∞}, length at 50% and 95% maturity (16.1 cm). The Length-Based Spawning Potential Ratio (LB-SPR) is a length-based modelling generates the estimation of Spawning Potential Ratio (SPR), developed by Hordyk et al. (2015) for data-limited fisheries, where a representative sample of the catch size structure and some life history parameters are available. A harvest strategy which targets a fishing mortality rate that is expected to result in 40% of unfished spawning output (so-called '40% SPR'), is considered risk-averse for many species (Clark 2002). The application using the R package shiny (Chang et al. 2017) was used, which is available on the repository site (https://github.com/merrillrudd/LIME_shiny).

Results

Size distribution and sex ratio of the stock

Total lengths of whiting ranged from 6.1–23.3 cm (Figure S3). Overall, the mean length of females (13.63 cm) was greater than males (12.61 cm). At larger sizes (> 13 cm TL), the female proportion increased linearly with fish size, female proportion: $0.087 + 0.048 \times L$ ($R^2 = 0.74$, df = 10, $P < 0.05$). No effect was evident on the sex proportion–fish size relationship between months (Kruskal–Wallis rank sum test, $P > 0.05$). Generally, females are the dominant sex almost year-round.

Length-weight relationship and growth parameters

The LWR equations calculated for all individuals, and also separately for unsexed, females and males are presented in Table S1. The length-weight relationships were found to be highly significant ($P < 0.001$), with R^2 values ranging between 0.95 and 0.98. The monthly analysis of the *b* parameter showed a decline to 2.90 in February while the rest of the year (aside from November), had *b* values over 3.

The TL data of whiting specimens were classified into 18 size classes of 1 cm interval size classes (Table S2). The estimated population dynamics parameters according to different techniques during the sampling period are shown in Table S3. Results showed that ELEFAN_GA had the best goodness of fit, so its growth parameters were used in the subsequent analysis (Figure S4). Seasonal oscillation of growth (C = 0.43) was stronger and the time of the slowest growth period corresponded to late February (WP = 0.19). The result of the bootstrapped ELEFAN_GA analysis indicated that the maximum density values after 500 resamples were closer to the initial analysis (Table S3, Figure 2 and Figure S5).

Spawning cycle

The monthly GSI averages for males and females followed the same trends (Figure 3), however the female GSI was proportionately higher than the male GSI. The GSI increased from October onwards, with a significant peak in March before decreasing from May to the September. There were three distinct phases to the GSI values: (i) an increase beginning in October; (ii) maximum levels between December and April; and (iii) low reproductive activity between May and September. The monthly evolution of the maturity stages showed that spawning capable (III) and mature (IV) were year-round but dominated from October to April. Outside the spawning period, the percentage of the mature/spawner class was relatively low (about 20%). Figure S6 indicates that whiting stores energy before spawning and the highest values were recorded in October (higher energy storage at the beginning of the spawning period) and January. HSI showed a decreasing trend during peak spawning. In both sexes, the annual cycle of K was very marked, with two clear peaks in January (middle of the spawning seasons) and May (end of the spawning season), then it decreases gradually (Figure S7).

Modelling on the GSI values

The findings of GAM modelling for the GSI are presented in Table 1. The contribution of all four variables: total length, temperature, time of year and gonadal stages were highly significant ($P < 0.001$). Overall, the model

