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Sexual seasonal growth of the European anchovy (*Engraulis encrasicolus*) caught by mid-water trawl and purse seine in the southern Black Sea

SABRI BILGIN, BURAK TAŞÇI AND HATICE BAL
Recep Tayyip Erdoğan University, Faculty of Fisheries, Rize-17100, Turkey

The seasonal growth pattern and size composition of the European anchovy, Engraulis encrasicolus *caught by mid-water trawl and purse seine was studied in the southern Black Sea between October 2010 and April 2011. Total length (TL) and size distribution of females caught by purse seine was higher than males and females obtained from mid-water trawl (P < 0.05). The seasonal von Bertalanffy growth parameters, computed from monthly length–frequency distributions, were estimated as asymptotic length to which the fish grow (L_∞) = 13.01 cm TL, growth-rate parameter (K) = 0.993 year^{-1}, amplitude of the sinusoidal growth oscillations (C) = 0.800, and the time of the year when the growth rate is slowest, the winter period (WP) = 0.298 for males and as L_∞ = 13.69 cm TL, K = 1.249 year^{-1}, C = 0.950, and WP = 0.151 for females caught by mid-water trawl. The seasonal von Bertalanffy growth parameters for anchovy obtained from purse seine fishing in the Rize region were estimated as L_∞ = 14.00 cm TL, K = 0.800 year^{-1}, C = 0.980, and WP = 0.212 for males and as L_∞ = 13.93 cm TL, K = 0.994 year^{-1}, C = 0.725, and WP = 0.319 for females. The period of slowest growth for males and females estimated between February and April, which is the period with a relatively low water temperature and consequently anchovy in the southern Black Sea have a seasonal growth pattern.*

Keywords: *Engraulis encrasicolus*, seasonal growth, size-distribution, mid-water trawl, purse seine, Black Sea, ELEFAN

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INTRODUCTION

European anchovy, *Engraulis encrasicolus* is distributed in the Eastern Atlantic: Bergen, Norway to East London, South Africa, the Mediterranean and the Black Sea (Froese & Pauly, 2011). European anchovy are regularly caught in the Mediterranean and Black Sea on the coasts of Spain, France, Italy, Russia, Ukraine, Bulgaria, Croatia, Romania, Greece, Georgia and Turkey. European anchovy is one of the most important commercial fish species for fishing in Turkey and for past decades, the average annual catch is 280,679 ± 23,295 tons (between 138,569 and 385,000 tons), which constitutes about 68.8% of the total marine fisheries production of Turkey (TUIK, 2001–2010). Purse seine and mid-water trawl are two commercially important coastal pelagic species fishing vessels in the Black Sea. Both fishing gears have a different operation method and different parts of the fishing gear, but both of them are operated in the same fisheries. Legal anchovy fisheries with mid-water trawl towed behind two boats (pair trawling) are conducted mostly in the Samsun region in Turkey.

Mid-water trawls are rigged to fish in mid-water, from the surface water to large depth depending on the anchovy flock position. It is also advantageous gear compared to purse seine in terms of easy regulation of the cod-end mesh size. Together with mid-water trawls the purse seine is used commercially for anchovy fisheries all over the Black Sea and others sea around Turkey.

Length–frequency distribution analyses (LFDAs) can be used for estimating age-class and growth parameters (Pauly & David, 1981), and they can also be applied to calculate growth of fast growing and short lived fish species, such as *Engraulis ringens* (Pauly & Tsukayama, 1983; Palomares *et al.*, 1987), *E. encrasicolus* (Bellido *et al.*, 2000) and *E. australis* (Dimmlich, 2010). The growth of *E. encrasicolus* based on otoliths was investigated by Erkoyuncu & Ozdamar (1989), Ünsal (1989), Karacam & Düzgünes (1990), Özdamar *et al.* (1994, 1995) and Samsun *et al.* (2004, 2006) on the Turkish Black Sea coasts. The application of length–frequency data is a useful tool for analyses of growth of anchovy (short lived and fast growing species) (Pauly & Tsukayama, 1983; Palomares *et al.*, 1987). A seasonal growth pattern has been reported for different pelagic species, such as *E. ringens* (Pauly & Tsukayama, 1983; Palomares *et al.*, 1987), *E. mordax*, *Trachurus symmetrius* and *Scomber japonicus* (Mallicoate & Parrish, 1981). However there is no information on the seasonal growth rate of *E. encrasicolus* in the Black Sea. In addition, knowledge about the computation of the monthly length–frequency distribution of *E. encrasicolus* caught by mid-water trawl and purse seine is very limited in the literature. The aims of this study were to investigate and compare seasonal and non-seasonal von

Corresponding author:
S. Bilgin
Email: sbrbilgin@hotmail.com

Bertalanffy growth patterns for both sexes caught by mid-water trawl and purse seine by using length–frequency data and to investigate length structure with respect to size distribution of *E. encrasicolus*.

