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# Estimation of Growth and Mortality Parameters for the Annular Seabream *Diplodus annularis* (Linnaeus, 1758) in the Southern Aegean Sea

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A B S T R A C T

The growth and mortality parameters were examined for the annular seabream *Diplodus annularis* collected from the Didim coast, southern Aegean Sea. A total of 654 annular seabream individuals, 263 female (40.21%) and 391 male (59.79%), were sampled by commercial trawlers and trammel nets from September 2022 to January 2024. The total length varied between 9.0 and 24.3 cm for females, 8.6 and 24.0 cm for males, and the weight varied between 8.60 and 146.57 g for females, 7.00 and 128.96 g for males. The length-weight relationships were calculated for females, males, and all individuals as $W = 0.0115 \times L^{2.9641}$, $W = 0.0131 \times L^{2.8995}$, and $W = 0.0118 \times L^{2.9440}$, respectively. The growth pattern was determined as negative allometric. The maximum age class was V for both females and males. The von Bertalanffy growth parameters were $L_\infty = 25.27$ cm, $k = 0.424$ year$^{-1}$, $t_0 = -0.308$ years for females; $L_\infty = 25.63$ cm, $k = 0.338$ year$^{-1}$, $t_0 = -0.935$ years for males; $L_\infty = 27.43$ cm, $k = 0.283$ year$^{-1}$, $t_0 = -1.121$ years for all individuals. The growth performance index ($\Phi'$) for females, males, and all individuals were 2.432, 2.347, and 2.329, respectively. The total ($Z$), natural ($M$), and fishing ($F$) mortality rates were computed for all individuals as 0.311, 0.248, and 0.062 year$^{-1}$, respectively. The exploitation rate ($E$) was 0.200 year$^{-1}$. The fishing mortality and exploitation rates were found lower than the biological reference points ($F_{opt} = 0.124$ year$^{-1}$ and $F_{limit} = 0.165$ year$^{-1}$) and optimum exploitation rate ($E_{opt} = 0.333$ year$^{-1}$), respectively. This study concluded that there is a low fisheries pressure on *D. annularis* stocks along the Didim coastal area, but this can be sustained with effective management, regular stock assessment, and monitoring of fishing pressure.

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## Introduction

The annular seabream *Diplodus annularis* (Linnaeus, 1758), a commercially and recreationally captured demersal species belonging to the family Sparidae, is distributed in the Eastern Atlantic, from the Bay of Biscay along the coast of Portugal and the Canary Islands, as well as throughout the Mediterranean, including the Black Sea and the Sea of Azov (Froese & Pauly, 2023). They inhabit mainly in Zostera seagrass beds but are also found in Posidonia beds and sandy bottoms, occasionally on rocky bottoms at depths ranging from 0-50 m, where they feed carnivorously on worms, crustaceans, molluscs, echinoderms, and hydrozoans (Bauchot & Hureau, 1986). Thus, while being part of the ecological balance, they also serve as prey for other predators, contributing to the maintenance of biodiversity. Previously, the sexual pattern of *D. annularis* was considered as a protandric hermaphrodite (Tortonese, 1975; Whitehead et al., 1986; Pajuelo & Lorenzo, 2001), but findings obtained in the last 20 years have concluded that the species is a non-functional hermaphrodite (Matic-Skoko et al., 2007; Alos et al., 2010). Alonso-Fernandez et al. (2011) also demonstrated non-functional hermaphroditism in histological analysis of annular sea bream by not detecting functional tissues degenerating into one sex and no proliferation indicative of sex reversal. The maximum total length reported is 28 cm (Mehanna & Farouk, 2021), and the maximum age reported is 17 years (Darmanin et al., 2019).

Given the dynamic nature of changes in length and weight of fish over time, growth parameters including the length-weight relationship (LWR) and von Bertalanffy growth function (VBGF) constants and mortality parameters, which examine the relationship between the decrease in stocks and fishing or natural causes, provide dynamic parameters that lead to important mathematical inferences about stock assessments of species in a given geographical region (Pauly, 1983; Sparre & Venema, 1998). Growth and mortality parameters facilitate the determination of the dynamic structure of fish populations, mathematical explanation of the growth rates of fish according to their ages, clarification of the current stock status, elaboration of long-term sustainable fishing strategies, and definition of catch limits.

Growth parameters of *D. annularis* have been investigated in various studies around the world (Dulcic & Kraljevic, 1996; Gordoa & Moli, 1997; Merella et al., 1997; Pajuelo & Lorenzo, 2001; Morey et al., 2003; Dulcic & Glamuzina, 2006; Matic-Skoko et al., 2007; Nouacer & Djebar, 2007; Cherif et al., 2008; Alos et al., 2010; Ghailen et al., 2010; Kapiris & Klaoudatos, 2011; Torres et al., 2012; Bolognini et al., 2013; Moutopoulos et al., 2013; Espino et al., 2016; Darmanin et al., 2019; Miled-Fathalli et al., 2019; Gharred et al., 2020; Soldo, 2020; Mehanna & Farouk, 2021; Falsone et al., 2022; Oussellam et al., 2023; Rodriguez-Garcia et al., 2023), and in Türkiye (Tosunoğlu et al., 1997; Kınacıgil & Akyol, 2001; Torcu-Koç et al., 2002; Çiçek et al., 2006; Karakulak et al., 2006; Akyol et al., 2007; Gökçe et al., 2007; İşmen et al., 2007; Gürkan et al., 2010; Demirel & Dalkara, 2012; Acarlı et al., 2014; Bilge et al., 2014; Altın et al., 2015; Kara et al., 2016; Dede, 2017; Samsun et al., 2017; Kara et al., 2018; Cengiz et al., 2019; Erat, 2019; Ayyıldız & Altın, 2020; Beğburs et al., 2020; Babaoğlu et al., 2021; Çolakoğlu, 2021). Among these studies, mortality parameters were examined by Torcu-Koç et al. (2002), Matic-Skoko et al. (2007), and Erat (2019).

