Abstract—We investigated young-of-the-year (YOY) growth, age, and hatching distributions of common pandora (*Pagellus erythrinus*) by analyzing otolith microstructure. This study was carried out in shallow waters (0–20 m) off the island of Gökçeada, Turkey, from June 2013 through June 2014. A total of 231 YOY common pandora were measured and aged. These fish ranged from 12 to 110 mm in total length and from 38 through 242 d in age. The indices for determining variability in daily age estimates (average percentage error and coefficient of variation) were 4.9% and 3.4%, respectively. Average daily growth rate was calculated from a linear regression of the age–length data set as 0.52 mm/d. A linear relationship was found between otolith morphometric measurements (otolith length, width, and radius) and total length for YOY common pandora. The hatching times of common pandora were back-calculated to occur from February through October, and 2 main hatching cohorts were evident in spring (March) and summer (August).

Age and growth rates at the early life stages of common pandora (*Pagellus erythrinus*) based on analysis of otolith microstructure

Hakan Ayyildiz (contact author)
Aytac Altin

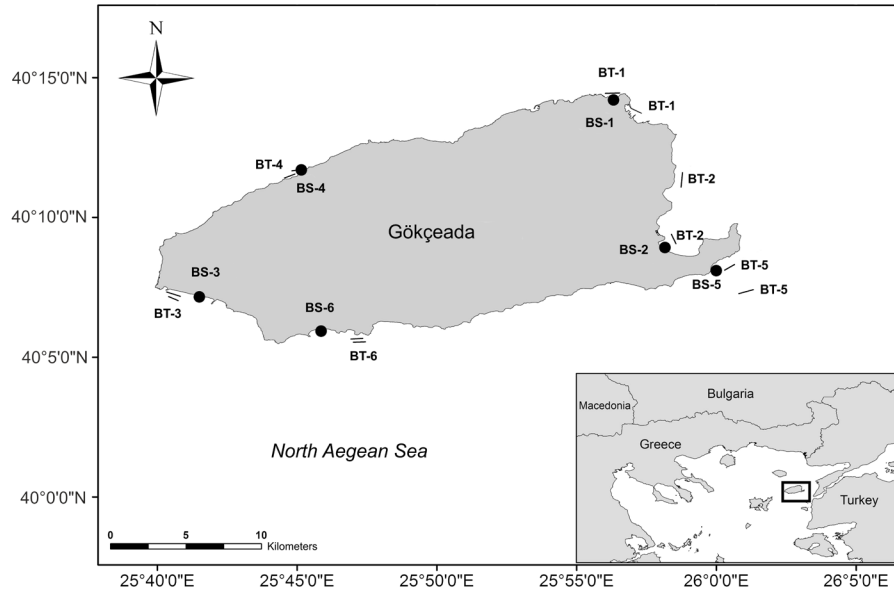Email address for contact author: ayyildizhakan@gmail.com

Department of Fisheries Technology
Gökçeada School of Applied Sciences
Çanakkale Onsekiz Mart University
Yeni Mahalle Dr. Sadık Ahmet Sokak No. 25
Gökçeada, Çanakkale 17760 Turkey

The common pandora (*Pagellus erythrinus*) is distributed throughout the Mediterranean Sea and the northeastern Atlantic Ocean from Norway to Cape Verde (Bauchot and Hureau, 1986; Whitehead et al., 1984–1986). This fish is a protogynous hermaphrodite, and individuals are first female and become male in the third or fourth year of life. The length of time of sex reversal for common pandora is different among the different regions of the Mediterranean Sea (Zei and Županović, 1961; Klaoudatos and Klaoudatos, 2004; Zarrad et al., 2010; Saoudi et al., 2017). This species inhabits shallow waters down to 120 m, mostly among rock, gravel, and sandy–muddy sediments (Jukić and Arneri, 1984; Papaconstantinou et al., 1988). The spawning period of this species has been reported to occur from spring to early autumn depending on region and hydrological conditions (Pajuelo and Lorenzo, 1998; Coelho et al., 2010; Metin et al., 2011).

