

Investigation of Some Population Parameters of Common Sole, *Solea solea* (L., 1758) from İskenderun Bay

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Abstract: Data on age, growth, reproduction, mortality and exploitation were examined for common sole collected in İskenderun Bay from March 2000 to February 2001. The examined individuals were aged between 1 and 8 years. Total length ranged from 8.8 to 28.2 cm. The length-weight relationships for males ($a = 0.0117$, $b = 2.998$) and females ($a = 0.0091$, $b = 3.077$) showed no significant difference from isometric growth. Von Bertalanffy growth parameters were $L_{\infty} = 26.03$ cm, $k = 0.221$ year⁻¹, $t_0 = -1.31$ for males and $L_{\infty} = 29.95$ cm, $k = 0.181$ year⁻¹, $t_0 = -1.55$ for females. The reproductive activity of the common sole in the Bay of İskenderun took place between April and May, peaking in April. First maturity lengths (L_m) were 14.8 cm for males and 15.2 cm for females.

Total (Z), natural (M) and fishing (F) mortalities were $Z = 1.32$ year⁻¹, $M = 0.50$ year⁻¹ and $F = 0.82$ year⁻¹, respectively. The exploitation ratio $E = 0.62$ indicates that the population is being heavily exploited.

Key Words: Common sole, *Solea solea*, İskenderun Bay, Age, Growth, Reproduction, Mortality and Exploitation

İskenderun Körfezi'nden Dil Balığı, *Solea solea* (L., 1758)' nın Bazı Populasyon Parametrelerinin İncelenmesi

Özet: İskenderun Körfezi'nden Mart 2000 ile Şubat 2001 tarihleri arasında toplanan dil balıklarında yaş, büyüme, üreme, ölüm ve sömürülme oranı incelenmiştir. İncelenen bireyler 1-8 yaşlar arasında dağılım göstermiştir. Toplam boy 8,8-28,2 cm arasında değişmiştir. Erkek ($a = 0,0117$, $b = 2,988$) ve dişilerin ($a = 0,0091$, $b = 3,077$) boy-ağırlık ilişkileri izometrik büyümeden önemli bir farklılık göstermemiştir. von Bertalanffy büyüme parametreleri erkekler ve dişiler için sırasıyla, $L_{\infty} = 26,03$ cm, $k = 0,221$ yıl⁻¹, $t_0 = -1,31$ ve $L_{\infty} = 29,95$ cm, $k = 0,181$ yıl⁻¹, $t_0 = -1,55$ olarak hesaplanmıştır. Nisan ve Mayıs aylarında gerçekleşen üreme etkinliği, Nisan ayında en üst düzeye ulaşmıştır. İlk cinsi olgunluk boyları (L_m) erkekler ve dişiler için sırasıyla 14,8 ve 15,2 cm olarak hesaplanmıştır.

Toplam (Z), doğal (M) ve balıkçılık (F) ölümlerinin sırasıyla, $Z = 1,32$ yıl⁻¹, $M = 0,50$ yıl⁻¹ ve $F = 0,82$ yıl⁻¹ olarak hesaplandığı araştırmada, $E = 0,62$ olarak bulunan sömürülme oranı, populasyonun yoğun bir şekilde avcılık baskısı altında olduğunu göstermektedir.

Anahtar Sözcükler: Dil Balığı, *Solea solea*, İskenderun Körfezi, Yaş, Büyüme, Üreme, Ölüm ve Sömürülme

Introduction

The common sole, *Solea solea* (L., 1758), is a demersal brackish marine fish distributed in the eastern Atlantic, southward from Trondheim Fjord (including the North Sea and western Baltic) and the Mediterranean Sea (including the Sea of Marmara, Bosphorus and southwestern Black Sea). Elsewhere, it extends southward to Senegal, including the Cape Verde Islands (1). It occurs at a temperature range of 8.0-24.0 °C (2), burrows into sandy and muddy bottoms, retreats to deeper water during winter, feeds on worms, molluscs and small crustaceans at night, is marketed fresh and

frozen and is used steamed, fried, broiled, microwaved and baked (3). This species, of great commercial importance, is a cultured game fish, and a show aquarium fish (1).