MATERIALS AND METHODS

European anchovy, *Engraulis encrasicolus* samples were obtained from mid-water trawl (cod-end mesh size 20 mm) surveys conducted between October 2010 and March 2011 in the middle Black Sea, Samsun region and from purse seine (6 mm mesh size) surveys between October 2010 and April 2011 in the south-eastern Black Sea, Rize region which is closed to mid-water and bottom trawl fisheries.

Anchovies were sampled from the commercial catch of vessels on-board and then samples were taken to the laboratory and were measured (total length), weighted and sexed. Size comparisons and size–frequency distributions between sexes and sampling gears were conducted using the *t*-test and Kolmogorov–Smirnov two-sample test. Statistical analyses were considered significantly different at the level of $\alpha = 0.05$.

Growth

The non-seasonal version of the von Bertalanffy growth (VBG) equation $L_t = L_\infty[1 - e^{-K(t-t_o)}]$ estimates length as a function of age and is used so that the growth pattern of a species does not change within a year. The seasonal growth was described using the Hoenig & Hanumara (1982) version of the VBG equation:

$$L_t = L_\infty\left[1 - e^{\left[-K(t-t_o)+\left(C\frac{K}{2\pi}\right)\sin 2\pi(t-t_S)-\left(C\frac{K}{2\pi}\right)\sin 2\pi(t_o-t_S)\right]}\right]$$

where, L_t is predicted length at age t, L_∞ is the asymptotic length to which the fish grow, K is the growth-rate parameter, t_o is the nominal age at which the length is zero, C is the amplitude of the sinusoid growth oscillations ($0 \leq C \leq 1$), t_S is the phase of the seasonal oscillations ($-0.5 \leq ts \leq 0.5$) denoting the time of year corresponding to the start of the convex segment of sinusoidal oscillation. This equation resumes to the original VBG equation if $C = 0$, i.e. if the effect of changing season on growth is ignored.

The time of the year when the growth rate is slowest, known as the winter point (WP), was calculated as:

$$\mathrm{WP} = \mathrm{t_S} + 0.5.$$

The Electronic Length Frequency Analysis (ELEFAN) (Pauly, 1987) procedure first restructures length–frequencies and then fits a VBG curve to the restructured data. Seasonal and non-seasonal VBG curves are fitted to the length distributions after providing a range of values for the parameters to be estimated and then iteratively reducing the range until the goodness of fit (Rn) of the curves to the data is maximized. Rn is calculated as:

$$Rn = \frac{10^{\frac{ESP}{ASP}}}{10},$$

where ASP is the available sum of peaks, computed by adding the best values of the available peaks, and ESP is the explained sum of peaks, computed by summing all the peaks and troughs hit by the VBG curve.

To estimate VBG parameters from length data, monthly length–frequency distributions were constructed using 0.5 cm total length (TL) size-class intervals. The VBG parameters of the seasonal and non-seasonal versions were estimated using the ELEFAN (Pauly, 1987), with the computer package Length Frequency Distribution Analysis (LFDA, version 5.0) (Kirkwood *et al*., 2001). These estimations were conducted for females and males caught by mid-water trawl and purse seine in the southern Black Sea separately. Because of the fact that significant differences of total length and size distribution were determined between males and females, seasonal and non-seasonal growth equations were not derived for combined sexes.

