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Population Dynamics and Stock Asssessment of Atlantic Horse Mackerel (*Trachurus trachurus*) Stocks in the Western Egyptian Mediterranean Waters

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ABSTRACT

The present study aimed to evaluate the fishery status of the Atlantic horse mackerel (*Trachurus trachurus*) stock in the western Egyptian Mediterranean waters. Random monthly samples of fish were collected during the period from April 2015 to March 2016, with a total of 1054 fish. Growth parameters were determined and the vectors of natural mortality (M) by age, total mortality (Z) and fishing mortality (F), length cohort analysis, and Beverton & Holt Yield per recruit analysis were performed by FiSAT and Virtual Population Analysis (VIT software) programs to estimate the limit and target reference points. The present results showed that the Von Bertalanffy growth parameters were L_∞ = 29.58 cm, K = 0.27 years^{-1}, and t_0 = -1.49 year. The mean values of Z, F and M were 0.828, 0.575 and 0.253 year^{-1}, respectively. The exploitation rate (E) was 0.694 year. The current yield per recruit (Y/R), biomass per recruit (B/R), and spawning stock biomass (SSB) at the current fishing mortality (0.575 year^{-1}) were 14.27, 31.35 and 12.15g, respectively. The percentage of the current B/R to the virgin biomass was 25.11%. The reference point $F_{0.1}$ = 0.27, and the limit reference point (F_{MAX}) was 0.48 year^{-1}. These two values are lower than the current value of fishing mortality (0.575 year^{-}). The ratio between F_C and $F_{0.1}$ was 2.128; this value indicates that *T. trachurus* stock in the Egyptian Mediterranean waters is at a high over exploitation state.

INTRODUCTION

Carangidae is a widely distributed fish family including several commercial species that are common in tropical, subtropical, and temperate waters. The genus *Trachurus* is one of the most important carangid genus; it includes 3 species with worldwide distribution: Mediterranean horse mackerel, *Trachurus mediterraneus*; Atlantic horse mackerel, *Trachurus trachurus* and blue jack mackerel, *Trachurus picturatus* **(Turan, 2004)**.

Atlantic horse mackerel (*Trachurus trachurus*) is a pelagic, migratory fish, commonly found in the northeastern Atlantic, Mediterranean Sea, and Black Sea **(Kerkich *et al*., 2013)**. The fish species under study is laterally more compressed than the other two mackerel species; the head is large and heavy: about one – third the total length. Along the lateral line, the scales have developed into bony scutes, which carry spines increasing in size towards the

tail. The back is blue- grey with greenish tints. The flanks are silvery, while the belly is white.

Atlantic horse mackerel is a schooling pelagic species, caught with purse seines, pelagic trawls, gill nets, and long lines, often close to the sea floor **(Abaunza *et al*., 2008)**. As a result of overfishing and increasing value of bycatch species, horse mackerel became a crucial species in the 1980s, 1990s and has become one of the three most important pelagic species in the European fish industry **(Abaunza *et al*., 2003)**. The global commercial catch of *T. trachurus* reported in 1999 was 320,203 tons, decreasing to 140,258 tons (representing about 85% of the total landing of the genus *Trachurus*) in 2018. On the other hand, the global commercial catch of the two other species, *T. mediterraneaus* and *T. picturatus*, were 19,262 and 4,884 tons in 2018, respectively **(FAO-GFCM, 2020)**. Genus *Trachurus* is dominated in Netherlands, Spain, and Ireland.

Genus *Trachurus* in the Egyptian Mediterranean waters is composed of the three above- mentioned species. However, the last species is rare. The total landing of the Atlantic horse mackerel has been steadily increasing; from 1,533 tons in 2000 to 5654.6 tons in 2018, whereas the production of *T. mediterraneaus* is seemingly stable for the same years (4451-4863.6 tons) **(FAO-GFCM, 2020)**. *Trachurus* represents about 1.3% of the total Egyptian Mediterranean catch **(GAFRD, 2019)**. However, limited information is available on the population status of *T. trachurus* in the Mediterranean Sea in terms of growth, mortality, and fishery status **(Alegría- Hernández, 1984; Karlou-Riga & Sinis, 1996, 1997)**.

The present study aimed to shed light on the current fishery status of horse mackerel (*T. trachurus*) stock in the western Egyptian Mediterranean waters, providing a management advice for the sustainable exploitation of that stock.