Features such as age, growth and reproduction in this species have been examined by several researchers in different areas. The length-weight relationship exponents of the species were 3.00 in the North Sea (4) and Adriatic Sea (5), 3.21 in Douarnenez Bay (6), 3.31 in the North Atlantic (7) and 2.71-2.83 in İzmir Bay (8). The von Bertalanffy growth parameters of the species were $L_{\infty} = 31.2$ cm, $k = 0.18$ year⁻¹ in the North Sea (4), $L_{\infty} = 40.1$

cm, $k = 0.68 \text{ year}^{-1}$ in the Adriatic Sea (5), $L_{\infty} = 34.7 \text{ cm}$, $k = 0.28 \text{ year}^{-1}$ in İzmir Bay (8) and $L_{\infty} = 48.8 \text{ cm}$, $k = 0.24 \text{ year}^{-1}$ in the Gulf of Lion (9). The reproduction characteristics of the species from different areas were also investigated (10,11).

In İskenderun Bay, *Solea solea* is of great commercial interest. It is common in small-scale fishing, contributing $\approx 4\text{-}8\%$ of the total catches of demersal fish (12), and is caught all year round (except for prohibited seasons) with significant seasonal differences in landings. The common sole is exploited in this area with bottom trawlnets.

Despite its fishing importance, no adequate information about sex, reproduction, age and growth and the mortality of common sole population in İskenderun Bay has been published. In addition, there is no information about the fishing size of this species in the fishing circular of the Turkish Ministry of Agriculture and Rural Affairs (13). The present study fills that gap with information about these features of the species. The importance of this study is enhanced by the fact that catches of this species are declining and increasing efforts are being made to fish it in the area.

Materials and methods

A total of 1083 specimens of *S. solea* were obtained by a random sampling method from commercial catches (trawl nets, at depths of 10-50 m) in different fishing areas of İskenderun Bay (Figure 1), between March 2000 and February 2001.

For each fish, the total length (L) was measured to the cm and total weight (W) to 0.1 g. Sex and maturity stages were then determined macroscopically and the weight of the gonads (Wg) was recorded to 0.01 g.

Age Determination

The sagitta otoliths were chosen for reading and interpretation. Otoliths removed from individuals were cleaned, broken and dipped in hydrochloric acid and sodium hydroxide solution and ethyl alcohol (14,15). In order to enhance the contrast and thus facilitate the reading and interpretation of growth marks the otoliths were dipped in glycerol and observed under a dissecting microscope with reflected light at a magnification of 16x. All the readings and interpretations were carried out independently by three researchers. A nominal birth date of *Solea solea* was used to allocate age groups correctly.

