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Weight - Length Relationships (WLRs) of Anchovy, *Engraulis encrasicolus* with the Evaluation of Overfishing Effects on the Slope (b) in the Black Sea (Turkey)

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Abstract: The present study was conducted to determine the weight-length relationships (WLRs) of Anchovy (*Engraulis encrasicolus*) caught by purse seine off the Rize and Trabzon provinces coasts of the southeastern Black Sea, Turkey and to compare as a whole the WLRs parameters of *E. encrasicolus* obtained from different fishing seasons and locality for contributing fisheries management of this Black Sea' key fish species. The WLRs parameters showed that *E. encrasicolus* exhibited negative allometric growth characteristics for both sexes (Pauly't test, $P < 0.05$). To compare the estimations calculated from the present study with other studies, *Log* (*a*) values were plotted against values of slope (*b*), proved to be consistent with previous studies data. In addition to this, when the WLRs parameters (*b*) of Anchovy is evaluated historically, it has been determined that the Anchovy exhibited positive allometric growth in the mid-1985, isometric growth from 1990 to 2000 and negative allometric growth after the 2000s. The overexploitation on anchovy stocks has shown itself in fish growth over the years. This study provides new basic information on the WLRs for Anchovy stocks, in support of sustainable fisheries management of this species and especially of the coastal waters in the Black Sea, Turkey.

Keywords: Anchovy, Black Sea, *Engraulis encrasicolus*, fisheries management, weight-length relationships (WLRs).

Karadeniz'de (Türkiye) Hamsi Balığı'nın, *Engraulis encrasicolus* (Linnaeus, 1758) (Clupeiformes: Engraulidae) Ağırlık-Boy (WLRs) İlişkisi ile Av Baskısının Eğim Parametresi (b) Üzerine Etkisinin Değerlendirilmesi

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Öz: Bu çalışma, hamsi (*Engraulis encrasicolus*) balığının boy ağırlık ilişkisi (WLRs) parametrelerini belirlemek için güney doğu Karadeniz'de Rize ve Trabzon illeri civarında gırgır ağları ile örneklenen bireyler üzerinden yürütülmüş olup ayrıca bu anahtar balık türünün Karadeniz'deki balıkçılık yönetimine katkı sağlamak amacıyla daha önce farklı av sezonlarında yürütülmüş çalışmalardan elde edilen WLRs parametreleri bir bütünlük içerisinde karşılaştırılmıştır. WLRs parametreleri dişi ve erkek bireylerin negatif allometrik büyüme (Pauly t-test, $P < 0,05$) özelliği gösterdiğini ortaya koymuştur. Ayrıca, önceki çalışmalardan elde edilen *Log* (*a*) ve *b* değerleri regresyona tabi tutulduğunda, bu çalışmada elde edilen sonuçların önceki çalışmalarla tutarlı olduğu belirlenmiştir. WLRs denklemi parametresi (*b*) tarihsel olarak değerlendirildiğinde, Hamsi balığının 1985 ortalarında pozitif allometrik büyüme, 1990-2000 arasında izometrik büyüme ve 2000'lerden sonra ise negatif allometrik büyüme sergilediği tespit edilmiştir. Hamsi stoklarındaki aşırı sömürü, yıllar boyunca balık büyümesinde kendini göstermiştir. Bu çalışma, Türkiye'nin Karadeniz kıyı sularında Hamsi stoklarının sürdürülebilir balıkçılık yönetimini desteklemek için türün boy ağırlık ilişkisi hakkında yeni temel bilgiler sunmaktadır.

Anahtar kelimeler: Ağırlık-boy ilişkisi (WLRs), balıkçılık yönetimi, *Engraulis encrasicolus*, Hamsi, Karadeniz.