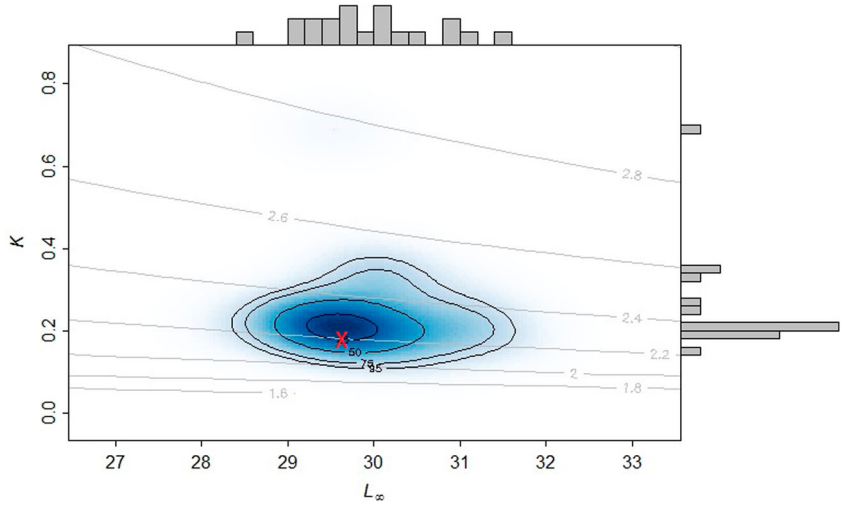


Figure 2. Plot of bootstrapped ELEFAN_GA parameters k and L_∞. Red dot represents estimated L_∞ and k per resampled length-frequency catch data. Marginal histograms show univariate density for both parameters, while density lines and colour intensity indicate the multivariate density. (L_∞ refers the asymptotic length and k refers the growth coefficient (years^{-1})).

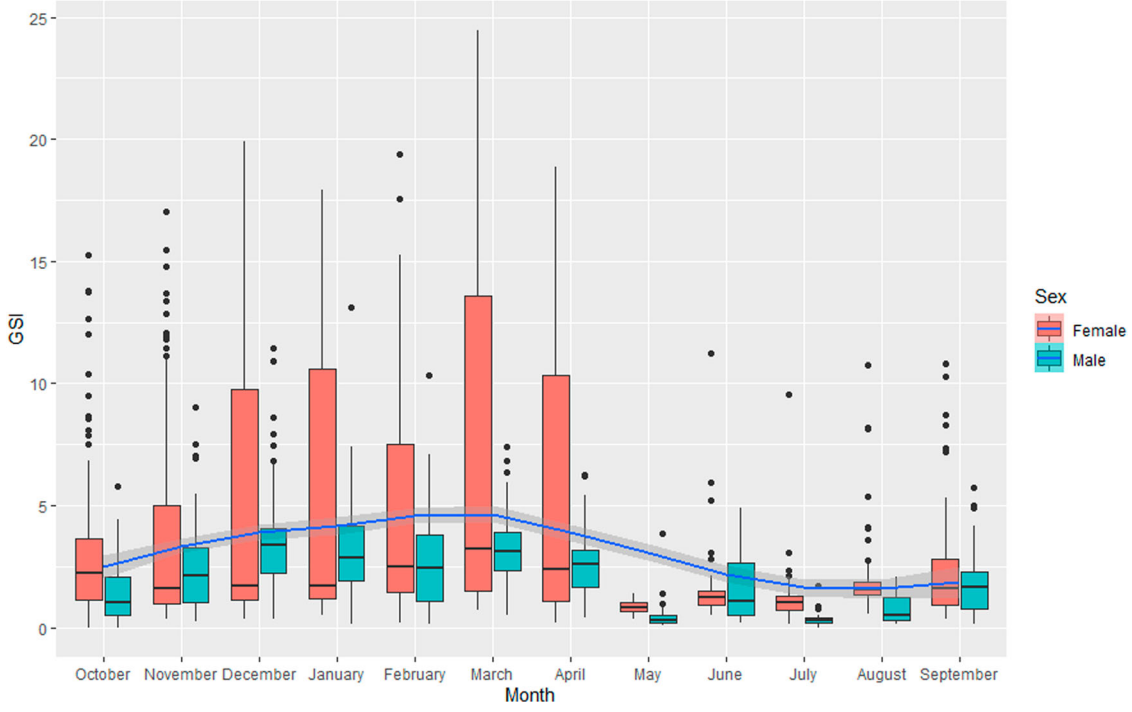


Figure 3. Box-plot of Gonadosomatic Index (GSI) by sexes for whiting during the annual sampling period. Box-plot representation: the horizontal line inside the box represents the median, and the lower and upper borders of the box represent the 25th and 75th percentiles, respectively. The upper and lower whiskers indicate the maximum and minimum range of the data excluding outliers.

