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EMPIRICAL USE OF GROWTH, MORTALITY AND TEMPERATURE DATA FOR ANCHOVY

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ABSTRACT: To estimate the empirical relationships in anchovy, the instantaneous natural mortality rate (*M*) calculated from von Bertalanffy Growth Function (VBGF) parameters, maximum total length (L_{max}) and sea surface temperature (*T*,°C) were reviewed in the Black Sea. Empirical equations were presented for evaluation of *M* data in their relationships to VBGF parameters, *T* and L_{max}. Based on biological consideration and regressional definition, it was recommended to use following formulas for estimating of natural mortality rate of small pelagic fish such as anchovy. $M = 0.3237 + 1.3174*(K) - 0.0036*(L_\infty) - 0.0117*(T)$; $M = 0.2639 + 1.3676*(K) - 0.0003*(L_{max}) - 0.0124*(T)$.

KEYWORDS: Fisheries management; population dynamics; small pelagic fish; Black Sea

INTRODUCTION

Natural mortality rate (*M*, year^{-1}) can be defined as the removal of fish from the stock due to causes not associated with fishing. Such causes can include disease, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish. Moreover, *M* should be related to fish size and/or growth e.g. von Bertalanffy Growth Function (VBGF) parameters such as L_∞ expressing the asymptotic total length that the fish would reach if they were to grow indefinitely and *K* expressing the rate at which the asymptotic length is approached, because of the fact that large sized fish have fewer predator than small fish. Furthermore, it has been suggested that the natural mortality rate in fish may be related to water temperature (*T*, °C). All of these relationships can be expressed as multiple regression for growth parameters depend on length data. Due to the relationships described above, the following multiple regression equations have been developed to estimate *M* for different taxonomic groups such as fish, mollusks, cetaceans, etc. from different geographical regions by different authors such as Beverton and Holt (1959), Pauly (1980), Hoening (1983), Gulland (1987), Djabali *et al.* (1993), Srinath (1998). Among the empirical estimators of M, the Pauly (1980) and Hoenig (1983) multiple regression equations are the two most widely applied estimators. The proposed model by Pauly's (1980) was based on 175 fish stocks from polar to tropical areas for the estimation of *M* of fish based on VBGF parameters (L_∞ and *K*) and mean annual water temperature (*T*). Pauly (1980)'s model including only one anchovy data set from Alger and also five Mediterranean data sets. According to Djabali *et al.* (1993), the Mediterranean environment has its own characteristics and the wide use of Pauly's equation in the Mediterranean may thus lead to errors. Therefore, Djabali *et al.* (1993) has developed a regional model for the 56 stocks of Mediterranean Actinopterygii fish for estimation of *M*. Djabali *et al.* (1993)'s model including 24 fish species data sets but not anchovy.

In the Black Sea, European anchovy (*Engraulis encrasicolus*) is one of the most important commercial fish species for fishing in Turkey and annual catch constitute about 68.8% of the total marine fisheries production of Turkey (Bilgin *et al.*, 2012). Anchovy stocks has been under overexploitation from the 1985s to the present due to strong fishing fleet in the Black Sea (Bilgin, 2006; Bilgin *et al.*, 2016). Furthermore the Black Sea is a marginal sea and has its own environment characteristics. Life history parameters of fish species are important indicators to reveal different life history strategies and to indicate population responses to fishing pressures. So, life history traits and their variations are important to marine fisheries and marine ecosystem studies. A recent study conducted in the coastal area between Fujian Coast and Taiwan Island to determine the variations of life history information including size, growth, maturation and life span of 26 populations of 25 fish species (Hu *et al.*, 2015). In that study, five life history groups of fish species identified by PCA analysis and most of the fish were categorized to life history group which were dominated by pelagic species and characterized as small in size, short-life, mature at early age, and mid-range growth. It was also reported that the changes of life history traits under long-term overexploitation and a general increase trend in growth rate and a decline trend in size, age and size at maturity (Hu *et al.*, 2015). Furthermore, specific fishery management strategies were proposed to different fish groupings and species due to the above-mentioned explanations. Hence, in this paper plots of natural mortality (*M*) versus growth parameters (L_∞, *K*, L_{max}) and mean annual sea water temperature (*T*) comprising different fishing seasons data were investigated for single European anchovy (*E. encrasicolus*) in the Black Sea.