INTRODUCTION

Anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), is distributed Eastern Atlantic: Bergen, Norway to East London, South Africa, Mediterranean and Black Sea (Froese & Pauly, 2019). 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. Feeds on planktonic organisms such as fish eggs and larvae, Ctenophorans and copepods, etc. (Mazlum et al., 2017). Spawns from April to November with peaks usually in the warmest months (Ribeiro et al., 1996; Froese & Pauly, 2019). It is one of the most important migratory commercial small pelagic and fast growing fish species in the Black Sea and mainly caught by mid-water trawl (legal Anchovy fisheries with mid-water trawl towed behind two boats are conducted only in Samsun region in Turkey) and purse seine in the seven and a half months during the fishing season (between 31 August and 15 April) along the coast of Turkey. Anchovy tends to move further north and into surface waters in summer, retreating and descending in winter and during a fishing season average annual catch constitute about 69% of the total marine fisheries production of Turkey (Bilgin et al., 2013). In the Black Sea, the spawning season of Anchovy lasts from mid May, when water temperature is about 15-16°C, to the middle or end of August when the temperature is about 25-26°C (Lisovenko & Andrianov, 2006). Within the spawning season one average female can produce about 50 batches of more than 200,000 eggs (Lisovenko & Andrianov, 2006). The maximum total length of Anchovy was reported as 16.85 cm in 1986-1987 fishing season by Karacam & Düzgünes (1990) and also four age groups (0, I, II and III) were reported by different authors in different fishing seasons in the Black Sea (Erkoyuncu & Özdamar, 1989; Karacam & Düzgünes, 1990; Ünsal, 1989; Mutlu, 1994; Özdamar et al., 1995; Kayalı, 1998; Mutlu, 2000; Gözler & Çiloğlu, 1998; Samsun et al., 2004; Samsun et al., 2006; Aka et al., 2004; Bilgin et al., 2006; Şahin et al., 2008; Erdoğan Sağlam & Sağlam, 2010). All reproductive, growth and also mortality parameters of Black Sea Anchovy are very variable seasonally and annually (Bilgin, 2006; Lisovenko & Andrianov, 2006; Bilgin et al., 2016).

Knowledge on biological features such as reproduction, growth and weight length relationships (WLRs) are important tools for fisheries management. The information on the WLRs could contribute to the management of natural stocks of fish species which is ecologically and economically important, and possibly has suffered threats from overfishing, pollution and climate change (Oliveria et al., 2012) and also the WLRs allow estimating food and feeding, life histories of certain species (Stergiou & Moutopoulos, 2001). In addition to these, the WLRs parameters can be affected by different factors such as environmental conditions, gonad maturity stages, sex, stomach fullness, health condition, season, population and differences within species (Froese, 2006; Oliveria et al., 2012). Thus, they are an important component of fisheries biology and when properly calculated they can be very useful to fisheries management (Froese et al., 2011). The weight (W) of fish and other organisms is exponentially related to their length (L) according to the equation $W = aL^b$, where a is the intercept and b is the slope of the relation (Le Cren, 1951). Based on the slope (b) of the relation between W and L, one can check whether the growth of a fish species is isometric ($b = 3$), negative allometric-hypoallometric ($b < 3$) or positive allometric-hyperallometric ($b > 3$).

The Anchovy is the main object of fishing industry in Turkey. So the knowledge of its biological properties including the WLRs parameters is necessary for fisheries management. The WLRs parameters of this Black Sea' key fish species were previously reported from different geographic regions and different fishing seasons in the Black Sea (Erkoyuncu & Özdamar, 1989; Karacam & Düzgünes, 1990; Ünsal, 1989; Mutlu, 1994; Özdamar et al., 1995; Kayalı, 1998; Mutlu, 2000; Gözler & Çiloğlu, 1998; Samsun et al., 2004; Samsun et al., 2006; Aka et al., 2004; Bilgin et al., 2006; Şahin et al., 2008; Erdoğan Sağlam & Sağlam, 2010). Moreover, previous research into the WLRs parameters of Anchovy has been rather fragmentary in the Black Sea. The present study was conducted to determine the WLRs of Anchovy caught by purse seine during the 2013-2014 fishing season off the Rize and Trabzon provinces coasts in the southeastern Black Sea, Turkey and also to compare as a whole the WLRs parameters of Anchovy from different geographical locality and fishing seasons in support of sustainable fisheries management.