MATERIALS AND METHODS

Horse mackerel (*Trachurus trachurus*) in the Egyptian Mediterranean fisheries is generally caught by purse seine (surrounding nets) and landed at major landing centers distributed along the Egyptian cost. From April 2015 to March 2016, monthly random samples of these fish were collected from the landing center in Alexandria (Egypt), which is the most important landing center in the western Egyptian Mediterranean coast. The total number of samples collected during this period was 1054 fish (547 males, 353 females, and 154 unidentified). The following data were recorded for each fish sample: total length (TL) to the nearest cm; total weight to the nearest g. and otoliths were also extracted and stored in special envelops (on which detailed information on fish length, weight, sampling date and site were recorded) and used for age determination. Monthly length frequency distribution of the samples was raised to the monthly landings in Alexandria landing site, and then to the total Egyptian Mediterranean landings of the species under study.

Length-weight relationship was estimated according to **Le Cren (1951)**. Von Bertalanffy's growth parameters were estimated using the method of **Ford (1933)** and **Walford (1946)** for the sexes combined.

The constants generated from Von Bertalanffy growth model (VBGM) were used to estimate the length at first capture (L_c) according to **Beverton and Holt (1956)**. The corresponding age at first capture (t_c) was also calculated using the equation of **Beverton and Holt (1957)**. Length at recruitment (L_r) was estimated in the same manner by applying the VBGM **(Von Bertalanffy, 1938)**.

Mortality coefficient for each length group was estimated using the virtual population analysis (VIT) software **(Lleonart & Salat, 1997)**. The vectors of natural mortality by age were estimated from Caddy's formula, using the PRODBIOM excel spreadsheet **(Abella *et al*., 1998)**. These vectors (per each age group) were then converted to vectors per each length class by using the estimated length at age. VIT software was used for pseudo cohort analysis using length frequency distribution **(L1eonart & Salat, 1997)**; the total and fishing mortalities for the different length groups were estimated. Yield per recruit (Y/R) was estimated using the yield per recruit model of **Beverton and Holt (1957)**. Biomass per recruit (B/R) was estimated by using the equation of **Sparre and Venema (1998)** and the biological reference points of fishing mortality ($F_{0.1}$ & F_{max}) of **Cadima (2003)**.

RESULTS

Length- weight relationship

Length weight relationship of *T. trachurus*, determined by the power equation, was represented by the following equation (Fig. 1):

$W = 0.0146L^{2.8019}$, $R^2 = 0.8794$

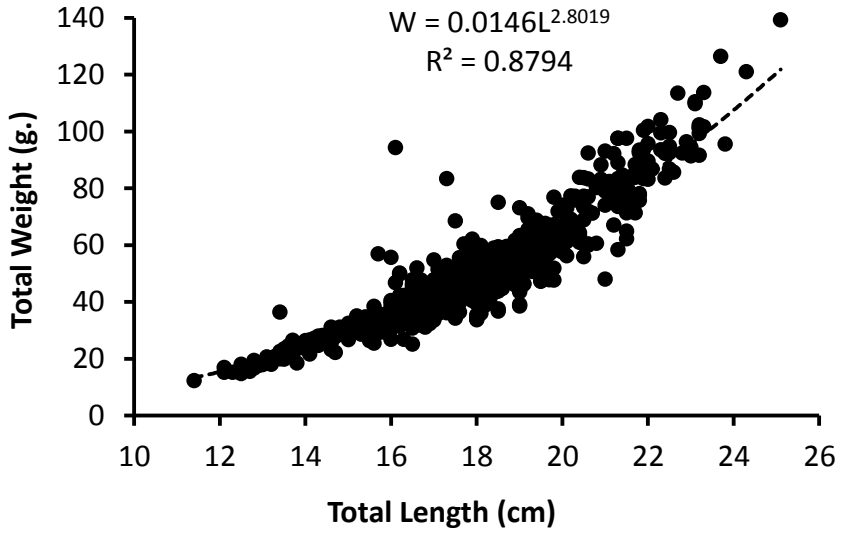

Fig. 1. Length- weight relationship of *T. trachurus* collected from the western Egyptian Mediterranean waters

Length frequency distribution

Length frequency distributions (LFD) of the whole period of sampling for the combined and separated sexes are shown in Figs. (2, 3). Monthly LFD is displayed in Fig. (4), where all months showed a quite similar distribution except for August, September, and November. Length composition of *T. trachurus* ranged from 11 to 25 cm. Most fishes were found in the length groups of 17 and 18cm (Fig. 2). LFD of the combined sexes was used in VIT program since LFDs of males and females were almost identical.