Growth performance comparisons were made using the growth performance index (Φ') which is preferred rather than using L_∞ and K individually (Pauly & Munro, 1984) and is computed as:

$$\Phi' = \log(K) + 2\log(L_\infty).$$

RESULTS

A total of 2328 European anchovy (1000 females, 329 males, 43 unidentified caught by purse seine and 588 females, 293 males, 75 unidentified caught by mid water trawl) were sampled between October 2010 and April 2011. The TL of females ranged between 7.7 and 14.6 cm (mean 11.83 ± 0.033 cm) caught by purse seine was higher than males ranged between 8 and 13.4 cm (mean 11.30 ± 0.065 cm) (*t*-test, $P = 3.24\text{E-}14$). The TL of females ranged between 6.1 and 14.4 cm (mean 11.57 ± 0.043 cm) caught by mid-water trawl was higher than males ranged between 6.4 and 13.8 cm (mean 11.19 ± 0.063 cm) (*t*-test, $P = 0.0076096$) (Figures 1 & 2). The TL of females caught by purse seine

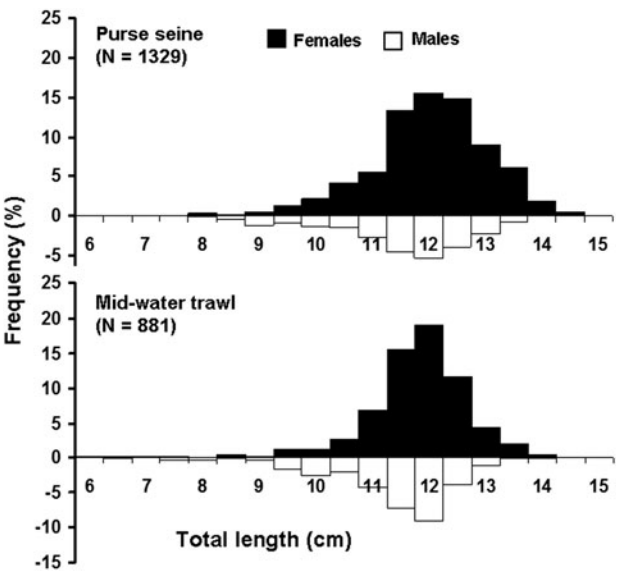

Fig. 1. Length composition of females and males of *Engraulis encrasicolus* caught by purse seine and mid-water trawl between October 2010 and April 2011 in the Black Sea.

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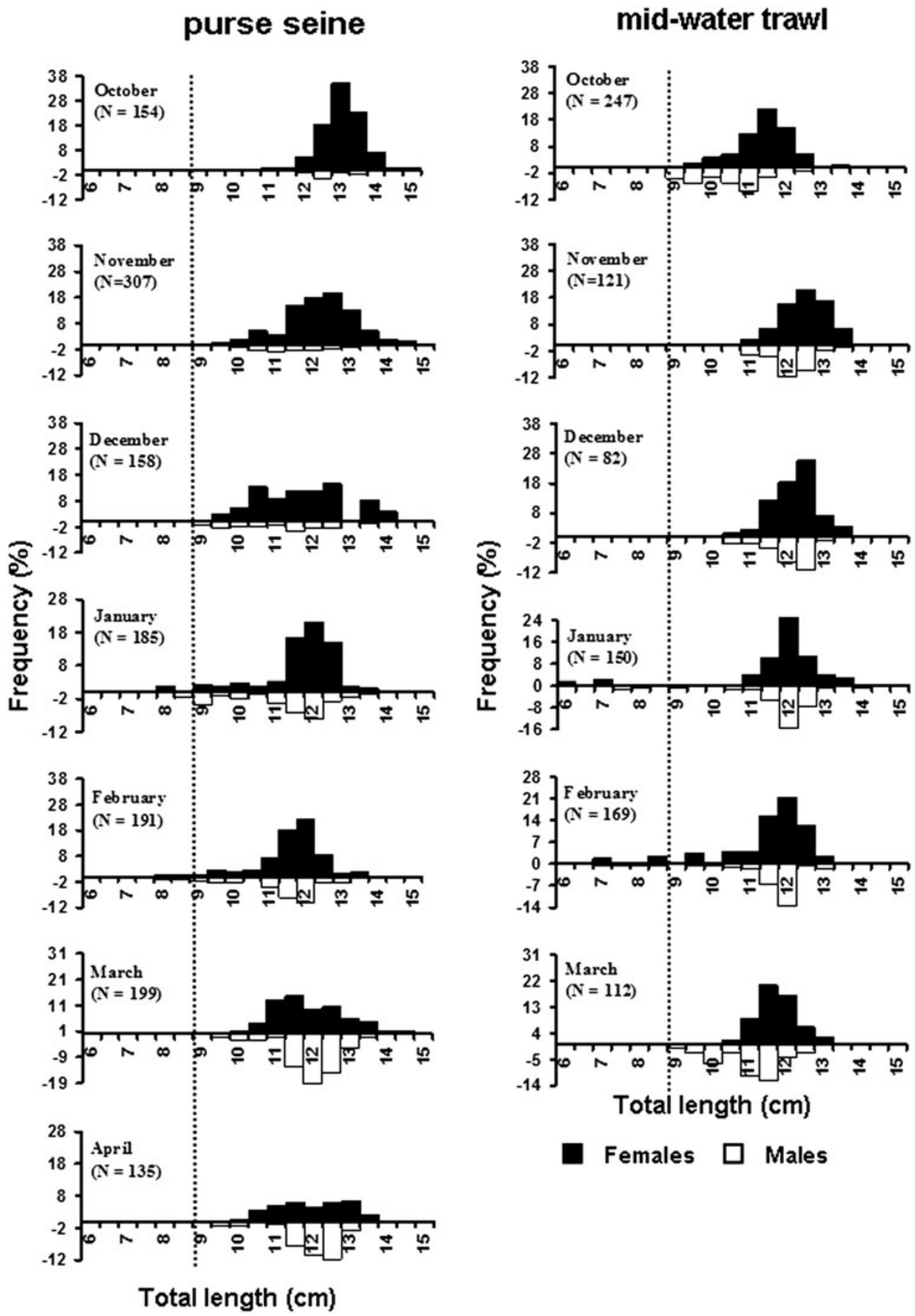