Despite the extensive research on the dynamic parameters of *D. annularis* populations across various regions of Türkiye, Didim—an important coastal area of the southern Aegean Sea for both fisheries and aquaculture—has not kept pace with other Aegean coastlines in conducting population dynamics studies of economically significant fish species. Therefore, this study aims to reveal information on growth and mortality parameters for optimal exploitation of *D. annularis* stocks, thereby paving the way for the development of practical implications for fisheries management and potential conservation efforts along the Didim coast, the southern Aegean Sea.

## Material and Methods

Between September 2022 and January 2024, the specimens of *D. annularis* caught with trammel net (34-36 mm mesh size) and commercial trawl net along the coast of Didim were collected from Taşburun fishery shelter (Figure 1).

The total length of the specimens was determined to the nearest 0.1 cm and the weight to the nearest 0.01 g. Following the macroscopic examination of the gonads, the sex ratio was evaluated using the chi-square test ($\chi^2$) to determine whether it deviated significantly from the expected 1:1 ratio (Nikolsky, 1963). Age readings were obtained by counting growth rings from each collected sagittal otolith as recommended by Holden & Raitt (1974). All otoliths then underwent ethanol clearing before being immersed in glycerine for examination. Age determination was made using a reflected light binocular microscope.

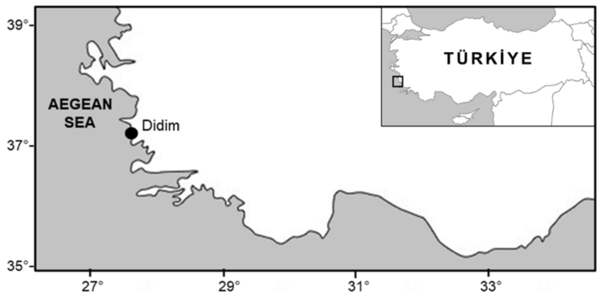


Figure 1. Sampling area of *Diplodus annularis* individuals

The length-weight relationships (LWRs) were separately estimated for females, males, and all individuals with the formula according to Ricker (1975):

$$W = a \times L^b \quad (1)$$

where $W$ is total body weight (g), $L$ is the total length (cm), $a$ is a coefficient relative to body form and exponent $b$ is the allometry coefficient of the linear regression equation expressing isometric (= 3), positive allometric (> 3) and negative allometric (< 3) growth in length. This equation can be elucidated logarithmically as log $W$ = log $a$ + $b$ log $L$. The significance of the regression was controlled by ANOVA (Zar, 1999). A Student's $t$-test with a confidence level of 95% was utilized to determine if the $b$ values derived from the linear regressions differed significantly from the null hypothesis of isometric growth ($H_0$: $b = 3$) using the equation suggested by Sokal & Rohlf (1987):

$$t_s = (b - 3) / sb \quad (2)$$

where $t_s$ is the $t$-test value, $b$ is the slope, and $sb$ is the standard error of the slope ($b$). Hypothetical growth parameters for females, males, and all individuals were calculated using the von Bertalanffy growth function (VBGF) (Beverton & Holt, 1957):

$$L_t = L_\infty \left[1 - e^{-k(t-t_0)}\right] \quad (3)$$

where $L_t$ is the total length (cm) at the time $t$ (year), $L_\infty$ is the mean asymptotic length (cm), $k$ is the growth constant (year$^{-1}$), and $t_0$ (year) is the theoretical age at zero length. The growth performance index ($\Phi'$) was estimated with the following formula proposed by Munro and Pauly (1983):

$$\Phi' = \log k + 2 \log L_\infty \quad (4)$$

The total mortality rate ($Z$) was estimated based on mean length (cm) using the equation suggested by Beverton & Holt (1957):

$$Z = k \times (L_\infty - \overline{L}) / (\overline{L} - L') \quad (5)$$

where $\overline{L}$ mean length (cm) of all individuals, $L'$ the length (cm) of the smallest fish in the data set. Natural mortality ($M$) was calculated using the following formula based on mean weight (g) proposed by Ursin (1967):

$$M = \overline{W}^{-(\frac{1}{b})} \quad (6)$$

where $\overline{W}$ mean weight of all individuals, and $b$ is the coefficient of LWRs. Fishing mortality ($F$) was computed using the equation (Pauly, 1980):

$$F = Z - M \quad (7)$$

The exploitation rate ($E$) was estimated by the following equation (Sparre and Venema, 1998):

$$E = F / Z \quad (8)$$

Fishery resource status was evaluated according to Patterson (1992) through the comparability of current fishing mortality with the optimum ($F_{opt}$) and limit ($F_{limit}$) biological reference points defined in the following formula:

$$F_{opt} = 0.5\, M \quad (9)$$

$$F_{limit} = 2/3\, M \quad (10)$$

The optimum exploitation rate ($E_{opt}$), on the other hand, was computed using the Gulland (1971) equation:

$$E_{opt} = F_{opt}(M + F_{opt})^{-1} \quad (11)$$

Statistical analyses were conducted using Microsoft Excel 2016 (Microsoft, Redmond, WA, USA) and SPSS Statistics 19.0 (SPSS Inc., Chicago, IL, USA).

## Results and Discussion

### *General Informative Characteristics of The Sampling*

A total of 654 *D. annularis* samples, 263 female (40.21%) and 391 male (59.79%), were collected from the Didim coast during the research. The overall sex ratio (F:M) was determined as 1:1.48. The chi-square test ($\chi^2$) showed that the sex ratio was significantly different from the expected 1:1 ratio ($\chi^2$, $P < 0.05$). Total length intervals were 9.0-24.3 cm for females, 8.6-24.0 cm for males, and weight intervals were 8.60-146.57 g for females, 7.00-128.96 g for males. The mean length and weights were 18.31 ± 3.05 cm and 68.72 ± 29.88 g for females, 17.12 ± 3.45 cm and 54.88 ± 29.22 g for males, 17.59 ± 3.34 cm, and 60.45 ± 30.21 g for all individuals, respectively.