The common pandora is a high-value species among the porgies (Sparidae) (Coelho et al., 2010). This species is an important demersal resource throughout the Mediterranean Sea and Black Sea. The common pandora is caught in trawls, trammel nets, gill nets, bottom long lines, and hand lines (Metin et al., 2011). Fishing pressure and increased adult mortality have resulted in earlier maturity at a smaller size (Beverton and Holt, 1956). Size at first maturity of the common pandora has been reported to be 11–16 cm in total length (TL) in the Aegean Sea (Metin et al., 2011), 14–16 cm TL in the central Mediterranean Sea (Zarrad et al., 2010; Ali Ben Smida et al., 2014), 17–18 cm TL off Portugal (Coelho et al., 2010), and 17–23 cm TL off the Canary Islands (Pajuelo and Lorenzo, 1998).

Information on population parameters, such as daily age, growth, and hatching times of heavily exploited fish species provide important information for stock assessments and fishery management (Aliaume et al., 2000). The common pandora is listed in the IUCN Red List of Threatened Species as a species of least concern (Russell, 2014). Despite the wide distribution and ecological and economic importance of this species, most studies on the age and growth rates of this species have focused on adult individuals, and there is no study on age and growth of early life stages. However, information on early life stages is essential for understanding population traits, such as recruitment and productivity.

Figure 1

Six sampling stations where young-of-the-year common pandora (*Pagellus erythrinus*) were collected with beach seine (BS) or beam trawl (BT) from the shallow waters (<20 m) off the island of Gökçeada, Turkey, from June 2013 through June 2014.

In this study, we investigated young-of-the-year (YOY) age, growth rates, and back-calculated hatching dates of common pandora collected from the island of Gökçeada, Turkey, by analyzing their otolith microstructure. We also examined the relationships between otolith morphometric measurements (length, width, and radius) and fish total length.

Materials and methods

During the daytime, YOY common pandora were collected with a beach seine and beam trawl from 6 sites in shallow waters (<20 m) off Gökçeada, Turkey (Fig. 1). Samples were taken from June 2013 through June 2014. Beam trawling speed was 2–3 kt. The beach seine hauls were made parallel to the shore.

Total length of common pandora was measured to the nearest 1 mm, and total weight was measured with a digital balance with precision to 0.01 g. A total of 261 pairs of sagittal otoliths were removed, cleaned, and placed in clean, labeled vials. One otolith of the sagittal pair was randomly selected and subsequently embedded in epoxy resin, mounted on a glass slide, and ground to expose the core (Miller and Storck, 1982; Secor et al.[1]; Jones, 1992; Hayes, 1995).

Otolith daily growth rings were counted from the core to the outer edge under a light microscope at magnifications of 40× and 100× (Fig. 2). The number of daily increments between right and left otoliths were compared with a paired *t*-test. Two readers independently counted the daily rings without prior knowledge of fish length, and, when counts differed from each other by more than 10%, these otoliths were not included in the study.

Estimates of the precision of daily growth ring counts between readers were determined by using the average percentage error (APE) of Beamish and Fournier (1981) and coefficient of variation (CV) (Chang, 1982).

It was assumed that growth increments in the sagittal otoliths are formed daily. Daily ring formation has not been validated for common pandora; however, it has been validated for many fish species (Pannella, 1971; Campana and Neilson, 1985). The slope of the regression analysis of the TL and the number of otolith daily growth rings was used to estimate the overall YOY growth rates. Daily growth rates for the capture date of each cohort (except when the number of samples (*n*) was <5, see Table 3) also were estimated by fitting a linear model. The differences in slopes were compared by using an analysis of covariance (ANCOVA) to identify the significant differences in daily growth for each cohort.