MATERIAL AND METHOD

Sample Collection: Samples of the Anchovy (*Engraulis encrasicolus*) were collected at random from the commercial purse seine at the southern area of the Black Sea (off Rize and Trabzon provinces, Turkey) from September 2013 to April 2014 in 2013-2014 fishing season. After the purse seine fishing operation, a box of Anchovy (≈18 kg) was taken from the catch and brought to the Recep Tayyip Erdoğan University Fisheries Faculty Laboratory for examination.

Weight - Length Relationships (WLRs): The total length (TL) and the wet body weight (W) of *E. encrasicolus* were measured after blot drying with a piece of clean towel. All specimens were measured to the nearest 0.1 cm and weighed to the nearest 0.01 g. The weight-length relationships (WLRs) parameters were calculated and analyzed using MS Excel software. However to compare the

WLRs results for *E. encrasicolus* obtained in this study with the results of previous studies, the *Log (a)* values were drawn against *b* values.

The weight length relationship was estimated as (Le Cren, 1951):

$W = aTL^b$,

where *W* is the body weight (g), *TL* is the total length (cm), *a* is the intercept, and *b* is the slope of the regression line. Comparison of the difference of slope value from *b* = 3 (isometric growth), Pauly's *t*-test was performed (Pauly, 1984). Pauly's *t*-test statistic was calculated as below:

$$t = \frac{Sd_{\log TL}}{Sd_{\log W}} \frac{|b-3|}{\sqrt{1-r^2}} \sqrt{n-2}$$

where Sd_{logTL} is the standard deviation of the log *TL* values, Sd_{logW} is the standard deviation of the log *W* values, n is the number of specimens of *E. encrasicolus* used in the computation. The value of *b* is different from *b* = 3 if calculated *t* value is greater than the table *t* values for n-2 degrees of freedom (Pauly, 1984). Comparison of the difference of correlation coefficient (*r*) from zero *t*-test (Snedecor & Cochran, 1989) was calculated as follow:

$$t = \frac{r * \sqrt{(n-2)}}{\sqrt{(1-r^2)}}$$

where *n* is the number of fish used in the computation and *r* is the correlation coefficient. The value of correlation coefficient is different from zero if *t* value is greater than the tabled *t* values for n-2 degrees of freedom. T test was used to compare the means between the sexes in PAST ver. 1.75b software package (Hammer et al., 2001). Differences were considered statistically significant when $P < 0.05$.

RESULTS AND DISCUSSION

Size Structure: A total of 5485 *E. encrasicolus* (3336 female, 2149 male) were sampled from September 2013 to April 2014 and the maximum total length was measured as 13.8 cm for females and 13.2 cm for males. The mean total length of females (10.8±0.02 cm) was significantly greater than mean total length of males (10.1±0.03 cm) (*t* - test; $P < 0.05$).

Weight - Length Relationships (WLRs): The WLRs results and statistics of Anchovy showed below and in Fig. 1. Females: $W = 0.0159TL^{2.5609}$, $R^2 = 0.8093$, n = 3336, $Sd_{logL} = 0.04294$, $Sd_{logW} = 0.12225$, Pauly't test = 203.78, $P<0.001$). (95% conf. limits of *b*: from 2.5187 to 2.6032). Males: $W = 0.0078TL^{2.8757}$, $R^2 = 0.8783$, n = 2149, $Sd_{logL} = 0.053783$, $Sd_{logW} = 0.165031$, Pauly't test = 5.405, $P<0.001$). (95% conf. limits of *b*: from 2.8307 to 2.9209).