The maximum length and weight obtained from *D. annularis* individuals was 24.3 cm and 146.57 g. A statistically significant difference was found in overall length and weight values between male and female individuals ($t_{test}$, $P < 0.05$). Many individuals were between 17.0 and 19.9 cm in total length, accounting for a total of 31.04% of all samples (Figure 2).

### *Length-weight Relationships*

LWRs were separately determined in logarithmic form as $log\ W = -1.9389 + 2.9641\ log\ L$ for females; $log\ W = -1.8831 + 2.8995\ log\ L$ for males; $log\ W = -1.9280 + 2.9440\ log\ L$ for all individuals. The functional relationship in the fitted growth curve was envisioned by drawing the length-weight curve for females, males, and all individuals of *D. annularis* (Figure 3).

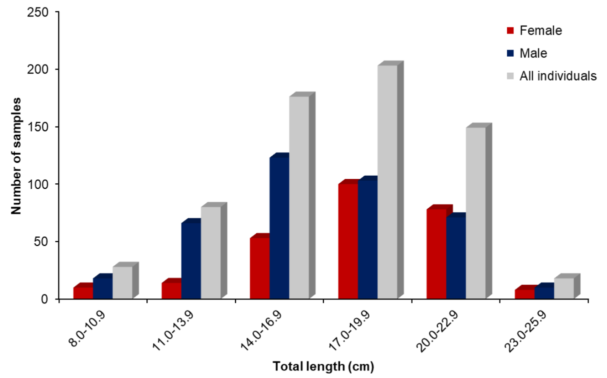


Figure 2. Total length frequency for female, male, and all individuals of Diplodus annularis from the Didim coast

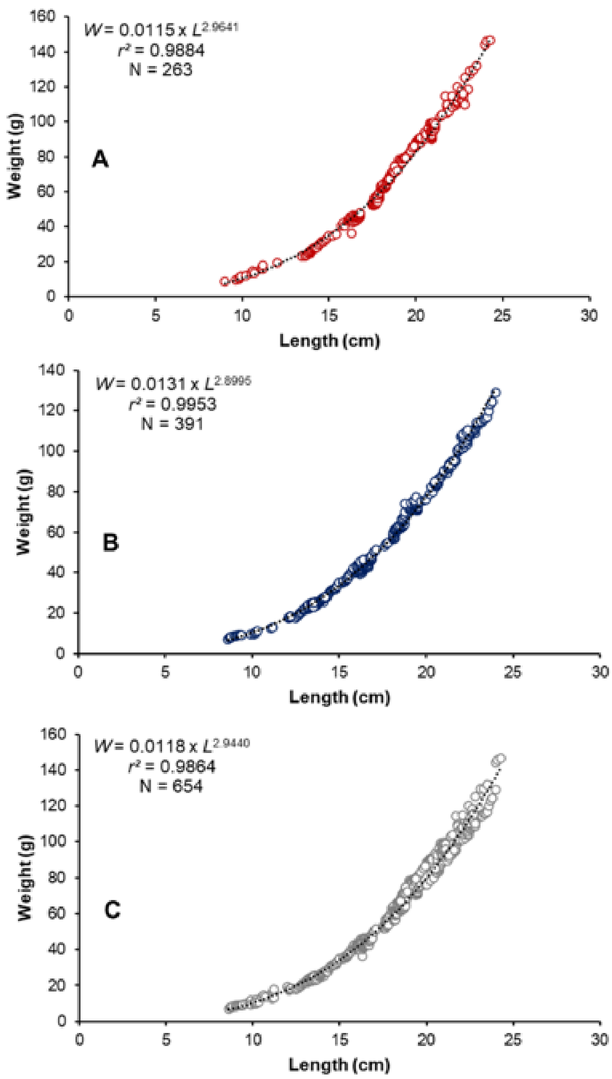


Figure 3. The LWRs for females (A), males (B), and all individuals (C) of *Diplodus annularis* from the Didim coast

Table 1 summarizes the LWRs computed for males, females, and all individuals of *D. annularis* sampled from the Didim coastline. The mean length and weight of females were higher than those of males, and all differences were found to be statistically significant ($t_{test}$, $P < 0.05$). The exponent of the $b$ parameter of female, male, and all individuals demonstrated negative allometry and was statistically significant ($P < 0.05$).

Table 1. Informative sampling statistics, LWR parameters between total length and weight for females, males, and all individuals, and the possibility of isometry tested by Student's *t*-test

| Sex | N | Range of TL (cm) ($L_{mean}$ ± SD) | Range of W (g) ($W_{mean}$ ± SD) | Regression parameters | | | | | t-test |
|---|---|---|---|---|---|---|---|---|---|
| | | | | a | b | SE of b | 95% CI of b | $r^2$ | |
| Female | 263 | 9.0–24.3 (18.30 ± 3.05) | 8.60–146.57 (68.72 ± 29.88) | 0.0115 | 2.9641 | 0.0181 | 2.9284–2.9997 | 0.9884 | 1.98* |
| Male | 391 | 8.6–24.0 (17.12 ± 3.45) | 7.00–128.96 (54.88 ± 29.22) | 0.0131 | 2.8995 | 0.0009 | 2.8803–2.9186 | 0.9953 | 10.33* |
| All | 654 | 8.6–24.3 (17.59 ± 3.34) | 7.00–146.57 (60.45 ± 30.21) | 0.0118 | 2.9440 | 0.0103 | 2.9237–2.9643 | 0.9864 | 5.41* |

N, sample number; TL, length; W, weight; SD, standard deviation; *a*, intercept; *b*, slope; SE, standard error; CI, confidence interval; $r^2$, coefficient of determination; * $t > t_{0.05,N>250} = 1.65$