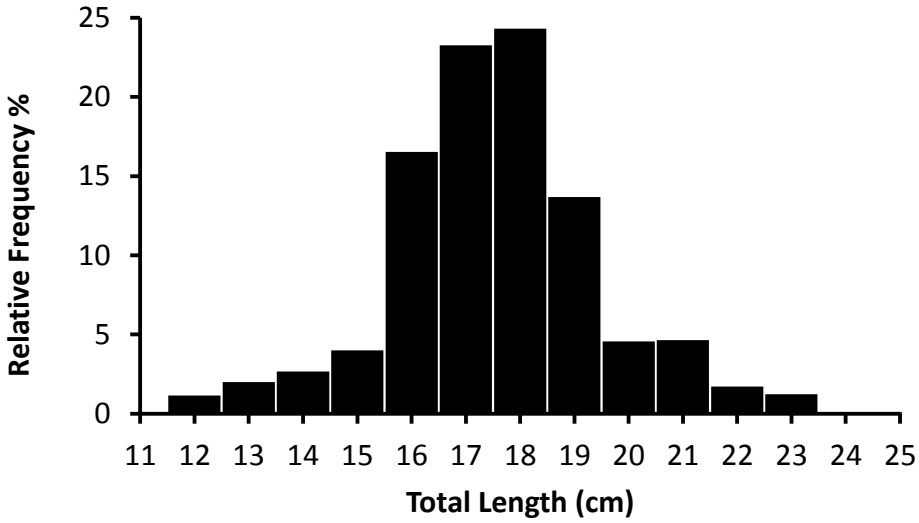

Fig. 2. Length frequency distribution of *T. trachurus* in the western Egyptian Mediterranean waters

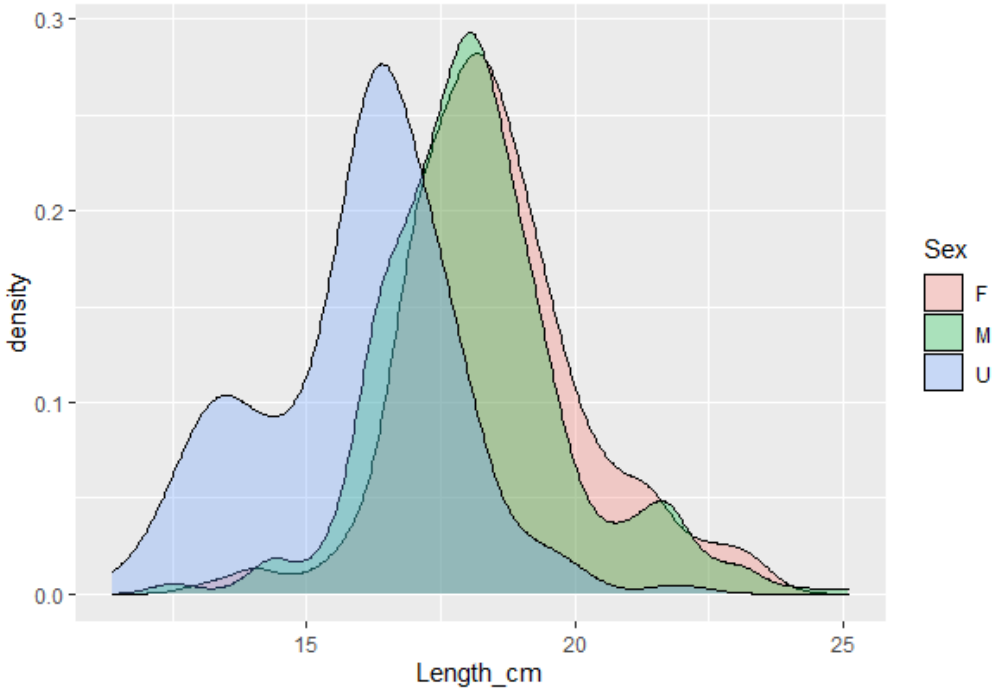

Fig. 3. Length frequency distribution of *T. trachurus* by sex in the western Egyptian Mediterranean waters