with the fitted variables explained 78.7% of the GSI (R^2 = 0.74). The GAM smoother for the partial effect of TL on GSI (Figure 4) showed a positive effect of TL on GSI beginning around 15 cm, while an increasing trend continues until 17 cm TL and then decreases. The seasonal changes in GSI depicted in Figure 3 were converted into an annual scale according to the result of GAM model. The highest GSI values are located in a narrower area below 10°C (Figure 4) and partial effect of temperature on GSI is negative with sea temperature warmer than 10°C.

Length at first maturity (L_{mat})

Comparison of L_{mat} curves showed a clear difference between males and females. The female L_{mat} was 13.9 cm TL with upper and lower 95% CI of 13.7 and

Table 1. Significance values (*p*-values) for GAM covariates of the final model for GSI. Summary of parameter estimates applied to explanatory variables and statistical tests for generalized additive model (GAM) on GSI data of whiting (***: < 0.001; **: <0.05)

GSI	Df	*p*-value	Sig.
s(TL)	2	< 2e-16	***
s(Time)	2	< 2e-16	***
s(Temperature)	2	0.00106	**
Gonadal stage		<2e-16	***
Total % variation explained		78.7 %	

14 cm TL (Figure 5). The largest immature female was 15.5 cm TL and the smallest matured female was 10.3 cm TL. The male L_{mat} was 12.5 cm TL with upper and lower 95% CI of 12.4 and 12.7 cm TL (Figure 5). The largest immature male was 14.3 cm TL and the smallest mature male was 9.9 cm TL. The L_{mat} for the entire population was calculated as 13.2 cm.

Mortality rates

The total mortality (Z) derived from the computed VBGP values was 1.64 (Figure S8), with natural mortality of 0.37. The estimated rate of fishing mortality (F) was 1.27 per year, with an exploitation ratio (E) of 0.78 which suggests that the whiting stock in the western Black Sea is overexploited (E > 0.5).

Yield per recruit

The estimation of the biological references is presented in Figure 6 and indicates that maximum yield according to Thompson and Bell model could be obtained when the F_{max} and E_{max} were at 0.61 and 0.63 $year^{-1}$, respectively. The current values of exploitation and fishing mortality, well above the optimal exploitation and fishing rate and values, is an indication that the species appears to be overexploited (Figure S9).

Length-based indicators

The length-frequency distribution indicated L_{∞} to fall far beyond the right tail of the distribution (Figure 7). In this setting ($L_{mat} = 13.2$, $L_{opt} = 17.9$, $L_c = 9.5$, $L_{\infty} = 29.6$, $L_{mean} = 12.9$, $L_{m=f} = 13.8$, $P_{mega} = 19.7$), length at first capture L_c, is much lower than L_{mat}, suggesting a risk to Spawning stock biomass (SSB). L_{mean} is much less than L_{mat} indicating a population dominated by immature fish and further suggesting a risk to SSB and biomass is below the one that can produce MSY. P_{mega} is high for fisheries, and L_{mean} is smaller than Lm = f, then F is going to be larger than M. LB-SPR estimated that whiting was overfished, with SPR of 0.11 and 0.05 in 2017 and 2018, respectively, and was quite below the 0.40 SPR target.