Table 2. Total length (TL) and weight (W) relationship parameters and growth patterns of *Diplodus annularis* obtained from various locations

| Locations | N | Sex | a | b | GP | References |
|---|---|---|---|---|---|---|
| Eastern Adriatic (Croatia) | 100 | F+M | 0.00009 | 2.928 | A- | Dulcic & Kraljevic (1996) |
| Balearic Islands, Western Mediterranean (Spain) | 94 | F+M | 0.0109 | 3.20 | A+ | Merella et al. (1997) |
| Canary Islands, NE Atlantic (Spain) | 155 | F | 0.000022 | 2.917 | I | Pajuelo & Lorenzo (2001) |
| | 194 | M | 0.000029 | 2.830 | A- | |
| Western Mediterranean (Spain) | 848 | F+M | 0.0115 | 3.1668 | A+ | Morey et al. (2003) |
| Babadillimani Bight, NE Mediterranean (Türkiye) | 89 | F+M | 0.0113 | 3.147 | A+ | Çiçek et al. (2006) |
| Eastern Adriatic (Croatia) | 425 | F+M | 0.0165 | 2.985 | A- | Dulcic & Glamuzina (2006) |
| Northern Aegean Sea (Türkiye) | 372 | F+M | 0.0068 | 3.315 | A+ | Karakulak et al. (2006) |
| Gökova Bay, Southern Aegean Sea (Türkiye) | 159 | F+M | 0.0179 | 2.985 | A- | Akyol et al. (2007) |
| Izmir Bay, Central Aegean Sea (Türkiye) | 718 | F+M | 0.0177 | 2.99 | A- | Gökçe et al. (2007) |
| Saros Bay, Northern Aegean Sea (Türkiye) | 108 | F+M | 0.01602 | 3.0192 | A+ | İşmen et al. (2007) |
| Gulf of Tunis, Central Mediterranean (Tunisia) | 287 | F | 0.01 | 2.86 | A- | Cherif et al. (2008) |
| | 183 | M | 0.033 | 2.72 | A- | |
| Gulf of Gabes, Central Mediterranean (Tunisia) | 161 | F+M | 0.0253 | 3.012 | I | Ghailen et al. (2010) |
| Çandarlı Bay, Central Aegean Sea (Türkiye) | 25 | F+M | 0.0085 | 3.288 | A+ | Gürkan et al. (2010) |
| Argolikos Gulf, Central Aegean Sea (Greece) | 68 | F | 0.00001 | 2.99 | A- | Kapiris & Klaoudatos (2011) |
| | 94 | M | 0.000005 | 3.23 | A+ | |
| Sea of Marmara (Türkiye) | 81 | F+M | 0.004 | 3.432 | A+ | Demirel & Dalkara (2012) |
| Gulf of Cadiz, NE Atlantic (Spain) | 166 | F+M | 0.0094 | 3.184 | A+ | Torres et al. (2012) |
| Western Adriatic (Italy) | 856 | F+M | 0.015 | 3.068 | A+ | Bolognini et al. (2013) |
| Korinthiakos Gulf (Greece) | 409 | F+M | 0.0114 | 3.114 | A+ | Moutopoulos et al. (2013) |
| Homa Lagoon, Central Aegean Sea (Türkiye) | 121 | F+M | 0.0100 | 3.190 | A+ | Acarlı et al. (2014) |
| Southern Aegean Sea (Türkiye) | 2254 | F+M | 0.0192 | 3.0425 | A+ | Bilge et al. (2014) |
| Gökçeada Island, Northern Aegean Sea (Türkiye) | 923 | F+M | 0.011 | 3.103 | A+ | Altın et al. (2015) |
| Canary Islands, NE Atlantic (Spain) | 99 | F+M | 0.0217 | 2.9025 | A- | Espino et al. (2016) |
| Izmir Bay, Central Aegean Sea (Türkiye) | 105 | F+M | 0.0098 | 3.221 | A+ | Kara et al. (2016) |
| Gökova Bay, Southern Aegean Sea (Türkiye) | 118 | F+M | 0.0058 | 3.4429 | A+ | Dede (2017) |
| Sinop Coast, Central Black Sea (Türkiye) | 210 | F+M | 0.031 | 2.84 | A- | Samsun et al. (2017) |
| Gediz Estuary, Central Aegean Sea (Türkiye) | 91 | F+M | 0.0085 | 3.249 | A+ | Kara et al. (2018) |
| Saros Bay, Northern Aegean Sea (Türkiye) | 159 | F+M | 0.0331 | 2.77 | A- | Cengiz et al. (2019) |
| Maltese Islands, Central Mediterranean (Malta) | 759 | F | 0.014 | 3.090 | A+ | Darmanin et al. (2019) |
| | 369 | M | 0.014 | 3.081 | A+ | |
| | 1661 | F+M | 0.013 | 3.108 | A+ | |
| Ünye Coast, Central Black Sea (Türkiye) | 295 | F+M | 0.0554 | 2.66 | A- | Erat (2019) |
| Gulf of Tunis, Central Mediterranean (Tunisia) | 78 | F+M | 0.0150 | 3.045 | I | Miled-Fathalli et al. (2019) |
| Gökçeada Island, Northern Aegean Sea (Türkiye) | 923 | F+M | 0.000008 | 3.1029 | A+ | Ayyıldız & Altın (2020) |
| Izmir Bay, Central Aegean Sea (Türkiye) | 103 | F+M | 0.007 | 3.332 | A+ | Beğburs et al. (2020) |
| Eastern Adriatic | 1325 | F+M | 0.017 | 2.9796 | A- | Soldo (2020) |
| Çandarlı Bay, Central Aegean Sea (Türkiye) | 85 | F+M | 0.007 | 3.327 | A+ | Babaoğlu et al. (2021) |
| Saros Bay, Northern Aegean Sea (Türkiye) | 23 | F+M | 0.0058 | 3.417 | A+ | Çolakoğlu (2021) |
| Mediterranean Coast of Egypt | 444 | F+M | 0.0217 | 2.840 | A- | Mehanna & Farouk (2021) |
| Southern Sicily, Central Mediterranean (Italy) | 86 | F+M | 0.0384 | 2.728 | A- | Falsone et al. (2022) |
| Marchica Lagoon, Western Mediterranean (Morocco) | 283 | F+M | 0.0122 | 3.1576 | A+ | Oussellam et al. (2023) |
| Gulf of Cadiz, NE Atlantic (Spain) | 698 | F+M | 0.0069 | 3.3140 | A+ | Rodriguez-Garcia et al. (2023) |
| Didim Coast, Southern Aegean Sea (Türkiye) | 263 | F | 0.0115 | 2.9641 | A- | Present study |
| | 391 | M | 0.0131 | 2.8995 | A- | |
| | 654 | F+M | 0.0118 | 2.9440 | A- | |

N, number of samples studied; *a*, intercept; *b*, slope; F, female; M, male; F+M, all individuals; GP, growth pattern; A+, allometric positive; A-, allometric negative; I, isometric.