The WLRs parameters showed that sampled specimens has negative allometric growth characteristics ($b < 3$) both females ($b = 2.5609$) and males ($b = 2.8757$) (Pauly' *t* test, $P < 0.05$) in 2014-2015 fishing season. However, in order to comparison of the difference of correlation coefficient (*r*) from zero *t*-test (Snedecor and Cochran, 1989) was applied and the values of (*r*) for females ($r = 0.8093$), for males ($r = 0.8783$) and for combined data ($r = 0.8517$) are different from zero ($P < 0.05$), indicated that Anchovy has higher correlation in WLRs equations.

To compare the estimations calculated from the present study with other studies (showed in Table 2), *Log* (*a*) values were plotted against values of *b* (Fig. 2), proved to be consistent with previous studies (from 1985-1986 fishing season up to 2014-2015 fishing seasons) data for *E. encrasicolus*. The results of regression analysis of *Log* (*a*) to slope (*b*) for *E. encrasicolus* showed below and in Table 1. Females: *Log* (*a*) = -0.9935*(*b*) + 0.7739 ($R^2 = 0.9900$, n = 11, $P < 0.05$). Males: *Log* (*a*) = -1.0131*(*b*) + 0.8289 ($R^2 = 0.9872$, n = 11, $P < 0.05$). Females+Males: *Log* (*a*) = -1.1661*(*b*) + 1.3103 ($R^2 = 0.9024$, n = 20, $P < 0.05$)

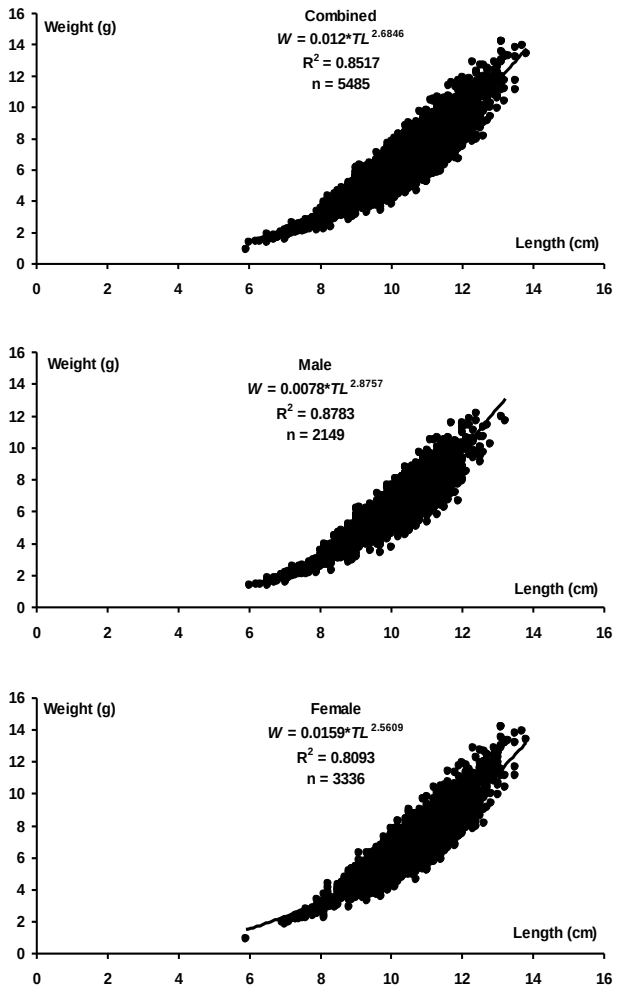

Figure 1. Weight - length relationships (WLRs) of the Anchovy (*Engraulis encrasicolus*) caught during the 2013-2014 fishing season in the Black Sea.