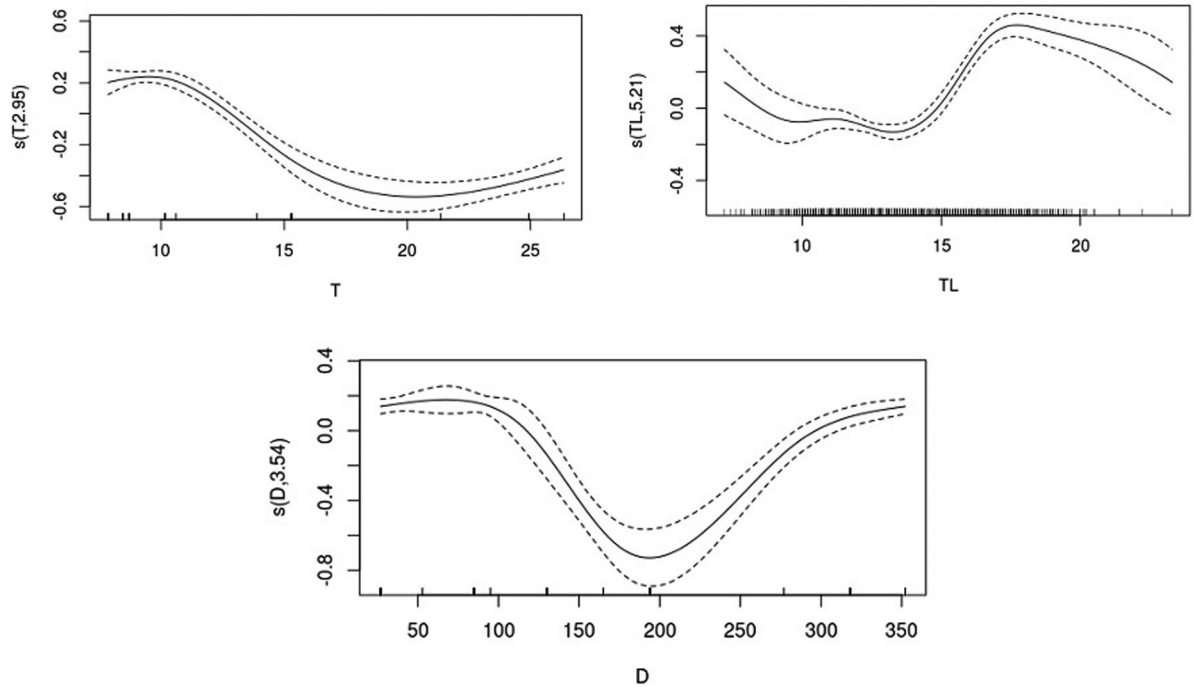


Figure 4. Generalized Additive Model (GAM) smoothing curves fitted to partial effects of mean sea water temperature (T), total length (TL), and days of year (D) for gonadosomatic index of whiting. GSI is represented as a function of predictors. Dashed lines represent 95% confidence intervals around the main effects.