Fig. 2. Length–frequency distribution (in percentages) of females and males of *Engraulis encrasicolus* between October 2010 and April 2011. Dotted line at 9 cm was drawn for illustration purposes of legal fishing length.

was higher than females caught by mid-water trawl (*t*-test, $P = 1.53E\text{-}06$). However, the mean TL of males was not significantly different (*t*-test, $P = 0.48376$) caught by purse seine and mid-water trawl.

Monthly length–frequency distribution showed that the amount of the anchovies under the legal size (9 cm TL) had negligible levels in January and February indicating groups of small individuals were not obtained by both purse seine and mid-water trawl fisheries in both areas (Figure 2). Furthermore, the TL of purse seine samples was bigger than mid-water trawl samples. Namely, the percentages of bigger than 13 cm length-class individuals were 17.6% for females and 2.9% for males sampled with purse seine, and 6.9% for females and 1.4% for males sampled with mid-water trawl. Furthermore, looking at the overall size–frequency distribution (Figure 1), dominant length interval was 11.5–12.5 cm for females (46.3%) and for males (20.3%) caught by mid-water trawl and it was 11.5–12.5 cm size-class for females (43.6%) and for males (13.8%) obtained from mid-water trawl surveys. Size–frequency distributions were

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Table 1. Seasonal and non-seasonal von Bertalanffy growth parameters estimated from length–frequency distribution analysis for males and females caught with purse seine and mid-water trawl. L_∞, asymptotic total length (cm); K, growth coefficient (year^{-1}); t_o, age at zero length; WP, winter point; t_s, the phase of the seasonal oscillation; C, amplitude of growth oscillation; Rn, goodness of fit index; Φ', growth performance index.

Purse seine					**Mid-water trawl**			
Parameters	**Seasonal**		**Non-seasonal**		**Seasonal**		**Non-seasonal**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
L_∞ (cm)	14.000	13.929	13.850	13.955	13.013	13.688	13.063	13.680
K (year^{-1})	0.800	0.994	0.855	0.993	0.993	1.249	0.978	1.188
t_o (year^{-1})	−0.230	−0.060	−0.250	−0.060	−0.820	−0.530	−0.800	−0.860
WP	0.212 (March)	0.319 (April)			0.298 (April)	0.151 (February)		
ts	−0.288	−0.181			−0.202	−0.349		
C	0.980	0.725			0.800	0.950		
Φ'	2.195	2.285	2.215	2.286	2.226	2.369	2.222	2.347
Rn	0.542	0.529	0.464	0.499	0.574	0.666	0.570	0.522

significantly different (Kolmogorov–Smirnov two-sample test; d = 0.20231, P = 2.277E-09) between males and females caught by purse seine and they were also significantly different between males and females (Kolmogorov–Smirnov two-sample test; d = 0.14574, P = 0.00042351) caught by mid water trawl. Size–frequency distributions were significantly different (Kolmogorov–Smirnov two-sample test; d = 0.11315, P = 0.03482) for males and they were significantly different for females (Kolmogorov–Smirnov two-sample test; d = 0.18109, P = 4.1298E-11) caught by purse seine and mid-water trawl.