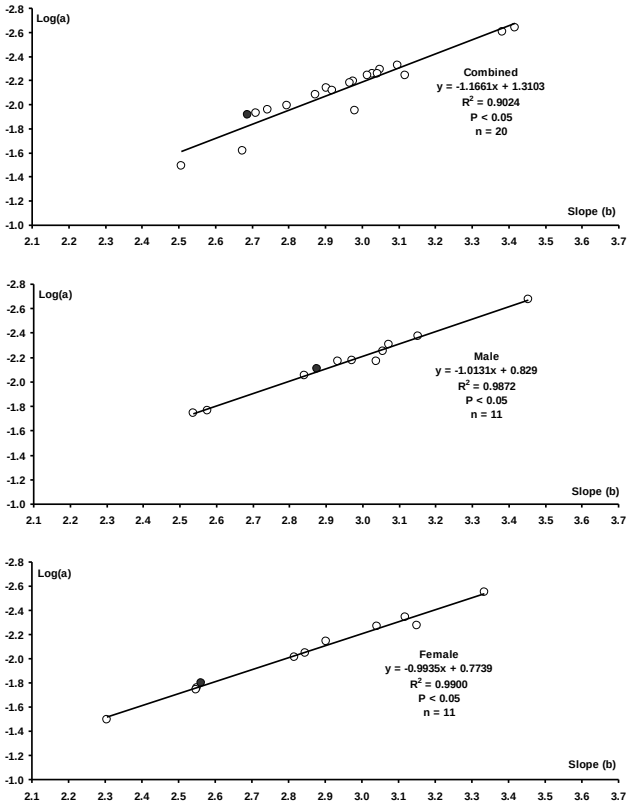

Figure 2. The test plot of *Log (a)* against *b* for different WLRs of the Anchovy (*Engraulis encrasicolus*). Black dot = present study parameter. White dot = estimated parameters of different studies conducted from 1985-1986 to 2013-2014 fishing seasons in the Black Sea (see Table 2).

In terms of fishing season variations, Anchovy exhibited positive allometric growth only in the first two fishing seasons (1985-1986 and 1986-1987). Later, isometric growth up to 1999-2000 fishing seasons and after 2000 years Anchovy has exhibited negative allometric growth and tended to be thinner (Fig. 3).

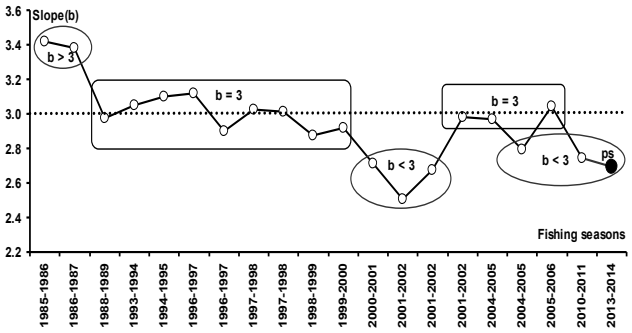

Figure 3. The slope (*b*) parameter values of the WLRs equation in Anchovy (*Engraulis encrasicolus*). Black dot (ps) = present study parameter. White dot = estimated parameters of different studies conducted from 1985-1986 to 2013-2014 fishing seasons in the Black Sea.

In all result of the previous studies (a total of 20 fishing seasons results), except for 11 fishing seasons results, conducted between 1985-1986 and 2013-2014 fishing seasons in the Black Sea, the *b* values were reported regardless of fish sexes (Table 1).

Table 1. Results of regression analysis of *Log* (*a*) to slope (*b*) for the Anchovy (*Engraulis encrasicolus*). Calculations were done using the data (*a* and *b*) shown in Table 2. *a* : Intercept, *b* (slope): x- variable 1.

	Coefficients	Standard Error (S.E)	*T - stat*	*P - values*	95% Confidence Limits of the Parameters	
Males+Females						
Intercept	1.3103	0.2668	4.9118	0.000112404	0.7498	1.8707
x - variable 1	-1.1661	0.0904	-12.9041	1.55379E-10	-1.3559	-0.9762
Log(a) = -1.1661*(*b*) + 1.3103 (R^2 = 0.9024, n = 20, *P* < 0.05)						
Males						
Intercept	0.8289	0.1141	7.2680	4.72392E-05	0.5709	1.0869
x - variable 1	-1.0131	0.0385	-26.3338	7.93126E-10	-1.1002	-0.9261
Log(a) = -1.0131*(*b*) + 0.8289 (R^2 = 0.9872, n = 11, *P* < 0.05)						
Females						
Intercept	0.7739	0.0949	8.1537	1.90063E-05	0.5592	0.9886
x - variable 1	-0.9935	0.0333	-29.8245	2.61713E-10	-1.0689	-0.9182
Log(a) = -0.9935*(*b*) + 0.7735 (R^2 = 0.9900, n = 11, *P* < 0.05)						