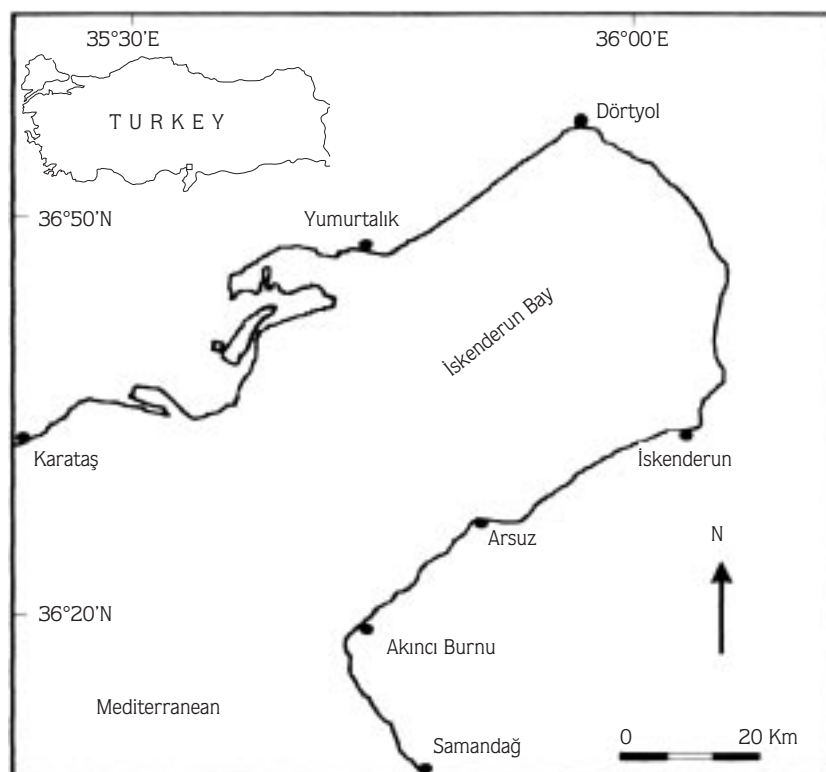


Figure 1. Map of İskenderun Bay, North East Mediterranean.

This nominal birth date was derived from the gonadosomatic index of this species. Corrected ages were calculated from raw age data using the blow equations (16).

$$Y_{\text{cor}} = T + CC, CC = (((SM - 1) * 30 + SD) - (((NBM - 1) * 30) + NBD)) / 365$$

where Y_{cor} is the corrected age, T age, CC correction coefficient, SM sampling month, SD sampling day, NBM nominal birth month (April for this species) and NBD nominal birthday (15th of April).

Growth

The von Bertalanffy growth curve was fitted to the observed lengths at corrected age data for the resulting age-length key by means of Marquard's algorithm for non-linear least squares parameter estimation. The form of the growth curve is (17)

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

where L_t is the length at age t, L_{∞} is the theoretical maximum length, K is a growth coefficient and t_0 is the hypothetical age for $L_t = 0$.

Reproduction

Stages of maturation were classified as: stage 0, immature; stage 1, resting; stage 2, developing; stage 3, ripe; stage 4, running; stage 5, spent; stage 6, recovering (18). The spawning season was determined from the monthly changes of the gonadosomatic index (GSI), calculated by the equation (18)

$$GSI = 100W_g/W$$

where W is total weight and W_g is gonad weight. For the estimation of the mean lengths at 50% maturity, a logistic function was fitted to the proportion of the mature individuals by size class using a non-linear regression. The function used is below (18)

$$P = 1 / \{1 + \exp[-r(L - L_m)]\}$$

where P is the proportion mature in each size class, r (-b: slope) is a parameter controlling the shape of the curve and L_m is the size at 50% maturity.

$$L_m = a / r$$

where a is intercept. The differences between the first maturity lengths of males and females were tested with a regression approach by comparing the slopes and intercepts of two equations belonging to both sexes. For this reason the following null hypothesis were tested

together; $H_0: \beta_1 = \beta_2$ and $H_0: \alpha_1 = \alpha_2$ (19). The overall ratio of males to females was tested with the chi-square test.

Length-Weight Relationship

The relation of weight to length was calculated applying the exponential regression equation by

$$W = aL^b$$

where W is total weight, L is total length, and a and b are parameters to be estimated (17). Confidence intervals of 95% were calculated for the slopes (b) to see if these were statistically different from 3. In addition, the differences between the slopes (b) of males and females were tested with a t-test.

Mortality and Exploitation Rates

The total mortality rate (Z) was calculated from the length-converted catch curve using the program ELEFAN by the equation (20).

$$\log_e(N / dt) = a + bt$$

where dt is the time needed to grow from the lower to the upper limit of a given length class, t the relative age corresponding to the midrange of the length class in question, and a and b the parameters to estimate. The natural mortality rate (M) was estimated from Tanaka's equation (21)

$$M = 3 / T_{\text{max}}$$

where T_{max} is the age of the oldest fish sampled. Following estimation of Z and M, the fishing mortality rate (F) was estimated from

$$F = Z - M$$

and the exploitation ration (E) from

$$E = F / Z \text{ (18)}.$$

The age groups 7 and 8 were ignored in the statistical calculations, since the number of samples in these ages was statistically insufficient.