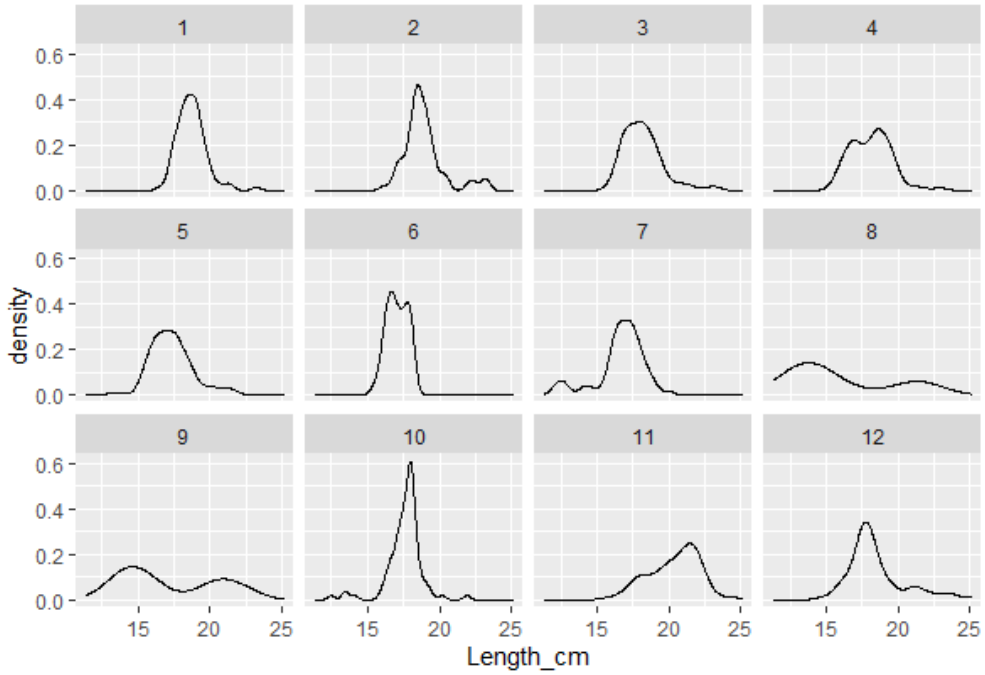

Fig. 4. Monthly length frequency distribution of *T. trachurus* in the western Egyptian Mediterranean waters

Von Bertalanffy growth parameters

The VBGM representing *T. trachurus* growth was:

$$\mathbf{L_t = 29.58\ [1- e^{(-0.274\ [t - (-1.49)]}}$$

Where, L_∞ = 29.58cm; K = 0.27 years^{-1}, and t_0 = -1.49 year (Table 1).

The value of W_∞ obtained by applying the length - weight relationship, using the value of L_∞ **(Pauly, 1981)** was 208g, accordingly, the W_t was:

$$\mathbf{W_t = 208\ [1- e^{(-0.274[t - (-1.49)]}}]^{\mathbf{2.9357}}$$

Table 1. Values of some fishery indices of *T. trachurus* from the Egyptian Mediterranean waters off Alexandria (2015-2016)

Parameter	Value
K	0.274
t_o	-1.49
L_∞	29.58
W_∞	208
L_c (length at capture)	13.56 cm
t_c (age at capture)	0.743 year
L_r (length at recruitment)	11.39 cm

Mortality estimates

Total mortality (Z), fishing mortality (F), and natural mortality (M) were computed for each length group (Table 2). The highest M value was obtained at length group 11cm (0.891/ year), and it gradually decreased with increasing fish length up to length group 25 (0.099/ year). The mean M value was 0.253. The lowest value of F was reported at length group 11cm (0.001/ year) after which it gradually increased up to length groups of 17 and 18cm (1.42/ year). A gradual decrease in fishing mortality from length 20 to 25cm was recorded. The average F for all length groups was 0.575/ year, whereas the mean Z was 0.828/ year. Using the mean F and mean Z of all length groups, the value of exploitation ratio was estimated as 0.694. This result indicated that the fishery of *T. trachurus* in the Egyptian Mediterranean suffers from a higher fishing mortality than natural mortality.