Table 2. The weight - length relationships (WLRs) parameters of the Anchovy (*Engraulis encrasicolus*) from 1985-1986 to 2013-2014 fishing seasons in the Black Sea. L_{max}: maximum total length (cm), *a*: intercept, *b*: slope. Data (*a* and *b*) has been used to draw of test plot of *Log* (*a*) against *b* in Figure 2.

Fishing seasons	Regions	Sex												References
		Males				Females				Males+Females				
		L_{max}	a	b	r^2	L_{max}	a	b	r	L_{max}	a	b	r^2	
1985-1986	Sinop-Trabzon									16.1	0.0023	3.4157		1
1986-1987	Trabzon		0.0021	3.4539	0.9978		0.0028	3.3331	0.9979	16.9	0.0025	3.3832	0.9994	2
1988-1989	Istanbul	13.0				13.0				13.0	0.0064	2.9743		3
1993-1994	Trabzon	14.4	0.0068	2.9320	0.9390	13.9	0.0072	2.9030	0.9410	14.4	0.0051	3.0480	0.9700	4
1994-1995	Sinop-Samsun									15.3	0.0047	3.0975	0.9800	5
1996-1997	Trabzon-Hopa		0.0068	3.0370	0.8600		0.0053	3.1490	0.9000	13.5	0.0057	3.1170	0.8900	6
1996-1997	Ordu-Hopa									15.7	0.0073	2.9030	0.9690	7
1997-1998	Ordu-Hopa									15.3	0.0055	3.0270	0.9746	7
1997-1998	Rize-Hopa	13.8	0.0049	3.0710	0.8010	13.8	0.0054	3.0400	0.9440	13.8	0.0057	3.0150	0.9250	8
1998-1999	Sinop		0.0088	2.8404			0.0317	2.3042		14.5	0.0083	2.8720		9
1999-2000	Sinop		0.0056	3.0549			0.0097	2.8156		14.5	0.0076	2.9190		9
2000-2001	Sinop	13.8	0.0179	2.5368	0.9000	14.1	0.0174	2.5498	0.9000	14.1	0.0118	2.7101	0.9600	10
2001-2002	Trabzon									10.9	0.0320	2.5078	0.8954	11
2001-2002	Sinop									10.4	0.0241	2.6738	0.9134	11
2001-2002	Istanbul									10.9	0.0111	2.9796	0.8649	11
2004-2005	Sinop-Samsun									15.2	0.0066	2.9669	0.9600	12
2004-2005	Rize		0.0067	2.9709			0.0089	2.8445		15.0	0.0101	2.7948	0.9286	13
2005-2006	Rize		0.0042	3.1518			0.0045	3.1187		15.0	0.0055	3.0425		13
2010-2011	Sinop-Trabzon		0.0170	2.5760	0.9240		0.0180	2.5470	0.8510	14.8	0.0110	2.7420	0.9350	14
2013-2014	Trabzon-Rize	13.2	0.0078	2.8757	0.8800	13.8	0.0159	2.5609	0.8100	13.8	0.0120	2.6880	0.8500	15

1: Erkoyuncu & Özdamar (1989); 2: Karacam & Düzgünes (1990); 3: Ünsal (1989); 4: Mutlu (1994); 5: Özdamar et al., (1995); 6: Kayalı (1998); 7: Mutlu (2000); 8: Gözler & Çiloğlu (1998); 9: Samsun et al., (2004); 10: Samsun et al., (2006); 11: Aka et al., (2004); 12: Bilgin et al., (2006); 13: Şahin et al., (2008); 14: Erdoğan Sağlam & Sağlam (2010); 15: Present study.