Table 3. Length key for females, males, and all individuals of *Diplodus annularis* depend on age classes from the Didim coast

| Intervals of TL (cm) | Age classes | | | | | Total |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | |
| 8.0-10.9 | 28 | | | | | 28 |
| 11.0-13.9 | 68 | 12 | | | | 80 |
| 14.0-16.9 | 24 | 152 | | | | 176 |
| 17.0-19.9 | | 16 | 167 | 20 | | 203 |
| 20.0-22.9 | | | 33 | 98 | 18 | 149 |
| 23.0-25.9 | | | | 13 | 5 | 18 |
| Total | 120 | 180 | 200 | 131 | 23 | 654 |
| Coverage | 18.34% | 27.53% | 30.59% | 20.03% | 3.51% | 100.00% |
| Mean TL ± SD | 12.53±1.84 | 16.11±1.07 | 18.91±0.88 | 21.37±1.36 | 22.61±0.95 | 17.59±3.34 |
| Mean W ± SD | 20.86±7.27 | 42.04±7.94 | 70.26±11.42 | 97.22±15.54 | 116.23±15.33 | 60.45±30.21 |
| Females (N) | 16 | 71 | 105 | 54 | 17 | 263 |
| Coverage | 2.45% | 10.86% | 16.05% | 8.26% | 2.59% | 40.21% |
| Males (N) | 104 | 109 | 95 | 77 | 6 | 391 |
| Coverage | 15.90% | 16.66% | 14.53% | 11.77% | 0.93% | 59.79% |
| F:M | 1:6.5 | 1:1.53 | 1:0.9 | 1:1.42 | 1:0.35 | 1:1.48 |

TL, total length; W, weight; SD, standard deviation; N, number of samples; F, female; M, male

Table 4. The growth comparisons of *Diplodus annularis* from different geographical areas

| Locations | Sex | $L_\infty$ | k | $t_o$ | Φ′ | References |
|---|---|---|---|---|---|---|
| Catalan Coast of Spain, NW Mediterranean | F+M | 20.37 | 0.544 | -0.033 | | Gordoa & Moli (1997) |
| Gülbahçe Bay, Central Aegean Sea (Türkiye) | F+M | 22.50 | 0.159 | -2.388 | | Tosunoğlu et al. (1997)* |
| Gulf of Gabes, Central Mediterranean (Tunisia) | F+M | 22.64 | 0.16 | -2.00 | | Bradai et al. (2001) |
| Izmir Bay, Central Aegean Sea (Türkiye) | F+M | 20.97 | 0.250 | -1.447 | | Kınacıgil & Akyol (2001)* |
| | F | 25.02 | 0.243 | -0.901 | | |
| Canary Islands, NE Atlantic (Spain) | M | 24.57 | 0.271 | -0.884 | | Pajuelo & Lorenzo (2001) |
| | F+M | 24.79 | 0.218 | -0.879 | | |
| | F | 17.21 | 0.21 | -1.73 | | |
| Edremit Bay, Northern Aegean Sea (Türkiye) | M | 18.36 | 0.14 | -2.936 | | Torcu-Koç et al. (2002)* |
| | F+M | 16.62 | 0.20 | -1.96 | | |
| Tyrrhenian Sea, Central Mediterranean (Italy) | F+M | 21.1 | 0.386 | - | | Wurtz & Matricardi (2002) |
| Gulf of Annaba, Central Mediterranean (Algeria) | F+M | 19.54 | 0.46 | -0.565 | | Nouacer & Djebar (2007) |
| | F | 22.13 | 0.126 | -1.593 | | |
| Eastern Middle Adriatic Sea (Croatia) | M | 21.94 | 0.125 | -1.684 | | Matic-Skoko et al. (2007) |
| | F+M | 23.95 | 0.126 | -1.664 | | |
| Mallorca Island, NW Mediterranean, (Spain) | F | 15.93 | 0.45 | -0.12 | | Alos et al. (2010) |
| | M | 15.17 | 0.47 | -0.07 | | |
| | F | 22.92 | 0.096 | -6.96 | 1.704 | |
| Maltese Islands, Central Mediterranean (Malta) | M | 24.63 | 0.091 | -6.07 | 1.744 | Darmanin et al. (2019) |
| | F+M | 21.38 | 0.123 | -5.40 | 1.750 | |
| Ünye Coast, Central Black Sea (Türkiye) | F+M | 24.15 | 0.490 | -0.451 | 2.456 | Erat (2019) |
| Salakta Coast, Central Mediterranean (Tunisia) | F+M | 20.04 | 0.18 | -2.60 | | Gharred et al. (2020) |
| Sayada Coast, Central Mediterranean (Tunisia) | | 20.29 | 0.16 | -3.03 | | |
| | F | 25.27 | 0.424 | -0.308 | 2.432 | |
| Didim Coast, Southern Aegean Sea (Türkiye) | M | 25.63 | 0.338 | -0.935 | 2.347 | Present Study |
| | F+M | 27.43 | 0.283 | -1.121 | 2.329 | |

F, female; M, male; F+M, all individuals; $L_\infty$, asymptotic length; *k*, growth coefficient (year$^{-1}$); $t_o$, theoretical age at length equal to zero; *Φ′*, growth performance index; *, using fork length

A strong correlation was observed between the length and weight in females, males, and all individuals ($P < 0.001$; $r^2 > 0.97$). A summary of the comparison between the length-weight relationships identified in this study and those from previous studies is presented in Table 2.