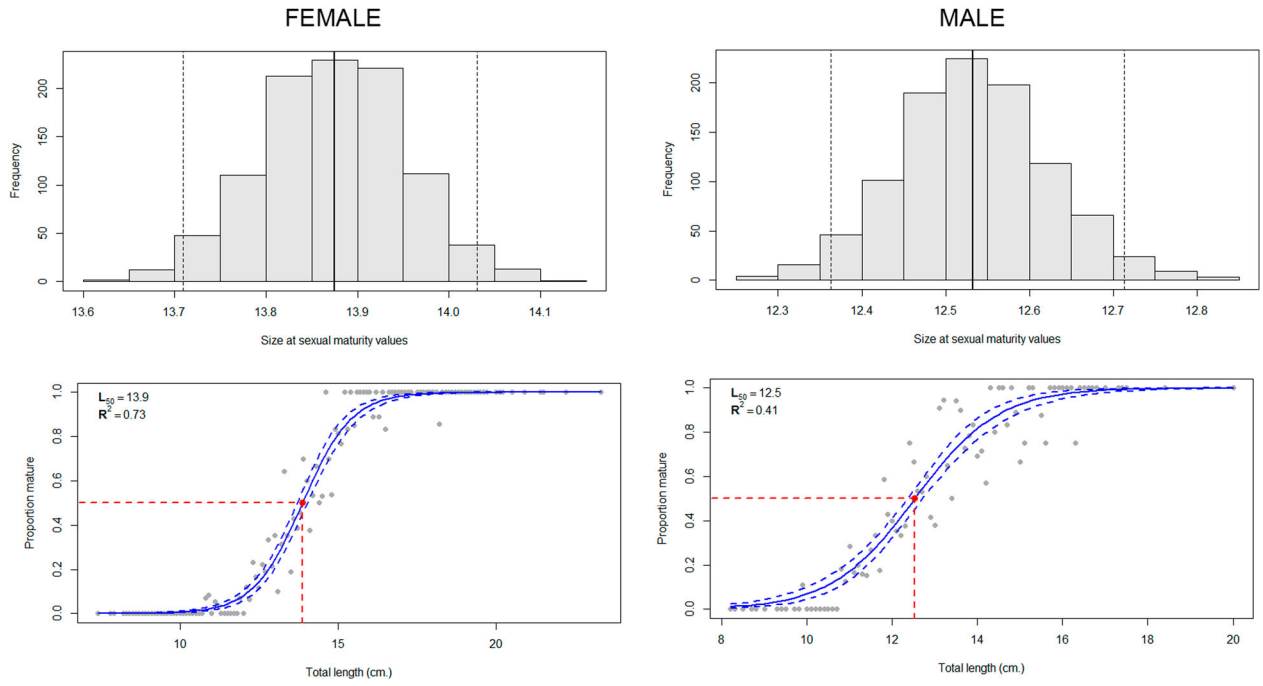


Figure 5. Maturity ogives in total length (TL) for whiting.

Discussion

Unfortunately, whiting landings have diminished considerably during recent decades in the Black Sea. We attempt to form a basis for sound management measures and to provision advice to fisheries managers, using length frequency and biological data (reproductive dynamics) collected in Turkey where most of the fisheries are managed within the data limitations.

In this study, sex ratio differed from the theoretical 1:1 and females were dominant. In general, the sex ratio for whiting in the Black Sea has been found to be in favour of females, except for a few studies (Samsun 1995; Samsun and Erkoyuncu 1998; Bilgin et al. 2012). On the other hand, in the Irish Sea, Bowers (1954) and Gerritsen et al. (2003) recorded the opposite trend, with that area being significantly represented by males. According to Milic and Kraljevic (2011) the sex ratio in whiting depends on sampling location, as larger fish prefer deeper waters due to sexual dimorphism in growth. In line with this information, the study revealed that females are the