Table 2. Mortality Coefficients (total mortality (Z), fishing mortality (F), and natural mortality (M)) of *T. trachurus* for different lengths groups from the Egyptian Mediterranean waters off Alexandria (2015-2016)

Length group	Z	F	M
11	0.892	0.001	0.891
12	0.908	0.017	0.891
13	0.927	0.037	0.890
14	0.951	0.061	0.890
15	0.361	0.104	0.257
16	0.739	0.482	0.257
17	1.135	0.878	0.257
18	1.574	1.422	0.152
19	1.573	1.421	0.152
20	0.881	0.765	0.116
21	1.361	1.244	0.117
22	0.903	0.787	0.116
23	1.060	0.944	0.116
24	0.200	0.101	0.099
25	0.198	0.099	0.099
Mean	0.828	0.575	0.253

Yield per recruit (YLR), biomass per recruit (BLR)

The current yield per recruit (Y/R) for *T. trachurus* was 14.27g, which corresponded to the current level of fishing mortality of 0.58 year^{-1} (Table 3). On the other hand, the value of biomass per recruit (B/R) at the current fishing mortality (0.58 year^{-1}) was 31.35g. Meanwhile, the percentage of the current B/R to the virgin biomass was 25.11%. The Y/R showed a decreasing trend with increasing fishing mortality (Fig. 5a).

Spawning stock biomass per recruit (SSBR)

The values of SSB at different values of fishing mortality were 12.15, 15.49, and 29.41 at F_c, F_{max}, and $F_{0.1}$, respectively (Table 3). Fig. (5b) represents the relationship

between fishing mortality vector with the B/R and the SSBR. This curve showed decreasing B/R and SSB due to increasing fishing mortality.

Biological reference points

Two biological reference points (BRP) were estimated; $F_{0.1}$ (target BRP) and F_{max} (limit BRP) **(Cadima, 2003)**. $F_{0.1}$ was 0.27 year^{-1}, while F_{max} was 0.477 year^{-1}. These results indicated that the two values of the BRPs (F_{max} and $F_{0.1}$) are lower than the current value of fishing mortality (0.58 year^{-1}). The ratio between F_c and $F_{0.1}$ was 2.13.

Table 3. Values of fishing mortality, yield per recruit (Y/R), biomass per recruit (B/R) and spawning stock biomass (SSB) at current, maximum and $F_{0.1}$ for *T. trachurus* in the Egyptian Mediterranean waters off Alexandria

Fishing mortality	Value	Y/R	B/R	SSBR
$\mathbf{F_0}$	0	0	124.86	101.99
$\mathbf{F_{0.1}}$	0.27	13.51	50.08	29.41
$\mathbf{F_{max}}$	0.477	14.35	35.11	15.49
$\mathbf{F_{current}}$	0.575	14.27	31.35	12.15

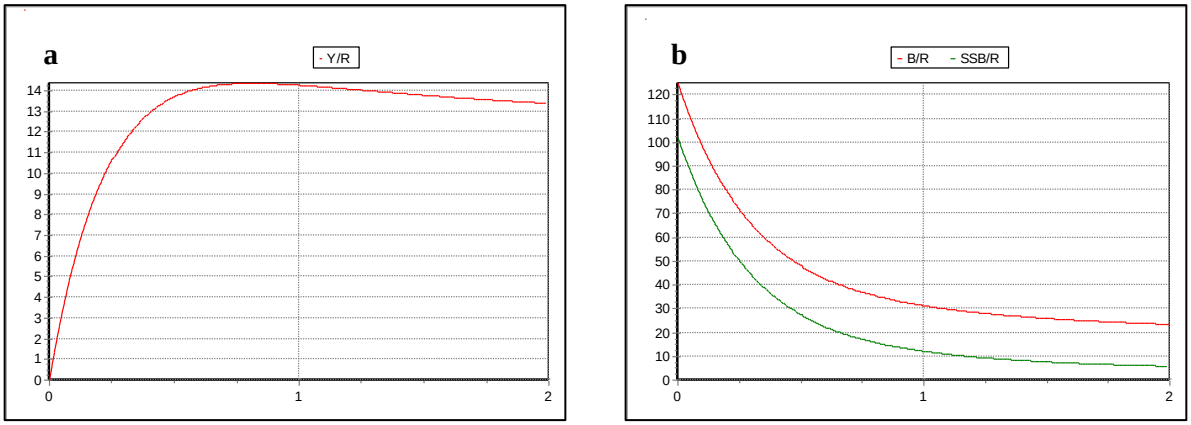

Fig. 5. a- Yield per recruit (Y/R); **b-** Biomass per Recruit (B/R) and spawning stock biomass per recruit (SSBR) of *T. trachurus* in the western Egyptian Mediterranean waters