The seasonal and non-seasonal VBG parameters obtained from the LFDA for each sex caught by purse seine and mid-water trawl are summarized in Table 1. The LFDA analyses showed that growth parameter estimated for the seasonal and non-seasonal VBG version varied between the fishing gears in both sexes. Compared to mid-water trawl, purse seine catches had higher values of L_∞ and lower values of K in both the seasonal and the non-seasonal version of the VBG curves in both sexes (Table 1).

Based on the goodness of fit index (R_n) scores, the seasonal VBG curves yielded better fits than the non-seasonal VBG curves in females and males caught by the mid-water trawl and by purse seine. The R_n value of non-seasonal growth curve for males and females improved when the seasonal growth curve was fitted, showing that, at least for our two years of data, males (Figure 3A, C) and females (Figure 3B, D) display a seasonal growth pattern.

Seasonal oscillations in growth for males (C = 0.980) caught by purse seine were larger than for males (C = 0.800) caught by mid-water trawl. However, larger seasonal oscillations for females were obtained in mid-water trawl

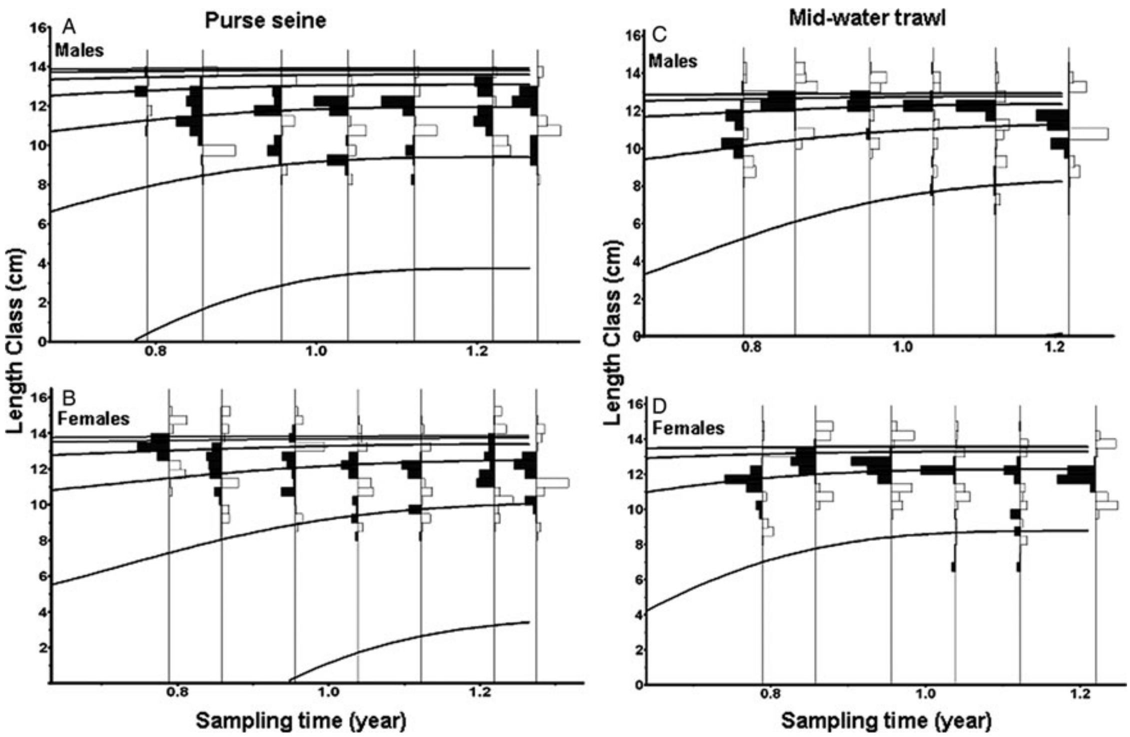

Fig. 3. Length–frequency distribution of *Engraulis encrasicolus* caught by purse seine (A, males; B, females) and mid-water trawl (C, males; D, females) with seasonal von Bertalanffy growth curves.