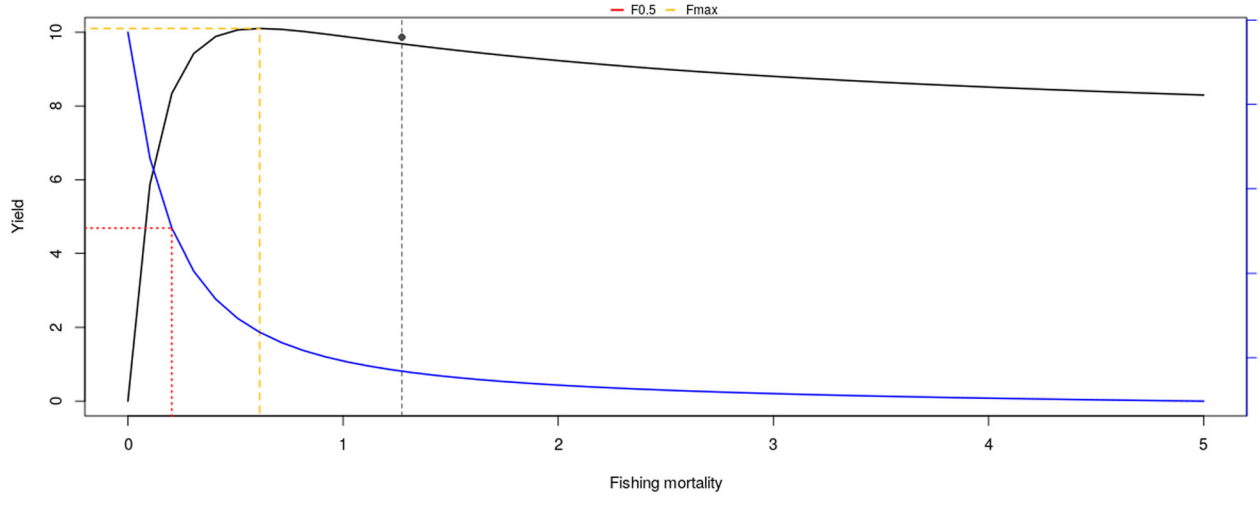


Figure 6. Results of the Thompson and Bell model: Curves of yield per recruit. The black dot represents yield under current fishing pressure. The yellow and red dashed lines represent fishing mortality for maximum sustainable yield (F_{msy}) and fishing mortality to fish the stock at 50% of the virgin biomass ($F_{0.5}$).

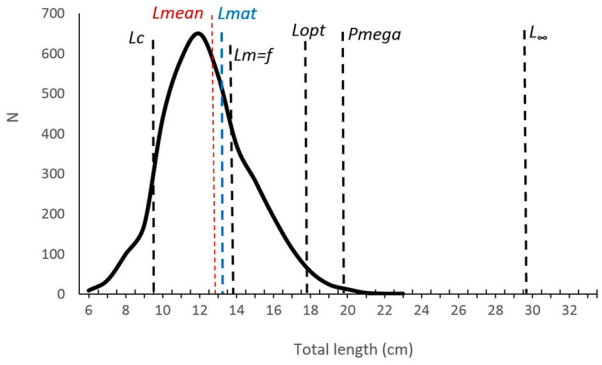


Figure 7. Length frequency distributions with length based biological reference points (the asymptotic length (L_∞)), the mean length of all samples (L_{mean}), length at 50% maturity (L_{mat}), length at first capture (L_c), length where growth rate in weight is maximum (L_{opt}), the theoretical length resulting from fishing with $F = M(L_{m=f})$, fish which are mega-spawner (P_{mega}).

dominant sex all the year round and especially in larger sizes in the Black Sea.

The length-weight regression for whiting was very similar to that of previous studies (Genç et al. 1998; Kalaycı et al. 2007; Sağlam and Sağlam 2012). Growth parameters were estimated in this study based on traditional length frequency techniques and applied with an ELEFAN improved by novel optimization routines with a bootstrapping framework which allows to estimate confidence intervals of growth parameters estimations (Mildenberger et al. 2017; Taylor and Mildenberger 2017; Schwamborn et al. 2018). Our estimated parameters (L_∞, k and Φ′) fall within the range of previous estimations made for whiting (Bilgin and Bilgin 2018). More importantly, our estimated values are similar to those estimated using otolith-assessed age-based data from the Black Sea (Samsun and Akyol 2017; Kasapoglu 2018). Outputs also suggested that there were seasonal oscillations in the growth rates of whiting, which could be related to change in water temperature, and the availability of food in the coastal shelf zone (Pauly 1987). C value (0.26), that is the amplitude of growth oscillation of whiting, was in line (0.23) with the result of an older study by İşmen (1995). The slow growth period coincided with maturation as well as spawning period, reflecting metabolic costs associated with reproductive activities. The present study also indicates that a large proportion of the whiting catches in the area are juveniles (59%), which might reflect overfishing (Froese et al. 2018). M/k ratio ranged from 1.7, substantially close to assumption that M/k is ~1.5 (Froese et al. 2018).

Spawning periods from this study are compared with other Black Sea studies in Figure 8, a few of which deduced that whiting have a year-round (12 month) reproductive season (Cohen et al. 1990; İşmen 1995; Genç et al. 1998), which may be the longest spawning duration documented for the Gadidae genus. Inherently, Oven et al. (1995) found whiting to spawn year-round in the Black Sea, but