MATERIALS AND METHOD

Empirical equations were created by using the data obtained from the studies on population dynamics of European anchovy (*E. encrasicolus*) in the Black Sea. Bibliography of anchovy population dynamic studies and temperature used as data in this study are summarized in Table 1. Data were obtained from journals, conference proceedings, theses, etc. Our review included articles on von Bertalanffy Growth Function (VBGF) parameters, mortality and temperature. These data including L_{max}: maximum total length (cm), *K*: parameter of the VBGF, of dimension year^{-1}, expressing the rate at which the asymptotic length is approached, L_∞: parameter of VBGF expressing the asymptotic total length that the fish would reach if they were to grow indefinitely (cm), *M*: natural mortality (year^{-1}), *T*: Sea surface temperature (°C). Additional information on sampling characteristics included sampling seasons. Annual sea surface temperature (*T*) obtained from Meteorological Data Information System (https://mevbis.mgm.gov.tr/mevbis) and Çakıroğlu *et al.* (2017).

The empirical equations were created using the data mentioned above. The regression models and/or empirical equations that were used (Table 2) have the same forms as the that of Pauly (1980) and Djabali *et al.* (1993) consists of a multiple linear regression (without logarithmic transformation of data).

Table 1. Bibliography of European anchovy (*Engraulis encrasicolus*) population dynamic studies and temperature used as data in this study. L_{max}: maximum total length, *K*: parameter of the von Bertalanffy Growth Function (VBGF), expressing the rate at which the asymptotic length is approached, L_∞: parameter of VBGF expressing the asymptotic total length that the fish would reach if they were to grow indefinitely, *M*: natural mortality, *T*: Sea surface temperature. +: data available.

Fishing Seasons	L_{max} (cm)	L_∞ (cm)	K (yr^{-1})	M (yr^{-1})	T (°C)*	References
1985-1986	+	+	+	+	+	1
1986-1987	+	+	+	+	+	2
1987-1988	+	+	+	+	+	3
1988-1989	+	+	+	+	+	3
1988-1989	+	+	+	+	+	4
1993-1994	+	+	+	+	+	5
1994-1995	+	+	+	+	+	6
1995-1996	+	+	+	+	+	7
1996-1997	+	+	+	+	+	7
1997-1998	+	+	+	+	+	7
1997-1998	+	+	+	+	+	8
1998-1999	+	+	+	+	+	9
1999-2000	+	+	+	+	+	9
2000-2001	+	+	+	+	+	10
2001-2002	+	+	+	+	+	10
2002-2003	+	+	+	+	+	10
2004-2005	+	+	+	+	+	11
2004-2005	+	+	+	+	+	12
2005-2006	+	+	+	+	+	12
2010-2011	+	+	+	+	+	13

1: Erkoyuncu and Özdamar (1989); 2: Karaçam and Düzgüneş (1990); 3: Özdamar *et al.* 1994; 4: Ünsal (1989); 5: Mutlu (1994); 6: Özdamar *et al.* (1995); 7: Mutlu (2000); 8: Gözler and Çiloğlu 1998); 9: Samsun *et al.* (2004); 10: Samsun *et al.* (2006); 11: Bilgin *et al.* (2006); 12: Şahin *et al.* (2008); 13: Erdoğan-Sağlam and Sağlam (2013). *: Annual sea surface temperature (T) obtained from Meteorological Data Information System (https://mevbis.mgm.gov.tr/mevbis/ui/index.html#/Workspace) and Çakıroğlu *et al.* (2017).

All statistical analyses and multiple regressions were performed using Microsoft Office Excel. The multiple regression is an extension of simple linear regression and it was used to predict the value of a variable based on the value of two or more other variables such as L_{max}, K, L_∞ and T in the present study. The predict and/or dependent value of variables were natural mortality, M and Brody growth rate coefficient, K.

Table 2. The regression models and parameters were applied to the data.