Results

Age and Growth

The ages of the samples ranged from 1 to 8 years. The ratio of males (553) to females (550) was 1.03:1, and the differences between sexes were not statistically significant ($\chi^2 = 0.534 > \chi^2_{1,0.05} = 3.84$). Males predominated in the younger ages, females in the older

ages and most of the samples were in the second age. The length of males ranged from 8.8 to 25.0 cm, and weight from 8.0 to 115.3 g. The lengths of females ranged from 10.5 to 28.2 cm, weighing from 10.3 to 183.0 g.

The slopes (b values) of the length-weight regressions did not differ significantly between the sexes ($p > 0.05$). Isometric growth was observed for common sole. The values of b for males and females were not significantly different from 3.0 (Table 1 and Figure 2).

Females grew to a greater asymptotic length (L_{∞}) than males, but the rate at which this was achieved (k) was less than in the males (Table 2 and Figure 3).

Mortality

The total, natural and fishing mortality rates, and the exploitation ratio were: $Z = 1.32 \text{ year}^{-1}$, $M = 0.5 \text{ year}^{-1}$, $F = 0.82 \text{ year}^{-1}$ and $E = 62$, respectively. The length-converted catch curves for all individuals are plotted in Figure 4.

Length at first maturity

The maturity ogives for the *S. solea* show that 50% of males (1) and females (2) were sexually mature at total lengths of 14.8 and 15.2 cm (Figure 5). There was no significant difference in length at 50% maturity between the sexes ($P > 0.05$).

$$P_{\text{male}} = 1 / \{1 + \exp[-1.083(L - 14.8)]\}$$

$$(n = 11, r^2 = 0.995) \tag{1}$$

$$P_{\text{female}} = 1 / \{1 + \exp[-0.911(L - 15.2)]\}$$

$$(n = 11, r^2 = 0.993) \tag{2}$$

Gonad development and spawning period

The GSI values of females were usually higher than those of males. However, both indices followed the same pattern during the year. The highest value for both sexes occurred in April when water temperature was $19.3 \text{ }^{\circ}\text{C}$ (Figure 6).

Sex	a	b	SE (b)	n	r ²	CI
Males	0.0117	2.988	0.0325	533	0.973	2.961-3.059
Females	0.0091	3.077	0.0334	550	0.960	2.979-3.131

Table 1. Parameters of the relationship ($W = aL^b$) between total length (L, cm) and total weight (W, g) for *S. solea*.

Sex	L_{∞} (cm)	K (year^{-1})	t_0 (year)	r ²
Males	26.03	0.221	-1.31	0.983
Females	29.95	0.181	-1.55	0.976

Table 2. The parameters of the V.B.G.E. for males and females of the *S. solea*.

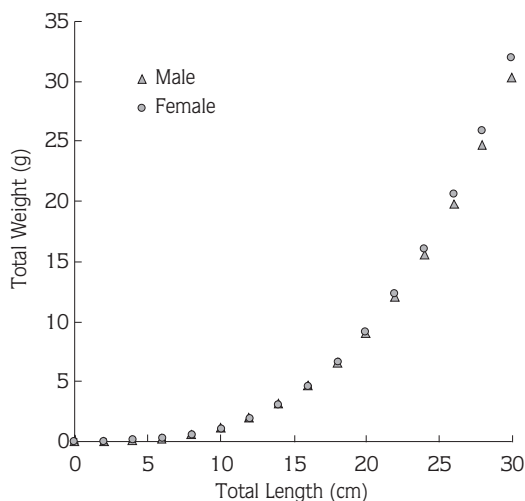


Figure 2. Length-weight relationships for the *S. solea* from İskenderun Bay.

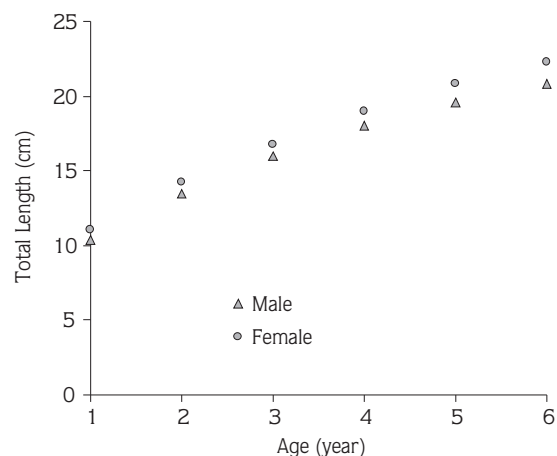


Figure 3. Von Bertalanffy's growth curves for the *S. solea* from İskenderun Bay.