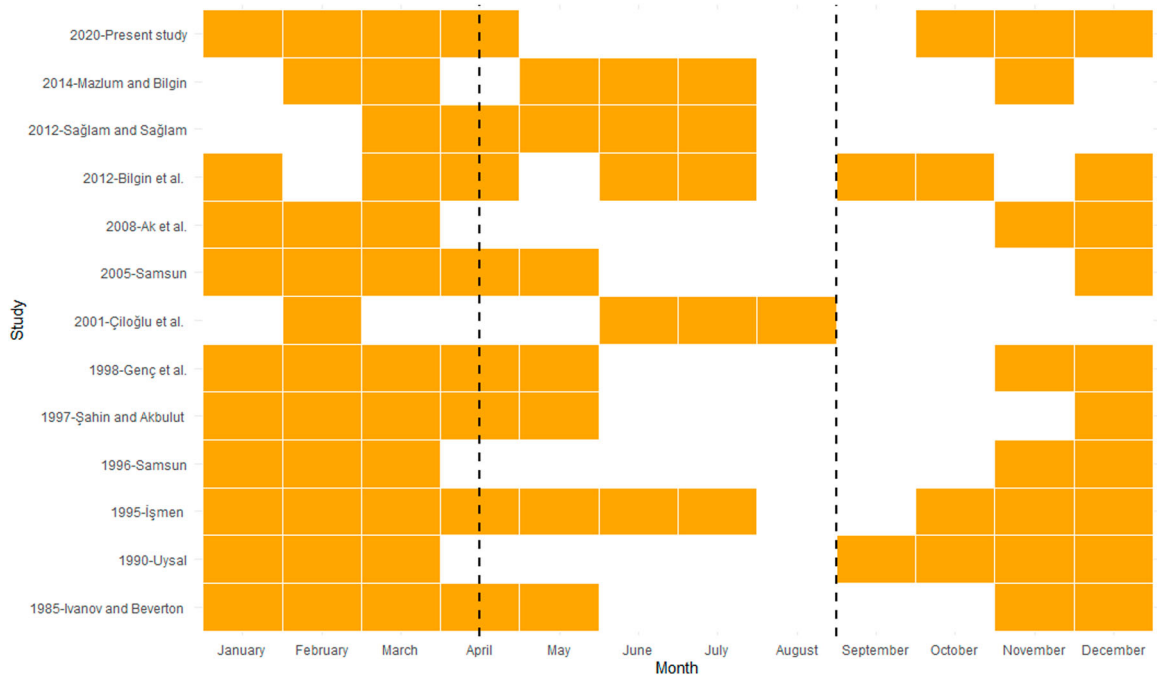


Figure 8. Spawning period of whiting from different Black Sea studies. Dashed lines indicate the closure period for industrial fisheries in Turkey (including bottom trawling).

most intensively during the winter season. Genç et al. (1998) indicated whiting reproduction decreases to a minimum value in summer, but that reproduction still continued for some of the stock. This study confirmed a low spawning activity in summer and autumn periods as highlighted by previous studies in different areas of the Black Sea (Ivanov and Beverton 1985; Uysal 1994; Samsun 1995; Genç et al. 1998; Samsun 2005). The monthly pattern of GSI coupled with monthly distribution of maturity stages seems to define a long reproductive period of whiting collected in the Western Black Sea extending from October to April, with peak spawning activity occurring in February–March with synchronized reproductive cycles for both males and females. This occurrence of the spawning peak was confirmed by the findings of eggs and larvae from the Black Sea (Dekhnik 1973). Moreover, according to histological examination of female gonads, whiting exhibited group synchronous ovarian organization with the presence of clear differences in oocyte size groups (Figure 1). In light of all this evidence, it is apparent that most of the whiting landings in the Black Sea occur during their prolonged spawning season which may negatively affect their recruitment success. A prolonged spawning season may be an adaptation to reduce the extent of annual fluctuations in the year class strength of a species (Hehir 2003), that could be a strategy to reduce temporal variance in offspring survival (Dominguez-Petit 2006), which seems to be beneficial for whiting in the Black Sea. Evidently, despite heavy bottom trawling pressure, especially in the Turkish shelf area, whiting remains the main component of the demersal community (Yildiz et al. 2019), and is considered as a keystone species.