Equation (1) $y = a + b_1x_1 + b_2x_2 + b_3x_3$, where $y = M$ (year^{-1}), $x_1 = K$ (year^{-1}), $x_2 = L_\infty$ (cm), $x_3 = T$ (°C), a is y-intercept term, b_1, b_2 and b_3 are the slope parameters to be estimated.
Equation (2) $y = a + b_1x_1 + b_2x_2 + b_3x_3$, where $y = M$ (year^{-1}), $x_1 = K$ (year^{-1}), $x_2 = L_{max}$ (cm), $x_3 = T$ (°C), a is y-intercept term, b_1, b_2 and b_3 are the slope parameters to be estimated.
Equation (3) $y = a + b_1x_1 + b_2x_2$, where $y = K$ (year^{-1}), $x_1 = L_\infty$ (year^{-1}), $x_2 = T$ (°C), a is y-intercept term, b_1 and b_2 are the slope parameters to be estimated.
Equation (4) $y = a + b_1x_1 + b_2x_2$, where $y = K$ (year^{-1}), $x_1 = L_\infty$ (cm), $x_2 = T$ (°C), a is y-intercept term, b_1 and b_2 are the slope parameters to be estimated.
Equation (5) $y = a + b_1x_1 + b_2x_2$, where $y = K$ (year^{-1}), $x_1 = L_{max}$ (cm), $x_2 = T$ (°C), a is y-intercept term, b_1 and b_2 are the slope parameters to be estimated.
Equation (6) $y = a + b_1x_1$, where $y = K$ (year^{-1}), $x_1 = L_{max}$ (cm), a is y-intercept term, b_1 is the slope parameter to be estimated

RESULTS AND DISCUSSION

The obtained regression analysis of natural mortality and brody growth rate coefficient to asymptotic total length that the fish would reach if they were to grow indefinitely, temperature and maximum total length are summarized in Table 3. The obtained results show that M is significantly related to sea surface temperature (SST), von Bertalanffy growth parameters and also maximum total length. Moreover, K is significantly related to other von Bertalanffy growth parameter (L_∞) with and without sea surface temperature. However, K is not significantly related to L_{max} with and without SST.

Calculating empirically of *M* parameter: According to previous studies, M is linked to fish size such as L_∞, W_∞, L_{max} and K value (Taylor, 1958; Pauly, 1980; Gulland, 1987; Djabali *et al.*, 1993; Srinath, 1998; Then *et al.*, 2015). M correlates directly with T, this effect being added to the effect of T on K and L_∞. According to Pauly (1980), of the three variables which determine the value of M, K has the highest partial correlation with M and also temperature has a very marked effect on the estimates of M. Since the K parameter and also the L_∞ are directly depend on the activity and metabolism of fish influenced mostly by water temperature (Taylor, 1958; Pauly, 1980; Gulland, 1987; Djabali *et al.*, 1993; Srinath, 1998), it can be easily deduced that M is related to L_∞, L_{max}, K and T values. Our results showed that the calculated $r^2 > 0.87$ and P values < 0.05 regressionly and statistically appropriate for the empirical calculation of M (equation 1 and 2). Biological significance of these results are that if the K, L_∞ and/or L_{max} parameters and annual mean sea surface temperature (T, °C) are known, the M value can be empirically calculated using the equation 1 and 2. For this reason it was recommended to use following formulas for estimating M.

$M = 0.3237 + 1.3174*(K) - 0.0036*(L_\infty) - 0.0117*(T)$ (1)
$M = 0.2639 + 1.3676*(K) - 0.0003*(L_{max}) - 0.0124*(T)$ (2)

Calculating empirically of *K* parameter: As mentioned above, K value is directly related to water temperature due to its direct effect on fish activities and metabolism. As a natural consequence of this, the K value is associated with the size of the fish e.g. asymptotic total length, L_∞. Our results showed that the calculated R^2 and P values were statistically significant and regressionly acceptable. Empirically calculated K equation 3 and 4 were proved to be regressionly related with L_∞ and temperature (T). Because of these results, the K value can be calculated by equation 3 and 4 when the L_∞ and T values are available. The recommended formulas for estimating K as follows.

$K = 0.9760 - 0.0303*(L_\infty) - 0.0114*(T)$ (3)
$K = 0.8192 - 0.0311*(L_\infty)$ (4)

Taylor (1958) suggested that fish reach the end of their life span at 0.95* L_∞. So from here, the L_∞ itself is correlated highly with the length of the largest individuals known from a population inference can be made (Froese and Binohlan, 2000). Therefore, it has been reported that estimated L_∞ in a lightly and/or unexploited population should be more or less equal to the L_{max}. Since the data of this study is obtained from the exploited population (Bilgin, 2006; Bilgin *et al.*, 2016), it may not be right approach to consider that anchovy individuals reach the end of their life span at (0.95* L_∞). This is confirmed by the calculated empirical equations 5 and 6 (where L_{max} is substituted for L_∞ in the formula were not proved to be regressionly related with temperature and maximum total length) in the present study. The calculated formulas are as follows.