***Determination of the von Bertalanffy growth function (VBGF) parameters***

Sagittal otolith examinations revealed age patterns ranging from I to V years for all individuals. Table 3 displays the total length frequencies for each age class of *D. annularis* from the Didim coast. Age class III (30.59%) was dominant, followed by II (27.53%), IV (20.03%), I (18.34%), and V (3.51%) classes.

The growth pattern in mean lengths from each age group was estimated for females, males, and all individuals of *D. annularis* from the Didim coast using the VBGF. The total length of individuals assigned to each age class for female, male, and all individuals is presented in Figure 4. The von Bertalanffy growth parameters were estimated as $L_\infty$ = 25.27 cm, $k$ = 0.424 year$^{-1}$, $t_0$ = -0.308 years for females; $L_\infty$ = 25.63 cm, $k$ = 0.338 year$^{-1}$, $t_0$ = -0.935 years for males; $L_\infty$ = 27.43 cm, $k$ = 0.283 year$^{-1}$, $t_0$ = -1.121 years for all individuals. The growth performance index (*Φ′*) was calculated for females, males, and all individuals as 2.432, 2.347, and 2.329, respectively. A summary of comparisons of von Bertalanffy growth parameters for *D. annularis* distributed in different geographical areas is presented in Table 4.

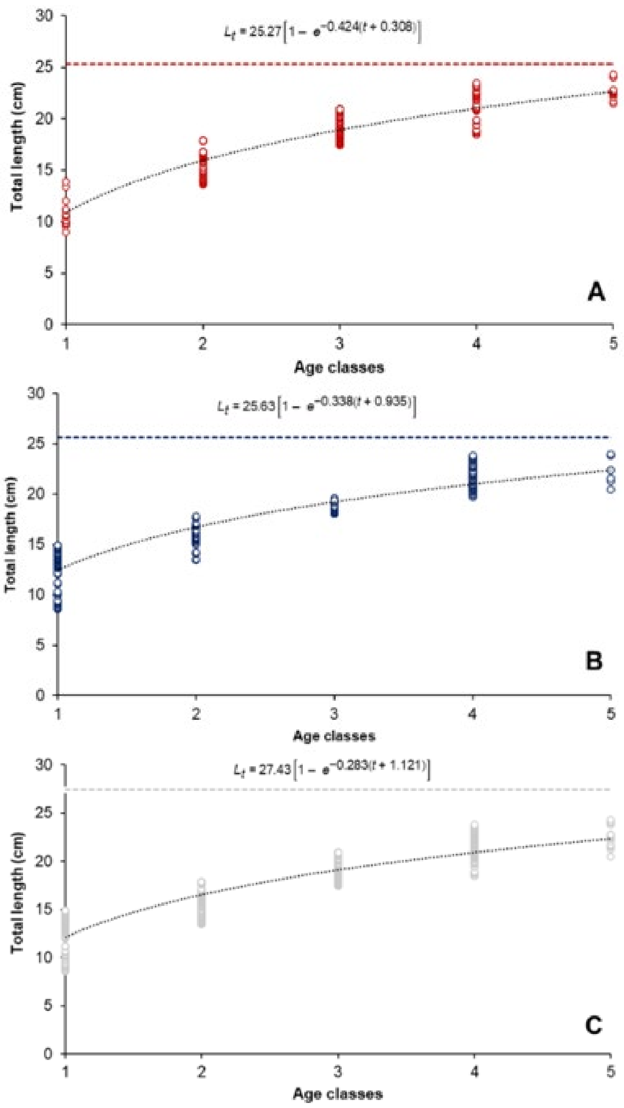


Figure 4. von Bertalanffy growth curves fitted on total length at age data for females (A), males (B), and all individuals (C) of *Diplodus annularis*

***Estimation of Mortality Rates***

The total, natural, and fishing mortality rates of *D. annularis* were determined separately for females, males, and all individuals. In this manner, total mortality (*Z*) was 0.318, 0.338, and 0.311 year$^{-1}$, natural mortality (*M*) rate was 0.240, 0.251, and 0.248 year$^{-1}$, and fishing mortality (*F*) was 0.078, 0.087, and 0.062 year$^{-1}$, respectively. The exploitation rate (*E*) was calculated as 0.200 year$^{-1}$ for all individuals. The biological reference points were calculated as follows: the optimum fishing mortality, $F_{opt}$ = 0.124 year$^{-1}$; the fishing mortality limit, $F_{limit}$ = 0.165 year$^{-1}$, and the optimum exploitation rate, $E_{opt}$ = 0.333 year$^{-1}$. The mortality parameters for all individuals of *D. annularis* were compared with the previous studies (Table 5).

Overall, information on the age and growth parameters of *D. annularis* in southern Aegean Sea populations is limited. Similar to other sparids distributed in the southern Aegean coast, *D. annularis* is of vital importance for the ecosystem of the region. Because they contribute to the biodiversity of seagrass beds and rocky areas. Hence, the growth and mortality data could have significant implications for ecosystem-based sustainable fisheries management. The present study is the first contribution to the growth and mortality parameters of *D. annularis* along the Didim coast (southern Aegean Sea). Comparisons of the length-weight relationships (Table 2), von Bertalanffy growth parameters (Table 4), and mortality rates (Table 5) have been conducted using data obtained from various geographical areas of the species. The observed sex ratio of 1:1.48, favoring males aligns with those obtained by Pajuelo & Lorenzo (2001), Torcu-Koç et al. (2002), and Kapiris & Klaoudatos (2011), but it contrasts with the findings obtained by Kınacıgil & Akyol (2001), Matic-Skoko et al. (2007), Cherif et al. (2008), Alos et al. (2010), and Darmanin et al. (2019). These alterations in sex ratio in different geographical regions can be referred to as seasonal variations, age at sexual maturity, feeding, and spawning grounds, as well as environmental factors affecting sex determination or different mortality rates between the sexes.