Otolith morphometric measurements (otolith length [OL], width [OW], and radius [OR]) were measured to the nearest 0.001 mm by using QCapture Pro[2] imaging
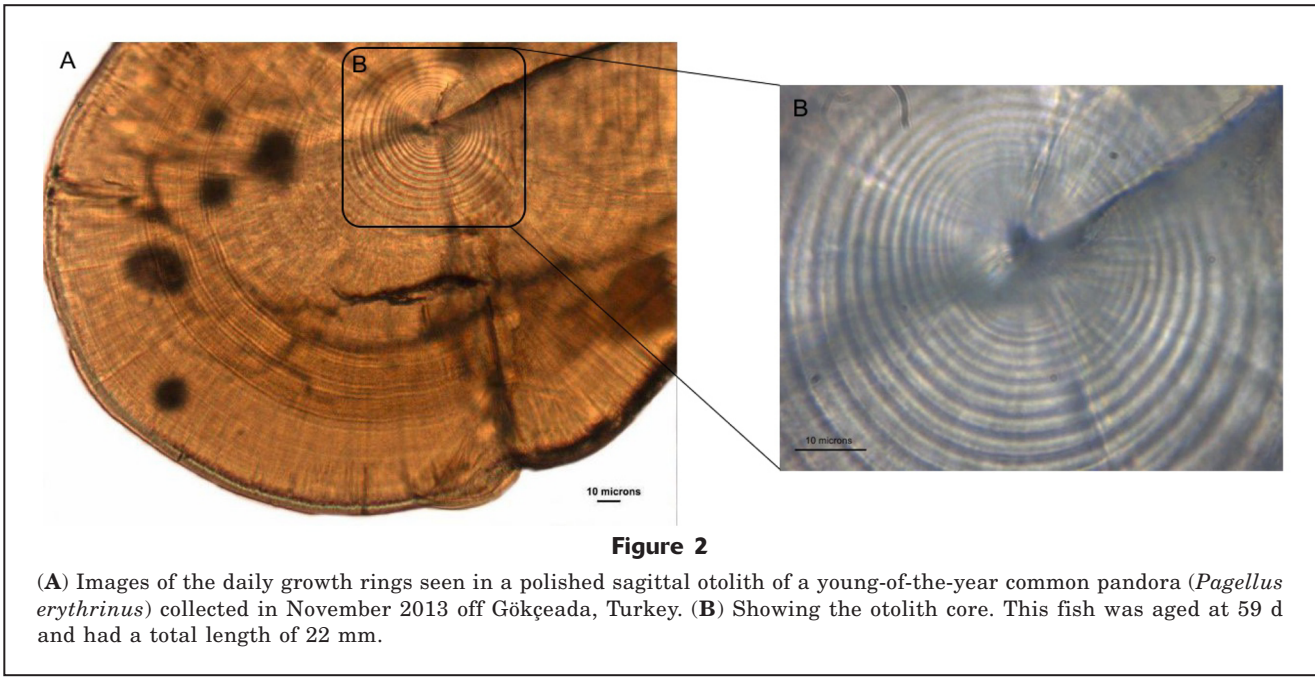
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[1] Secor, D. H., J. M. Dean, and E. H. Laban. 1991. Manual for otolith removal and preparation for microstructural examination. Belle W. Baruch Inst. Mar. Biol. Coast. Res., Tech. Publ. 1991-01, 55 p. [Available from Belle W. Baruch Inst. Mar. Coast. Sci., Univ. South Carolina, Columbia, SC 29208.]

Table 1

Summary of the total lengths in millimeters of young-of-the-year common Pandora (*Pagellus erythrinus*) collected in the shallow waters (<20 m) off Gökçeada, Turkey, from June 2013 through June 2014. The number of specimens (*n*) and range, mean, and standard error of the mean (SE) for total length are provided.

Month of capture	*n*	Min	Max	Mean	SE
March	3	51	82	65.67	8.99
April	1	110	110	110.00	…
May	1	85	85	85.00	…
June	42	15	73	45.33	1.97
July	67	12	80	41.73	2.37
August	34	25	70	47.47	2.08
September	3	18	33	25.33	4.33
October	43	13	98	25.74	2.93
November	66	16	86	32.98	1.88
December	1	43	43	43.00	…