The reported *b* values for combined specimens ranged between 2.5078 and 3.4157 (mean: 2.9439±0.05021, n = 20) (Table 1). From the reported *b* values for different fishing seasons from the Black Sea, it can be inferred that this fish species exhibits different growth characteristics by different time intervals. Our data fit the regression for the species *E. encrasicolus* excellently and growth parameters are similar to five of the eight results of fishing seasons conducted after the 2000s in the Black Sea (Fig. 3). Similarly, when the *b* values were evaluated according to sexes, our *b* values (2.8757 in males and 2.5609 in females) are similar to the studies (Samsun et al., 2004; Samsun et al., 2006); Şahin et al., 2008; Erdoğan Sağlam & Sağlam, 2010) conducted after the 2000s in the Black Sea. Namely, the *b* values of the WLRs showed that sampled specimens has negative allometric growth characteristics ($b < 3$) both females and males ($P < 0.05$) after the 2000s in the Black Sea. Based on the slope (*b*) of the relation between *W* and *L*, it can be checked whether the growth of a fish species is isometric ($b = 3$), hypoallometric ($b < 3$) and hyperallometric ($b > 3$) (Le Cren, 1951; Frose, 2006; Froese et al., 2011). In such a way that if the $b = 3$, all fish dimensions increase at the same rate, if the $b < 3$, a fish increases less in weight than predicted by its increase in length, i.e., it becomes more elongated, if the $b > 3$, a fish increases more in weight than predicted by its increase in length, i.e., it becomes less elongated or more roundish (Le Cren (1951; Froese et al., 2011).

Historical evaluation of the *b* values (Fig. 3) has shown that anchovy have become more elongated in recent years ($b < 3$). The differences in the *b* values may be due to seasonal changes in the water temperature and the maturity stage, different sampling area, age, sex and differences of other biotic and abiotic factors such as salinity, competition, food and feeding, degree of stomach fullness, etc. Furthermore, the overfishing on anchovy stocks has shown itself in fish growth over the years (from 1985 to present time). This time period can be divided into three parts according to the exploitation ratio (*E*) levels and the slope values of the WLRs for Anchovy. First time period; 1985s years when fishing pressure has just started ($b > 3$). Second period; the years when the fishing pressure continues to increase ($b = 3$) and third time period; recent years when stocks are completely affected due to overfishing ($b < 3$). Namely, the anchovy individuals are more roundish-plump ($b > 3$) in the 1985s that time fishing pressure has just begun on stocks and exploitation rate about 0.5 (Karacam & Düzgünes, 1990), all fish dimensions increase at the same rate ($b = 3$) with the effect of overfishing (exploitation rate, $E > 0.5$) had continued for many years (Bilgin, 2006), and it becomes more elongated in recent years ($b < 3$) when stocks are completely affected due to overfishing (Bilgin et al., 2016). The correlation coefficient (*r*) both females and males has higher correlation in the WLRs equations and also *log* (*a*) values were plotted against *b* values for *E. encrasicolus* proved to be consistent with previous studies data (Fig. 2). Similar result for different fish species such as thornback ray (*Raja clavata*), turbot (*Scophthalmus maximus*) and scaldback (*Arnoglossus kessleri*) was reported by Bilgin & Köse (2018) and Bilgin & Onay (2019) from the Black Sea.

In conclusion, it has been historically determined that the Anchovy exhibited positive allometric growth in the mid-1985, isometric growth for next 15 years and negative allometric growth after the 2000s. Namely, historical evaluation of the *b* values has shown that anchovy have become more elongated in recent years. The obtained results on the WLRs parameters by fishing seasons are expected to be helpful in support of sustainable fisheries management of this key fish species in the Black Sea, Turkey.

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