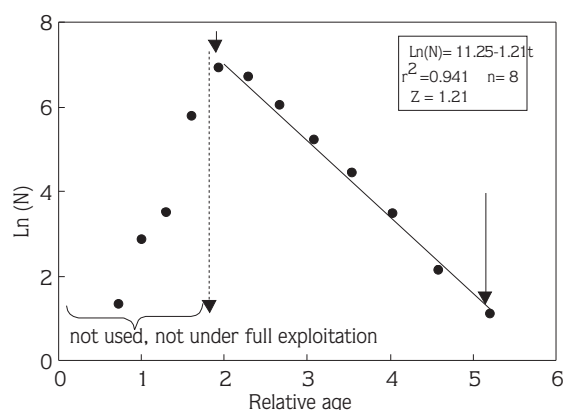


Figure 4. Length-converted catch curve of *S. solea*. Arrows indicate points used for the regression for the natural logarithm of *N* on age. *n* is number of fish per length class L_1 - L_2 corresponding to age class t_1 - t_2 , $dt = t_2 - t_1$ and $t = (t_1 + t_2) / 2$.

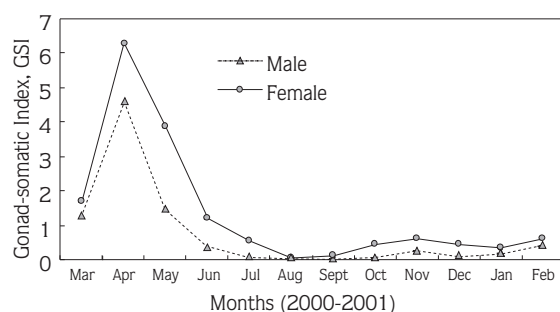


Figure 6. Gonad cycles of the *S. solea* from İskenderun Bay.

Discussion

A total of 1083 specimens of *Solea solea* from İskenderun Bay were examined from March 2000 to February 2001. The overall ratio of males to females was 1.03:1 and not significantly different from 1:1. The sex ratio in most species is close to one (22). Males were more numerous in the younger age groups, females in the other age groups, and the greatest number of samples were in the second age group. This situation was reported in İzmir Bay (8). The oldest male and female found were 7 and 8 years, respectively. In İzmir Bay, Hoşsucu et al. (8) reported the highest ages as 5 for males and 6 for females. In the North Sea, Beverton and Holt (23) reported figures of 8 years for both sexes, in the Amvrakikos Gulf, Stergiou et al. (24) reported 6 years for both sexes.

The theoretical maximal length values ($L_{\infty} = 26.03$ cm for males and $L_{\infty} = 29.95$ cm for females) were close to

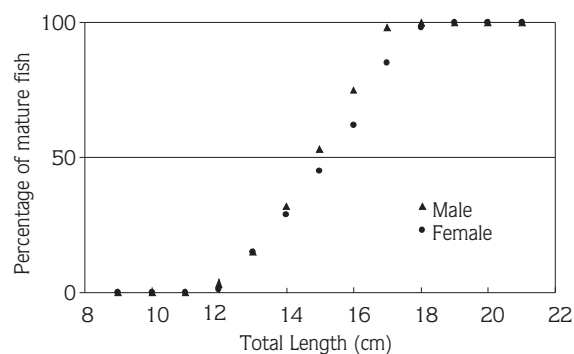


Figure 5. Ogive of 1st maturity of the *S. solea* from İskenderun Bay.