Figure 2

(**A**) Images of the daily growth rings seen in a polished sagittal otolith of a young-of-the-year common pandora (*Pagellus erythrinus*) collected in November 2013 off Gökçeada, Turkey. (**B**) Showing the otolith core. This fish was aged at 59 d and had a total length of 22 mm.
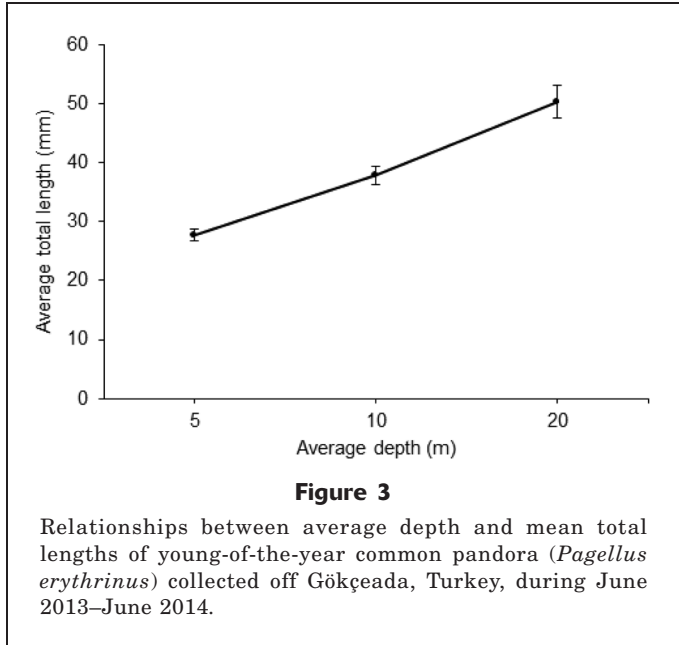
software (vers. 5.1; QImaging, Surrey, Canada). Otolith length is the longest axis between the anterior and posterior otolith edge, and OW is the distance from the dorsal to the ventral edge. Otolith radius is the longest axis between the core and posterior edge. A linear regression was used to describe the relationship between fish TL and otolith morphometric measurements for YOY common pandora.

Distributions of hatching dates of YOY common pandora were back-calculated from daily age estimates and date of capture. No mortality correction was applied to the hatching-date distributions (Campana and Jones, 1992).

Results

A total of 261 YOY common pandora were sampled from shallow waters off the island of Gökçeada. Young-of-the-year fish ranged in size from 12 to 110 mm TL (Table 1). Thirty pairs of sagittal otoliths were rejected because they were over ground or cracked, or there were discrepancies in daily ring counts among the age readers. Daily ages were determined successfully from 231 otoliths of YOY common pandora that ranged in size from 12 to 110 mm TL. We found that the average length of specimens increased with bottom depth (Fig. 3).

Figure 3

Relationships between average depth and mean total lengths of young-of-the-year common pandora (*Pagellus erythrinus*) collected off Gökçeada, Turkey, during June 2013–June 2014.

Table 2

Parameters of the linear relationship of the different otolith morphometric measurements, otolith length (OL), otolith width (OW), and otolith radius (OR), with fish length for young-of-the-year common pandora (*Pagellus erythrinus*) collected off Gökçeada, Turkey, during June 2013–June 2014. The number of specimens (n), y-intercept (a), slope of the regression line (b), and coefficient of determination (r^2) are provided.

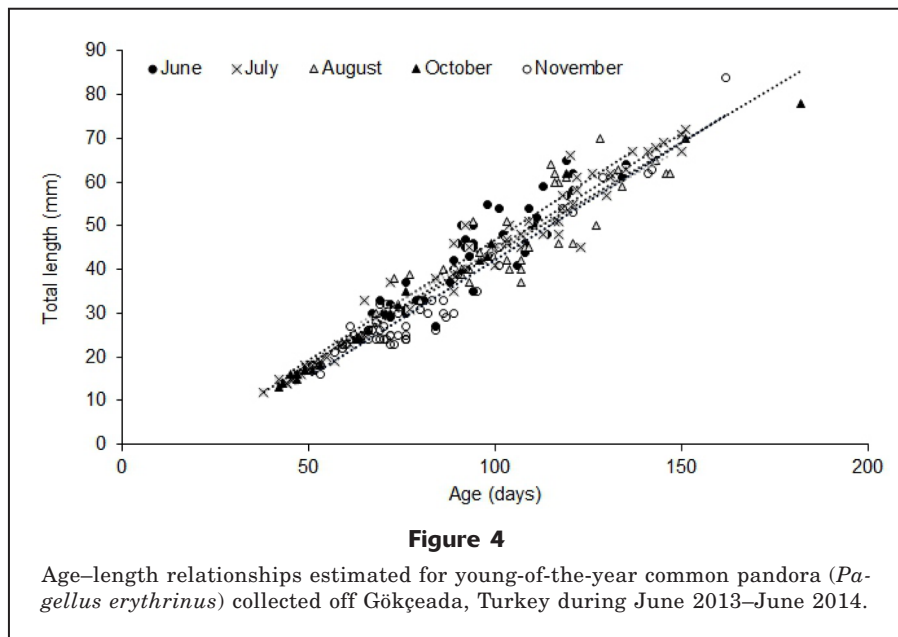| Morphometric measurements	n	a	b	r^2	P
OL	228	2.407	21.271	0.975	<0.01
OW	228	2.702	30.315	0.961	<0.01
OR	198	4.249	41.875	0.942	<0.01