Relative yield per recruit and biomass per recruit with different exploitation rates

The relative Y/R and relative B/R of *T. trachurus* in the Egyptian Mediterranean waters in relation to the exploitation rate E are graphically represented in Fig. (6). The maximum relative Y/R was obtained at an exploitation rate E_{max} = 0.625. The exploitation level which maintains the spawning stock biomass at 50% of the virgin spawning biomass (E_{50}) was at 0.357, while E_{10} was equal to 0.552.

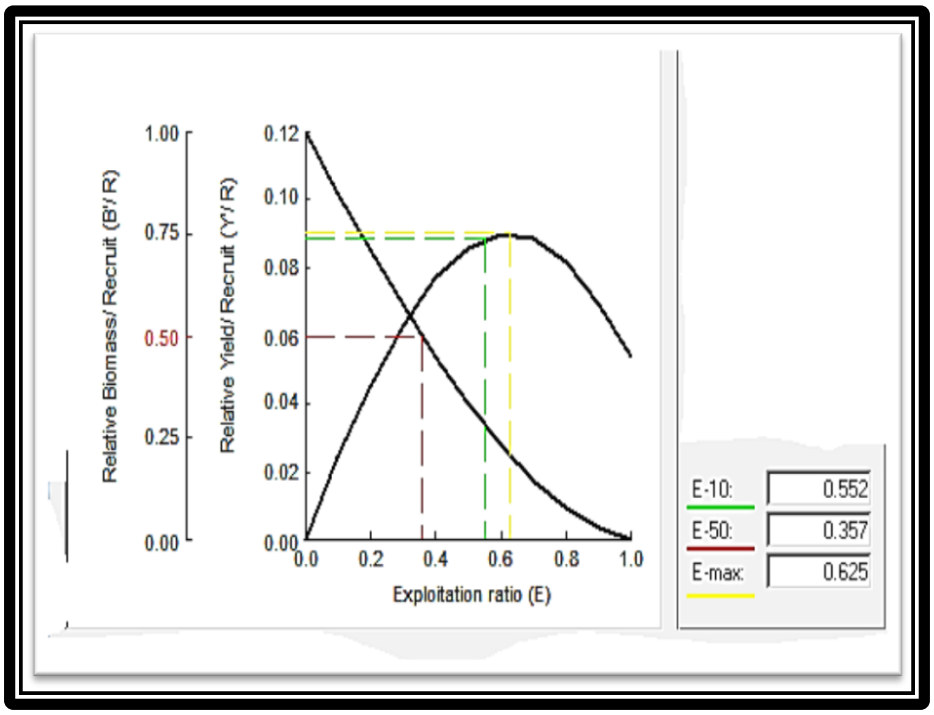

Fig. 6. Relative yield per recruit and biomass per recruit at the different exploitation rates of *T. trachurus* from the Egyptian Mediterranean waters off Alexandria (2015-2016)

DISCUSSION

The mathematical relationship between length and weight of fish is one of the most important studies of biological aspects **(Le Cren, 1951)**. Based on the value of the exponent b provided by the length-weight relationship in the present study, it could be clearly seen that *T. trachurus* in the western Egyptian Mediterranean water showed a negative allometric pattern of growth for their specific lengths. This value is close to the results reported in the Adriatic Sea **(Alegria-Hernadez, 1984; Carbonara & Casciaro, 2020)**, Portugese coast **(Arruda, 1984)**, and the coast of Galicia **(Farina-Perez, 1983)**. The reason for the negative allometric growth pattern might be the availability of food **(Margalef, 1974; Moutopoulos & Stergiou, 2002)**.