the size of the largest fish, and growth coefficient values ($k = 0.221 \text{ year}^{-1}$ for males and $k = 0.181 \text{ year}^{-1}$ for females) indicated relatively low attainment of maximal size. In the North Sea, De Veen (4) reported L_{∞} and k parameters of 31.2 and 0.180 in 1960, 30.1 and 0.289 in 1962 and 28.2 and 0.252 in 1966. Stergiou et al. (24) reported $L_{\infty} = 34.9$ and $k = 0.380$ and Hoşsucu et al. (8) reported $L_{\infty} = 34.7$ and $k = 0.280$ in İzmir Bay. However, different values were reported from France's Gulf of Lion ($L_{\infty} = 48.8$ and $k = 0.240$) by Vianet et al. (9), from Portugal's Tagus Estuary ($L_{\infty} = 48.3$ and $k = 0.470$) by Costa (25) and from the Italian Adriatic Sea ($L_{\infty} = 40.1$ and $k = 0.680$) by Piccinetti and Giovanardi (5). The differences in growth between regions can be attributed to the difference in size of the largest individual sampled in each area and to differences between species, because the largest fish found in the studies conducted by Piccinetti and Giovanardi (5), Vianet et al. (9) and Costa (25) were more than 30 cm. On the other hand, it is also possible that the variations in population parameters of the species represent epigenetic responses (22) to the different conditions (temperature and food) prevailing in different areas.

The exponents of length-weight relationships ($b = 2.988$ for males and $b = 3.077$ for females) of the *S. solea*, estimated in İskenderun Bay, show that weight increases isometrically with length. Similar results were reported by De Veen (4), Piccinetti and Giovanardi (5), Vianet et al. (9) and Campillo (26) as 3.04, 3.0, 3.0 and 2.99, respectively. However, different results were reported by Deniel (6) and Coull et al. (7) as 3.31 and 3.21, respectively. This variation in the exponents could be attributed to different stages in ontogenetic development, as well as to differences in age, maturity, sex and species. Geographic location and associated

environmental conditions, such as seasonality (date and time of capture), stomach fullness, disease and parasite loads, can also affect the value of b (22).

The lengths at first maturity of males and females were 14.8 and 15.2 cm, respectively. In the North Sea, De Veen (4) reported different values of 27.0 cm in 1965, 26.5 cm in 1967, 30.0 cm in 1969 and 29.5 cm in 1971. It has been observed that cool waters produce larger, older and later maturing individuals of a species than warm waters (22), because the mean annual temperature in İskenderun Bay is between 22 and 23 °C, while in the North Sea it was between 15.7 and 17.4 °C from 1965 to 1971. Thus, the differences in growth parameters may be connected to temperature and less food in İskenderun Bay.

In İskenderun Bay, spawning takes place in April and May with a peak in April. Off the Irish coast, spawning occurs in May and June, in the southern North Sea from April to June (10), in the Bay of Biscay from December to May, in the Mediterranean from January to April and in the North Sea from April to May (11). The spawning characteristics of fish vary in respect of their species and the ecological characteristics (such as food and temperature) of the water system in which they live.

The length-converted catch curves showed a typical form and justified the estimation of a single value of Z for all fish (27). The exploitation ratio ($E = 0.62$) is higher than 0.50. Gulland (28) suggested that as a rule of thumb a fish stock is optimally exploited at a level of fishing mortality which generates $E = 0.50$, where $F_{opt} =$

M , but in the present study $F > F_{opt} = M$. More recently, Pauly (29) proposed a lower optimum fishing mortality, $F_{opt} = 0.4 M$ ($F > F_{opt}$). Therefore, the stock of the common sole bream in İskenderun Bay is being heavily exploited.

In the light of these results and evaluations, in İskenderun Bay, a minimum size limit should be implemented for this species. The lengths of fish caught in the bay are smaller than the length at first maturity that is calculated from the data from this research. In order to maintain the population in equilibrium, it is of great importance to give each fish the chance to reproduce at least once in its lifetime. Therefore, in the case of the common sole, the minimum fishing size should be 20.0 cm in terms of total length, because the male and female of the species mature at 14.8 and 15.2 cm total lengths, respectively (L_m). In addition, fishing should be prohibited from April to July (during the spawning season of this species). The spawning stock and recruits should be safeguarded. If measures such as closed seasons, fishing size or changes in fishing pattern are not implemented, the stock will be exploited more and more, and risk disappearing in the near future.

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