There was no significant difference between the numbers of daily growth increments counted for the left and right otoliths (paired *t*-test: n=30, P>0.05). Therefore, only one otolith was randomly selected for daily age estimation. The maximum observed age was 242 d (for a fish at 110 mm TL), and the minimum observed age was 38 d (for a fish at 12 mm TL). The age group 58–77 d (for fish at 18–41 mm TL) was dominant (25.5%). Specimens of age groups 198–217 and 218–237 were absent. The APE and CV were calculated as 4.9% and 3.4%, respectively.

Sagittal otolith length, width, and radius were ob-

served in the ranges of 0.37–7.07 mm, 0.26–5.03 mm, and 0.18–3.59 mm, respectively. Relationships between TL and otolith morphometric measurements (OL, OW, and OR) were described by linear equations (Table 2).

The daily growth rate of YOY common pandora was estimated as 0.52 mm/d (Fig. 4). The maximum daily growth rate of 0.54 mm/d was found in the June cohort, and the minimum value of 0.46 mm/d was observed in the August cohort (Table 3). However, there were no statistically significant differences in either slope or adjusted mean among the equations (ANCOVA: F=1.216, df=4, P=0.305).
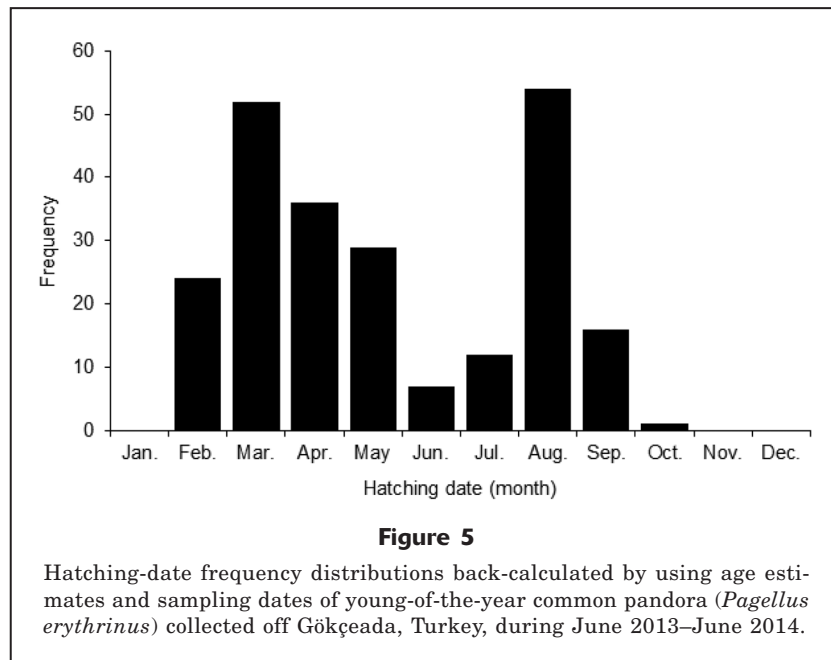
Spawning of YOY common pandora took place in 2 peaks represented by overlapping normal distributions (Fig. 5). The first spawning peak was observed in

Figure 4

Age–length relationships estimated for young-of-the-year common pandora (*Pagellus erythrinus*) collected off Gökçeada, Turkey during June 2013–June 2014.