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catches (C = 0.950) than purse seine catches (C = 0.725). The slowest growth rate was estimated to be in April (WP = 0.319) for females and in March for males (WP = 0.212) caught by purse seine. Similarly, the start of the slow growth period was estimated to be in February (WP = 0.151) for females and in April (WP = 0.298) for males caught by mid-water trawl.

The growth performance index (Φ'; Table 1) of females (2.285 for purse seine catches and 2.369 for mid-water trawl catches) was slightly more than it was for males (2.195 for purse seine catches and 2.226 for mid-water trawl catches).

DISCUSSION

Length–frequency distribution analysis showed that TL less than 11 cm for both sexes was almost non-existent in the samples. This length is the size of first sexual maturity for anchovy (Giraldez & Abad, 1995) indicating small individuals were not fished by two vessels in the Black Sea.

Although seasonal growth pattern is very common in decapod crustaceans and in tropical waters fish stocks, seasonal oscillation in growth can be seen in other species particularly in the short lived and fast growing crustaceans and fish species. However, seasonal growth does not only differ between species but also between sexes within a species. Our results for both regions (Samsun and Rize) showed that the tendency of the amplitude of seasonal growth oscillation of anchovy reach high values (between 0.98 and 0.80 for males, 0.725 and 0.95 for females) which indicates that both sexes had a fairly strong seasonal growth pattern. Pauly & Tsukayama (1983) found that the mean value of $C = 0.30$ suggests that the growth of *E. ringens* oscillates seasonally in sinusoidal shape, and that it is, during the warmest summer month, 30% higher than it would be if no oscillations occurred. *Rn* values of the non-seasonal VBG curve improved by 16.8–27.5% in females and 0.7–6.0% in males after fitting a seasonal VBG curve (see Table 1). Conversely, the growth of anchovy is reduced in winter. Like this, the period of slowest growth for males and females estimated between February and April, is the period with a relatively low water temperature. In the Black Sea, Erkoyuncu & Ozdamar (1989) concluded that growth decreased between December and March, which is probably explained by the lower water temperature and the shortage of the nutrients during these winter months. Also, the surface water temperature fluctuates by about 19°C annually, and consequently anchovy in both areas have a seasonal growth pattern.

The VBG curve fitted to age–length data showed that most of the growth of the anchovy is achieved during the first year of life which is the age of maturity of anchovy in the Gulf of Cádiz (south-western Spain) (Bellido *et al.*, 2000), in the Bay of Bénisaf (south-western Mediterranean) (Bacha *et al.*, 2010) and in the Black Sea (Erkoyuncu & Ozdamar, 1989; Karacam & Düzgünes, 1990). Bacha *et al.* (2010) reported that the population of anchovy occurs at different latitudes and inhabits environments that differ in both annual temperature and length of the growth season, i.e. from the end of the first year of life energy support is allocated to reproduction, with less energy available for somatic growth. Bacha *et al.* (2010) concluded that anchovy seems to have higher growth parameters most likely in relation to environmental variables such as prey diversity (plankton rich, i.e. chlorophyll-*a*

Table 2. Computation of growth and size of European anchovy, *Egraulis encrasicolus*, from different areas and fishing seasons. L_∞, asymptotic total length (cm); *K*, growth rate (year^{-1}); Φ', growth performance index; Lmax, maximum total length (cm); Lmean, mean total length (cm).