$K = 0.5566 + 0.0059*(L_{max}) - 0.0235*(T)$ (5)
$K = 0.1403 + 0.0104*(L_{max})$ (6)

It is well known that overfishing has played the most important role in many of the major decreasing of anchovy stocks and also global climate change can be thought to be other important key contributor to population variability in the Black Sea (Bilgin *et al.*, 2016). The most important influence factor on the growth of anchovy has been known as temperature (Bacha *et al.*, 2010; Gislason *et al.*, 2010). In the present study, empirical calculating of M and K of anchovy was suggested taking into account temperature.

Table 3. Results of regression analysis of natural mortality (*M*, year^{-1}) and brody growth rate coefficient (*K*, year^{-1}) to asymptotic total length (L_∞, cm), temperature (*T*,°C) and maximum total length (L_{max}, cm).

	Coefficients	Standard Error (S.E)	*P-values*	95% Confidence Limits of the Parameters	
		Empirical equation 1			
Intercept (a)	0.3237	0.32323	0.3315	-0.3615	1.0090
L_∞ (cm)	-0.0035	0.00838	0.6786	-0.0213	0.0142
K (yr^{-1})	1.3174	0.18057	***1.9E-06***	0.9347	1.7002
T (°C)	-0.0117	0.01820	0.5288	-0.0503	0.0269
$M = 0.3237 + 1.3174*(K) - 0.0036*(L_\infty) - 0.0117*(T)$ (1) ($R^2 = 0.8708$, n = 20, F = 35.9517, P = 2.4361E-07)					
		Empirical equation 2			
Intercept (a)	0.2639	0.37600	0.4928	-0.5332	1.0610
L_{max} (cm)	-0.0003	0.01085	0.9761	-0.0233	0.0227
K (yr^{-1})	1.3676	0.13782	***3.1E-08***	1.0754	1.6597
T (°C)	-0.0124	0.01921	0.5288	-0.0531	0.0284
$M = 0.2639 + 1.3676*(K) - 0.0003*(L_{max}) - 0.0124*(T)$ (2) ($R^2 = 0.8694$, n = 20, F = 35.4995, P = 2.65857E-07)					
		Empirical equation 3			
Intercept (a)	0.9760	0.3640	*0.0158*	0.2082	1.7439
T (°C)	-0.0114	0.0243	0.6457	-0.0626	0.0399
L_∞ (cm)	-0.0303	0.0085	0.0024	-0.0483	-0.0124
$K = 0.9760 - 0.0303*(L_\infty) - 0.0114*(T)$ (3) ($R^2 = 0.4606$, n = 20, F = 6.9727, P = 0.0061)					
		Empirical equation 4			
Intercept (a)	0.8192	0.13882	***1.4E-05***	0.5276	1.1109
L_∞ (cm)	-0.0311	0.00820	**0.0013**	-0.0483	-0.0138
$K = 0.8192 - 0.0311*(L_\infty)$ (4) ($R^2 = 0.4436$, n = 20, F = 14.3489 , P = 0.0013)					
		Empirical equation 5			
Intercept (a)	0.5566	0.6478	0.4021	-0.8100	1.9233
T (°C)	-0.0235	0.0333	0.4894	-0.0939	0.0468
L_{max} (cm)	0.0059	0.0190	0.7595	-0.0343	0.0461
$K = 0.5566 + 0.0059*(L_{max}) - 0.0235*(T)$ (5) ($R^2 = 0.04660$, n = 20, F = 0.4154, P = 0.6666)					
		Empirical equation 6			
Intercept (a)	0.1403	0.2653	0.6033	-0.4170	0.6976
L_{max} (cm)	0.0104	0.0177	0.5664	-0.0269	0.0476
$K = 0.1403 + 0.0104*(L_{max})$ (6) ($R^2 = 0.0186$, n = 20, F = 0.3412, P = 0.5664)					

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