The *b* constant of the LWR obtained from the present study indicated negative allometry for females (2.9641), males (2.8995), and all individuals (2.9440), which is partially consistent with the previous studies summarized in Table 2. Conversely, a positive allometric constant *b* was obtained in the Balearic Islands (Merella et al., 1997), Spanish coasts of Western Mediterranean (Morey et al., 2003), Babadillimani Bight (Çiçek et al., 2006), Turkish coasts of Northern Aegean Sea (Karakulak et al., 2006), Saros Bay (İşmen et al., 2007; Çolakoğlu, 2021), Çandarlı Bay (Gürkan et al., 2010; Babaoğlu et al., 2021), Argolikos Gulf (male individuals) (Kapiris & Klaoudatos, 2011), Sea of Marmara (Demirel & Dalkara, 2012), Gulf of Cadiz (Torres et al., 2012; Rodriguez-Garcia et al., 2023), Italian coasts of Western Adriatic (Bolognini et al., 2013), Korinthiakos Gulf (Moutopoulos et al., 2013), Homa Lagoon (Acarlı et al., 2014), Turkish coasts of southern Aegean Sea (Bilge et al., 2014), Gökçeada Island (Altın et al., 2015; Ayyıldız & Altın, 2020), Izmir Bay (Kara et al., 2016; Beğburs et al., 2020), Gökova Bay (Dede, 2017), Gediz Estuary (Kara et al., 2018), Maltese Islands (Darmanin et al., 2019), Marchica Lagoon (Oussellam et al., 2023). The constant *b*, which indicates the natural development of fish, varies between 2 and 4 (Tesch, 1971). A combination of factors such as methodological differences, sampling site, habitat, season, maturity, sex, age, diet, and differences in length ranges of fish samples can lead to the differences in length-weight relationships observed in various geographic regions (Ricker, 1975; Bagenal & Tesch, 1978).

Age determinations from otolith readings of *D. annularis* individuals collected from the coast of Didim revealed that both sexes were in age classes I to V. The most prevalent age class for females was III (105 individuals), while those for males were I (104 individuals) and II (109 individuals). Pajuelo & Lorenzo (2001) determined the most dominant age class of *D. annularis* from the Canary Islands as II for all individuals. Torcu-Koç et al. (2002) estimated that the predominant age class of *D. annularis* up to a maximum age of VII years in the Edremit Bay was III for females and II for males, aligning with the findings of this study. Matic-Skoko et al (2007) identified age class V as the most prevalent among all *D. annularis* individuals sampled up to XIII years of age from the Novigrad Sea and Kastela Bay in the eastern middle Adriatic Sea.

Table 5. The comparisons of mortality parameters for all individuals of *Diplodus annularis* from different geographical areas

| Locations | Sex | Z | M | F | E | References |
|---|---|---|---|---|---|---|
| Edremit Bay, Northern Aegean Sea (Türkiye) | F+M | 1.15 | 0.37 | 0.78 | 0.68 | Torcu-Koç et al. (2002) |
| Eastern Middle Adriatic Sea (Croatia) | F+M | 0.72 | 0.245 | 0.33 | 0.46 | Matic-Skoko et al. (2007) |
| Ünye Coast, Central Black Sea (Türkiye) | F+M | 1.75 | 0.96 | 0.79 | 0.45 | Erat (2019) |
| Didim Coast, Southern Aegean Sea (Türkiye) | F+M | 0.311 | 0.248 | 0.062 | 0.200 | Present study |

F+M, all individuals; *Z*, total mortality; *M*, natural mortality; *F*, fishing mortality; *E*, exploitation rate.

Darmanin et al. (2019) found that among all the *D. annularis* individuals observed in the Maltese Islands, age classes II and III were the most prevalent, with a maximum age of 17 years. The use of equipment like longlines and trammel nets, which enable the capture of larger specimens compared to trawling, along with the varying sample sizes among studies, may account for the observed discrepancies in age classes in research conducted across various regions (Uyan, 2024).

The asymptotic length ($L_\infty$) of *D. annularis* derived from this study was 25.27 cm for females, 25.63 for males, and 27.43 cm for all individuals which is around those in the previous studies presented in Table 4, not including Gordoa & Moli (1997), Kınacıgil & Akyol (2001), Torcu-Koç et al. (2002), Nouacer & Djebar (2007), Alos et al. (2010), and Gharred et al. (2020). Gordoa & Moli (1997) estimated the age and growth patterns of *D. annularis* from the Catalan Coast of Spain and found $L_\infty$ to be 20.37 cm for all individuals. Kınacıgil & Akyol (2001) studied the growth features based on the fork length of *D. annularis* in Izmir Bay and detected $L_\infty$ as 20.97 cm. Torcu-Koç et al. (2002) revealed the growth parameters of *D. annularis* in Edremit Bay using fork length and computed $L_\infty$ of female, male, and all individuals as 17.21, 18.36, and 16.62 cm, respectively. Nouacer & Djebar (2007) determined $L_\infty$ of *D. annularis* from the Gulf of Annaba as 19.54 cm. Alos et al. (2010) provided the growth pattern of *D. annularis* in Mallorca Island and calculated $L_\infty$ for females and males as 15.93 and 15.17 cm, respectively. Gharred et al. (2020) investigated the age and growth patterns of *D. annularis* from Salakta and Sayada Coasts of Tunisia and detected $L_\infty$ for all individuals as 20.04 and 20.29 cm, respectively. Santic et al. (2002) suggested that potential changes in food quality and water temperature may contribute to differences in growth characteristics. Especially, differences in estimated asymptotic length can be attributed to phylogeographic diversity as well as factors such as fishing pressure, global climate change, and pollutants (Uyan et al., 2020; 2024). An alternative interpretation is that *D. annularis* populations distributed across different geographic areas may exhibit significant variation in metabolism and growth in response to environmental conditions. This phenomenon, called phenotypic plasticity, is the capacity of a single genotype to exhibit different phenotypes that allow fish to respond adaptively to environmental change in their physiology and behaviour, and is the primary response to environmental variation in reproduction or survival (Turan, 1999; Uyan & Turan, 2017). Therefore, the degree of phenotypic plasticity may be affected by spatial differentiation of populations and even intraspecific or interspecific competition and may also mediate sex-specific differential growth responses to the same environmental conditions.