In the present study, the age of *T. trachurus* ranged from 0 to IV, with the age groups I and II being the most dominant. The von Bertalanffy growth model (VBGM) is one of the most used length- age models applied in fisheries fishery assessment because it is based on bioenergetics principles **(Beverton & Holt, 1957; Ricker, 1975)** and of its empirical success in describing growth **(Wootton, 1998; Quinn II & Deriso, 1999)**. The reported values of von Bertalanffy parameters; L_∞, k and L_0, for horse mackerel were varying significantly. For example, the published values of L_∞ ranged from 16.9 to 51.8 cm, while the values of k were 0.1 to 0.4, as estimated by different authors in some regions in the Mediterranean and Black Sea. This discrepancy has been attributed to sample size, methods of sampling, and statistical treatment of data **(Rounsefell & Everhart, 1953; Alegria Hernandez, 1989; Wootton, 1998)**, and the environmental conditions under which these fish live **(Pauly, 1981; Alegria-Hernandez, 1984, 1989)**.

Growth parameters did not significantly vary among males, females, and combined sexes. However, the value of L_∞ was much lower, while k and L_0 were higher than the values reported in the Bay of M'diq, Morocco **(Kerkich *et al.*, 2013)**. Nonetheless, these authors reported that their samples were not representatives of the harvested stock since small and large sizes were difficult to catch, and therefore, were not represented in the analyzed sample. This supports the assumption that sample size and homogeneity have a significant impact on the growth parameters. On the other hand, the current L_∞ value is much higher, while k and t_0 are lower than those reported for horse mackerel populations in the Mid Black Sea, Turkey **(Yücel & Erkoyuncu, 2000)**. However, the results of that study may not be reliable at all since the size range of the sample was only 9.2 to 17.2cm despite that this fish can reach over 50cm in length **(Carrasco, 1980)**.

In the present study, the values of the length at recruitment (L_r) and the length at first capture (L_c) were 11.39 and 13.56cm, respectively, which were attained in the first year of life (0.743 years). The corresponding values of t_r and t_c (age at recruitment and age at first capture) were 0.85 and 1.067 years, respectively. This finding suggests that this species grows relatively fast during the first year of life and may start suffering from fishing mortality at L_c higher than 13.56cm and t_c higher than 0.74 year. It is no surprise, therefore, that age group I represented 67% of the whole sample. This may also indicate that *T. trachurus* were caught before reaching sexual maturity. In other words, this fish species in the western Egyptian Mediterranean waters suffers from growth overfishing, meaning that heavy fishing pressure on small fish does not allow the fishery to produce its maximum yield. Growth overfishing may have led to recruitment overfishing due to the depletion of spawning biomass and their reproductive efficiency to the level, where it becomes unable to replenish itself. The length at age in the present study is lower than that reported in other Mediterranean GSAs. This finding may support the assumption that this species is suffering from overexploitation. Similar results have been reported on the jack mackerel *Trachurus picturatus* from Canary Islands, Spain (NW Africa), where maximum growth occurs during the first year of life **(Jurado-Ruzafa & Santamaría, 2018)**.

Despite the importance of horse mackerel in the Mediterranean fisheries, only a few studies have considered their mortality estimates as a necessary tool for their fisheries management **(Kerstan, 1985; Yücel & Erkyuncu, 2000; Yankova, 2013)**. The mean value of total mortality (Z) of *T. trachurus* in the present study (0.828 per year) was much lower than that obtained for the same species from the mid Black Sea (1.55 $year^{-1}$) **(Yücel & Erkyuncu 2000)**, but it is higher than the value reported in the Eastern Central Adriatic Sea **(Šantić *et al.*, 2002)**, and west of Great Britain and Ireland (0.57 $year^{-1}$) **(Kerstan, 1985)**.

Similarly, natural mortality (M) and fishing mortality (F) were widely varied, depending on fishing area, fishing methods and efforts, gear selectivity, and prevailing biotic and abiotic factors **(Ricker, 1975; Sparre & Venema, 1998; Šantić *et al.*, 2002)**. The mean value of M of *T. trachurus* in the present study (0.253 $year^{-1}$) was lower than the value reported in mid Black Sea (0.555 $year^{-1}$) **(Yücel & Erkyuncu, 2000)**, Eastern Central Adriatic Sea (0.461 $year^{-1}$) **(Šantić *et al.*, 2002)**, and Great Britain and Ireland (0.40 $year^{-1}$) **(Kerstan, 1985)**. However, as mentioned above, the comparison among these studies may not be reliable in some cases due to sample size and selectively. For example, it has been reported that larger fish in a given year class have mortality rates different from small fish of the same year class (generally higher). On the other hand, fast growing fish generally mature earlier and become more susceptible to death than slower growing fish of the same brood **(Ricker, 1975)**. This means that if the analyzed samples do not include large individuals, but include only early, fast growing year classes, fishing mortality may increase, but will represent only the first years of life, leading to misleading mortality estimates.