Table 3

Parameters of the linear models for the relationship between total length (TL) and number of daily increments (age) for young-of-the-year common pandora (*Pagellus erythrinus*) collected off Gökçeada, Turkey, during June 2013–June 2014. The number of specimens (*n*), size and age range with standard error of the mean (SE), y-intercept (*a*), slope of the regression line (*b*), and coefficient of determination (*r²*) are provided. Capture months during which less than 5 specimens were collected are not included.

Month of capture	*n*	Size (mm TL)	SE	Number of daily increments (age)	SE	*a*	*b*	*r²*	*P*
June	42	15–73	1.97	46–137	3.14	8.17	0.54	0.84	<0.01
July	67	42–63	2.37	38–151	4.25	8.06	0.52	0.96	<0.01
August	34	25–70	2.08	64–147	3.85	1.55	0.46	0.73	<0.01
October	43	13–98	2.93	42–182	5.48	7.30	0.50	0.97	<0.01
November	66	16–86	1.88	51–162	2.79	11.55	0.53	0.92	<0.01
All	231	12–110	21.12	38–242	31.59	8.41	0.52	0.93	<0.01

Figure 5

Hatching-date frequency distributions back-calculated by using age estimates and sampling dates of young-of-the-year common pandora (*Pagellus erythrinus*) collected off Gökçeada, Turkey, during June 2013–June 2014.

spring (March), and the second one was seen in summer (August). The hatching times of common pandora were back-calculated to occur between February and October.

Discussion

This study provides the first estimates of daily age and growth rates for the YOY of common pandora. Distinct light and dark bands, which can be used for age determination, were observed in the examined otoliths of YOY common pandora. Daily increment formation in otoliths is a general phenomenon that has been vali-

dated for many other species (Pannella, 1971; Campana and Neilson, 1985; Jones, 1992). Therefore, formation of increments on the otoliths of common pandora were assumed to occur daily. Campana (2001) suggested that acceptable levels for APE and CV were 5.5% and 7.6%, respectively. Therefore, our results (4.9% and 3.4%, respectively) are close to the acceptable values for both APE and CV.

Our findings are consistent with those of Somarakis and Machias (2002), who reported that the mean sizes of common pandora increased with bottom depth because smaller individuals were found in shallower and warmer waters. Few researchers have also addressed whether the decline in the number of older fish may

not only be due to mortality but also partially to movements of larger fish to deeper waters (Harmelin-Vivien et al., 1995; Ayyildiz et al., 2015).

No previous studies have used otolith microstructure analysis on age and growth rates of the early life stages of the common pandora. Therefore, we compared the data from our study of common pandora at early life stages with lengths at age 0 reported for adult common pandora in previous studies. The results of a recent study by Somarakis and Machias (2002) indicate that common pandora can reach a size of 120 mm TL at age 0. Similarly, a specimen of common pandora with a size of 100 mm TL was found at age 0 by Pajuelo and Lorenzo (1998). These results are supported by Hoşsucu and Çakır (2003), who found that average size at age 0 of common pandora was 77–78 mm TL and average size at 1 year of age was 117–119 mm TL. The results of our study match those observed in these earlier studies.

It is possible to estimate the length of fish by using morphometric measurements of otoliths (Harvey et al., 2000; Campana, 2004; Zan et al., 2015). Morphometric characteristics of the sagittal otoliths of YOY common pandora were linearly related to the logarithm of fish TL. Our results are consistent with those of other studies and indicate that the relationships between fish TL and otolith morphometric measurements are usually log linear (Ayyildiz et al., 2014; Dehghani et al., 2016; Al-Busaidi et al., 2017). However, according to Lleonart et al. (2000), the linear model is not appropriate because it cannot detect changes in the shape of otoliths.

The hatching times of common pandora were backcalculated to occur between February and October, and 2 main cohorts were estimated to occur in the spring (March) and summer (August). This result broadly agrees with the findings of Hoşsucu and Çakır (2003) and Zarrad et al. (2010) that indicate that the reproductive season of common pandora extended from April to October. Several studies also have revealed that the duration of the reproductive season of common pandora extends from April to September and peak spawning activity occurs between June and August (Pajuelo and Lorenzo, 1998; Valdés et al., 2004). A recent study by Coelho et al. (2010) reported a similar reproductive spawning season from March to July.

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