The growth performance index ($\Phi'$), reflecting the correlation between $L_\infty$ and $k$, of annular seabream on the coast of Didim was 2. 432 for females, 2.347 for males, and 2.329 for all individuals. These findings are compatible with the growth performance index obtained from the Ünye coast (Erat, 2019), while higher than those of the Maltese islands (Darmanin et al., 2019). The index provides evidence that the growth of *D. annularis* may be similar or different depending on the ecological conditions in different regions.

The total, natural, and fishing mortality parameters of *D. annularis* for all individuals were calculated and the comparisons from different locations were summarized in Table 5. Total mortality ($Z$) was 0.311 year$^{-1}$, which was considerably lower than Torcu-Koç et al. (2002) ($Z$ = 1.15 year$^{-1}$), Matic-Skoko et al. (2007) ($Z$ = 0.72 year$^{-1}$), and Erat (2019) ($Z$ = 1.75 year$^{-1}$). Natural mortality detected ($M$ = 0.248 year$^{-1}$) was lower than Torcu-Koç et al. (2002) ($M$ = 0.37 year$^{-1}$) and Erat (2019) ($M$ = 0.96 year$^{-1}$) but quietly closer to Matic-Skoko et al. (2007) ($M$ = 0.245 year$^{-1}$). Fishing mortality ($F$) was found to be 0.062 year$^{-1}$, which was extremely low compared to Torcu-Koç et al. (2002) ($F$ = 0.78 year$^{-1}$), Matic-Skoko et al. (2007) ($F$ = 0.33 year$^{-1}$), and Erat (2019) ($F$ = 0.79 year$^{-1}$). The total ($Z$) and fishing mortality rates ($F$) in this study were found to be noticeably lower than in previous studies, while the natural mortality rate ($M$) was found to be relatively close except for Erat (2019). The differences in total and fishing mortality rates can be attributed to fisheries efforts in various marine ecosystems as well as bio-ecological characteristics and behavioural trends of fishes (Hewitt & Hoenig, 2005). In particular, the possible reason for the fairly low fishing mortality in this study may be the deficiency of older age and larger length groups in the sampling owing to catchability factors. Sparre & Venema (1998) pointed out that variations in natural mortality rates for the same species may vary by region, depending on the density of predators and competitors and the status of fishing activities. Moreover, Pauly (1980) argued that the overall representative natural mortality rate for marine species of 175 fish stocks was $M$ = 0.2-0.3 year$^{-1}$. The natural mortality rate obtained in this study gives the impression that it is optimal due to indicating a reasonable value under the traditional assumption. Mortality parameters are crucial in the management of ecosystem-based sustainable fisheries, ensuring the stocks and the balance of the ecosystem. Total mortality reflects the risk of stock exploitation, whereas natural mortality signals the state of the ecosystem's health. Fishing mortality, which can be adjusted through management strategies, helps reduce fisheries pressure and secures stock sustainability. Therefore, monitoring these rates along the Didim coasts is extremely important in effective fisheries management to protect biodiversity and maintain ecosystem balance (Turan, 2021; 2022).

The exploitation rate ($E$) of *D. annularis* for all individuals was estimated as 0.200 year$^{-1}$, which was lower than Torcu-Koç et al. (2002) ($E$ = 0.68 year$^{-1}$), Matic-Skoko et al. (2007) ($E$ = 0.46 year$^{-1}$), and Erat (2019) ($E$ = 0.45 year$^{-1}$). Gulland (1971) emphasized that the optimal exploitation rate of a stock should not be more than 0.5. Gulland (1983) also put forward that in an optimally exploited stock, the fishing mortality rate ($F$) is equal to the natural mortality rate ($M$) or the exploitation rate ($E$) is equal to 0.5. On the other hand, the fishing mortality rate determined ($F$ = 0.062 year$^{-1}$) was lower than the biological reference points based on the fisheries resource status approach of Patterson (1992) as follows: $F_{opt}$ = 0.124 year$^{-1}$ and $F_{limit}$ = 0.165 year$^{-1}$. The exploitation rate ($E$ = 0.200 year$^{-1}$) was also found to be lower than the optimum exploitation rate ($E_{opt}$ = 0.333 year$^{-1}$). Considering this perspective, the fishing mortality rate being below the $F_{opt}$ and $F_{limit}$ reference points, along with the exploitation parameter being below $E_{opt}$, indicates that *D. annularis* from the Didim coast subjected low fisheries pressure, as probably evidenced by the lack of older and larger specimens in the study. The low exploitation rate observed in *D. annularis* along the Didim coast is currently advantageous for the sustainability of the stocks, but maintaining this situation requires effective management, regular stock assessment and monitoring of fisheries pressure. Adaptive management plans can allow the implementation of quotas, while legal regulations and effective inspections can provide the continuation of the low exploitation rate (Garcia & Cochrane, 2005).

## Conclusions

This study has significantly contributed to understanding the age, growth, and mortality parameters of *D. annularis*, distributed in Didim, an important fishery area in the southern Aegean Sea of Türkiye. However, limitations such as sample size or seasonal variability may have indirectly affected the results. Despite the low exploitation parameter observed in *D. annularis* along the Didim coast, long-term monitoring of population dynamics is crucial for the sustainability of fish stocks. Such efforts are significant for fisheries management, as they assist in setting catch limits and identifying fishery practices that protect vulnerable age groups, in addition to examining the effects of climate change on growth patterns. Further investigation of *D. annularis* populations in Turkish marine waters using different mtDNA regions and nuclear markers and morphological measurements, expanding sample sizes in the Didim coastal region in different seasons, and examining interactions with other species in the region will contribute to a more comprehensive understanding of the stock status and provide important data for sustainable fisheries management. Thus, this information will shed light on future studies by fisheries scientists and managers on other economically important species in this region.

## Declarations

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### *Conflict of Interest*

The authors declare that there is no conflict of interest.

### *Ethical Approval*

This study does not require ethics committee permission.

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