Fishing seasons	Males					Females					Combined					Reference
	L_∞ (cm)	K	Φ'	Lmax	Lmean	L_∞ (cm)	K	Φ'	Lmax	Lmean	L_∞ (cm)	K	Φ'	Lmax	Lmean	
1985–1986											16.77	0.324	1.960	16.1	12.4	Erkoyuncu & Ozdamar, 1989 (1)a
1986–1987											16.85	0.324	1.964	16.9	10.8	Karacam & Düzgünes, 1990 (1)a
1987–1988											14.14	0.920	2.265			Düzgünes & Karacam, 1989 (1)a
1987–1988											17.99	0.294	19.785	15.3	9.8	Özdamar *et al.*, 1994 (1)a
1988–1989											15.65	0.282	18.395	13.5	10.6	Özdamar *et al.*,1994 (1)a
1988–1989	13.82	0.528	2.004	13.0		14.03	0.583	2.060	13.0		15.73	0.317	1.895	13.0		Ünsal, 1989 (1)a
1994–1995											16.83	0.310	1.944	15.3	9.0	Özdamar *et al.*, 1995 (1)a
2000–2001	15.86	0.273	1.837	13.8	10.9	19.27	0.167	1.793	14.1	11.2	16.84	0.233	1.820		10.7	Samsun *et al.*, 2006 (1)a
2001–2002	17.37	0.237	1.854	13.6	10.9	19.94	0.202	1.905	14.6	11.8	18.46	0.217	1.869		11.3	Samsun *et al.*, 2006 (1)a
2002–2003	18.40	0.177	1.778	13.3	10.0	18.78	0.154	1.735	14.9	10.6	18.73	0.156	1.738		10.2	Samsun *et al.*, 2006 (1)a
1974–1990											19.40	0.570	2.331			Sinovcic, 2000 (2)a
1989–1993											18.95	0.900	2.509	18.5		Bellido *et al.*, 2000 (3)a
1989–1993											18.69	0.900	2.000	18.5		Bellido *et al.*, 2000 (3)b
2007	15.36	0.780	2.265			15.76	0.790	2.293			15.61	0.750	2.262	17.0		Bacha *et al.*, 2010 (4)a
2010–2011	13.01	0.993	2.226	13.8	11.2	13.69	1.249	2.369	14.4	11.8						Present study (mid-water trawl)d
2010–2011	14.00	0.800	2.195	13.4	11.3	13.93	0.994	2.285	14.6	11.8						Present study (purse seine)d

(1), Black Sea; (2), Adriatic Sea; (3), Gulf of Cádiz; (4), Mediterranean Sea; a, otoliths; b, ELEFAN; c, Powell–Wheterall methods; d, ELEFAN seasonal.

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concentration), energy allocation to somatic growth and water temperature.

The LFDA is a useful tool for analysing size–frequency distribution, and has been used for anchovy growth analyses (Bellido *et al.*, 2000; Dimmlich, 2010). However, LFDA may not be appropriate for a population where large variations in annual recruitment can occur. The reliability of the VBG estimation from ELEFAN using LFDA is discussed for different methods and fishing seasons (see Table 2). In early studies in the southern Black Sea concerning anchovy generally L_∞ was higher and K was lower than in our results (Table 2). However, Düzgünes & Karacam (1989) reported a K value of 0.92 for combined sexes for this species. Ünsal (1989) also recorded L_∞ values as 13.82 cm for males and 14.03 cm for females. These results are in accordance with our results. This similarity with Ünsal (1989) may be due to the similarity of length–frequency distribution of sampled anchovy. Nominally, maximum length was 13 cm and a dominant length interval was demonstrated between 10 and 12 cm total length-classes.

The growth performance index is a practicable tool for comparing species belonging to the same family or same species and useful for evaluation of growth under a variety of environmental stresses (Pauly, 1991; Sparre & Venema, 1992). The early studies concerning growth of anchovy Φ' are shown in Table 2. Calculated from published data of K and L_∞ in European anchovy Φ' ranges from 1.738 in the Black Sea (Samsun *et al.*, 2006) to 2.509 in the Gulf of Cádiz (Bellido *et al.*, 2000) for combined sexes, from 1.735 (Samsun *et al.*, 2006) to 2.347 for females (present study) in the Black Sea, and from 1.778 (Samsun *et al.*, 2006) to 2.265 for males in the Bay of Bénisaf (Bacha *et al.*, 2010). In the present study, the comparison of growth performance in the two areas was very similar to each other and consistent with other studies. However, our values of growth performance derived for *E. encrasicolus* from different areas showed a high variation compared to other studies. This variation could be partially considered as a result of the various ageing and growth methods, i.e. otoliths and length based models, but mostly it could be connected to differences of environmental conditions and a genetic basis (Khemiri *et al.*, 2007).

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Correspondence should be addressed to:
S. Bilgin
Recep Tayyip Erdoğan University, Faculty of Fisheries,
Rize-17100, Turkey
email: sbrbilgin@hotmail.com