The value of exploitation ratio (E) in the present study was 0.694. This value is about 40% higher than the optimum ratio (0.5) suggested by **Gulland (1971)**, and about 74% higher than the value proposed by the General Fisheries Commission for the Mediterranean (GFCM) which was 0.4 **(GFCM, 2013)**. This means that the population of *T. trachurus* in the western Egyptian Mediterranean waters suffered from overfishing. In other words, the fishing mortality of this species is higher than natural mortality. Meanwhile, the E value in the present study is close to the value of *T. trachurus* in the mid Black Sea (E= 0.64) **(Yücel & Erkoyuncu 2000)**. On the other hand, the value of E is higher than the value reported in the Eastern Central Adriatic (0.38) **(Šantić *et al*., 2002)**.

In the present study, the ratio between current fishing mortality (F_c) and $F_{0.1}$ of *T. trachurus* in the Egyptian Mediterranean waters was 2.128. Moreover, F_c (0.575) was higher than the values of biological reference points ($F_{0.1}$ and F_{max}), which were 0.270/ year and 0.477/ year, respectively. **Fletcher *et al*. (2002)** defined a fishery reference points as "a benchmark against which to assess the performance of management in achieving an "operational objectives". These findings mean that *T. trachurus* stock in western Egyptian Mediterranean waters is highly overexploited, and fishing mortality should be reduced by about 50% to reach the target reference point $F_{0.1}$.

The present results revealed that as fishing mortality increases, both the B/R and SSBR decrease. The value of spawning stock biomass per recruit (SSBR refers to the total weight (biomass) of the part of the stock that has already spawned at least once, or that is ready to spawn during the reference year); at the current, the fishing mortality was 12.153, which is lower than the virgin SSBR (101.997). This value represented 12% of the virgin SSB. **Rajesh *et al*. (2015)** proposed that SSBR can be used as target reference point and must be maintained at 20% of virgin SSBR. Moreover, the ratio of $SSBR_c$ / $SSBR_{0.1}$ = 5.827 (decreasing or increasing trend with relative level $SSBR_c$ / $SSBR_{0.1}$ = 1) **(UNEP, 2017)**.

The yield per recruit in the present study indicates that the exploitation of *T. trachurus* population is very close to the maximum sustainable yield (MSY), and SSB is far from this value; since the target $F_{0.1}$ gave a value of 29.41g. According to the present data, the yield per recruit was 14.268g, while Y/R of F_{max} was found to be 14.355g. The spawning stock biomass was 12.153g, which is about 12% of the virgin SSB. Furthermore, these results indicate that the population of *T. trachurus* in the Egyptian Mediterranean waters suffers from growth overfishing and recruitment overfishing.

In addition, it appears that the current exploitation rate (E) (0.694) was slightly higher than the value of E_{max} (0.625), while the reference target point $E_{0.1}$ was 0.552. This means that the current exploitation rate should be decreased to the value of $E_{0.1}$. **Jakubavičiūtė *et al*. (2011)** suggested that $E_{0.1}$ should be used as a proxy for the maximum economic yield and set as a target reference point (TRP). Moreover, the present results showed that the value of length at first sexual maturity, L_{50} **(Farrag, 2008)** is higher than the value of L_c (length at first capture), indicating that these fish are harvested before they are allowed to spawn at least once. This may suggest that the stock of *T. trachurus* in the Egyptian Mediterranean waters is not properly sustained under favorable conditions.

CONCLUSION

This study concluded that the fishing mortality of *T. trachurus* in the western Egyptian Mediterranean waters is higher than natural mortality, indicating that this species is suffering from overfishing. A reduction of fishing mortality by about 55% is suggested to reach the

target reference point (TRP). This can be achieved through enforcement of the closed fishing season and increasing the length at first capture to L_c to conserve the spawning stock.

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