With regard to size at maturity (L_{mat}; Table 2), no previous estimates are reported in the literature for whiting in the Western Black Sea. This information, taken into account with age-at length data from Yildiz (2016), indicates that whiting can become mature within the first year for males and second for females. The estimates are comparable with the L_{mat} reported in the eastern Black Sea studies from Turkish coasts. It should be noted that the L_{mat} values we obtained for females 13.9 cm TL are much lower than those reported for eastern areas in the Black Sea: specifically 14.7 cm TL by İşmen (1995) and 14.6 cm TL by Bilgin et al. (2012). It is worth mentioning that size at maturity was estimated from relatively small size ranges (TL) in the study of Bilgin et al. (2012) by using only gillnetting sampling. In general, all the studies agreed that there is a sexual dimorphism with regard to maturation, males maturing earlier than females. This could be explained by the difference in growth pattern between males and females in whiting reported by several authors (İşmen 1995; Çiloğlu et al. 2001; Yildiz 2016). In practice it means that the current minimum legal landing size of whiting in Turkey of 13 cm imposed by fisheries regulations (BSGM 2020) should be increased to 14 cm, at least for the Western Black Sea to guarantee the spawning success of stock.

Table 2. The length at 50% maturity (L_{mat}) values of whiting for the different areas of the Black Sea

		Sub-region	♀	♂	Σ
İşmen	1995	Entire	14.7	12.5	
Ak et al.	2008	Eastern			15
Bingel et al.	1996	Entire			13
Samsun	2005	Middle	13.8	12.9	
Bilgin et al.*	2012	Eastern	14.6	13.9	
Reşat	2013	Middle			13.9
Öztürk	2019	Eastern	13.3	12.5	
This study	2020	Western	13.9	12.5	

*Sampling was done only by gillnets.

In the current cod-end (40 mm diamond) allowed in the Black Sea bottom trawl fishery, the risk of catching individual whiting under the minimum landing size is high (Yildiz 2016). Most studies indicated that increasing the selectivity in cod-end reduces the retaining of small individuals by regulating the first catch size. According to the results of the selectivity studies (Genç et al. 1998; Özdemir et al. 2012) for whiting in the Black Sea, the catch rate of 50% (L50) in square-meshed trawl cod-ends was found to be higher than the first length at maturity. The fact that the L50 value obtained in the 40 mm diamond-shape cod-end is below the MLS indicates that the stocks under pressure of fishing in the region will be put under more pressure and reduce the recruitment power that ensures its continuity (Ceylan 2019). In this context, the bottom trawl nets used in the Black Sea must be designed and standardized to ensure the sustainability of stocks and fisheries. Correspondingly, for over-exploited stocks, more than selectivity or technical measures need to be considered.

Conclusion

The whiting supports a major demersal commercial fishery in the Black Sea, having been commercially exploited for a long time and it is especially important for the Turkish fishing fleet. There is a reliable catch history of whiting in the Black Sea but abundance indices are not available; some life-history parameters exist but catch at-size data are either not available or only available over sparse years. The findings from this study provide remarkable life history metrics that

can be used as a baseline in future management plans and to further understand ecosystem dynamics in the Western Black Sea. A set of management recommendations to transition towards more holistic approaches and management of whiting fishery is provided from the results of this study due to stock considered to be fished at biologically unsustainable levels. Three priorities are highlighted here: (i) whiting along with other species targets of the fishery should be monitored as part of regular fishery monitoring and assessments; (ii) the general closure period for bottom trawling in warmer season (15 April–15 September according to Turkish legislation) does not currently sufficiently protect the whiting population, so fishing season and minimum landing size must be reconsidered by national authorities; (iii) fishing pressure should be decreased to increase the reliability of stock conditions in the Black Sea, technically $F_{current}$ (1.27 y^{-1}) should be decreased under the F_{max} (0.61 y^{-1}). Management should be directed for reduction of fishing mortality to reduce immediate risk to SSB and increase length at first capture towards L_{opt} in the longer term to enable best yield-per-recruit and maximize the SSB.

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No potential conflict of interest was reported by the authors.

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