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Population dynamics of the garfish, *Belone euxini* (Belonidae: Belone) from the south-east Black Sea

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To describe the age, growth, mortality and distribution of the garfish, Belone euxini *and differences in these parameters from other populations, monthly samplings were conducted between December 2011 and July 2013 in the south-east Black Sea. Garfish catch decreased to its lowest levels in spring months, especially after May, and it was completely finished by the summer months. The mean total length (TL) of the female was significantly greater than the mean TL of the male ($P < 0.05$). The sex-ratio of female:male with size was skewed towards males up to 38 cm length-class, and skewed towards females above the 38 cm class ($P < 0.05$). The growth pattern of garfish was described by goodness of fit of the data and biological interpretation of growth parameters. The exponential (females: $L_\infty = 88.3$ cm TL, $K = 0.108$ yr^{-1}, males: $L_\infty = 71.9$ cm TL, $K = 0.151$ yr^{-1}) and von Bertalanffy (females: $L_\infty = 81.6$ cm TL, $K = 0.125$ yr^{-1}, $t_o = -2.25$ year, males: $L_\infty = 81.6$ cm TL, $K = 0.125$ yr^{-1}, $t_o = -2.13$ year) models were considered the most suitable growth models. Total instantaneous mortality rate, Z, was estimated as 1.04 yr^{-1} for females and 1.24 yr^{-1} for males. Instantaneous natural mortality ratio, M, was estimated higher for males than for females. The exploitation rate of both sexes was also higher than the optimum exploitation ($E = 0.5$) criterion, which is indicative of overfishing of the garfish population.*

Keywords: *Belone euxini*, growth, mortality, population structure, fisheries management, Black Sea

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INTRODUCTION

There are four garfish species, *Belone acus* Risso, 1827, *Belone euxini* Günther, 1866, *Belone svetovidovi* Collette & Parin, 1970 and *Tylosurus imperialis* (Rafinesque-Schmaltz, 1810), belonging to the Belonidae family in the Turkish seas (Dalyan & Eryılmaz, 2006; Fricke *et al.*, 2007). In the Black Sea and the Sea of Azov the garfish species was reported in previous studies as *B. belone euxini* by several authors (Salekhova *et al.*, 1988; Zaitsev & Mamaev, 1997; Samsun *et al.*, 2006). *B.b. euxini* Günther, 1866 was also recognized by Collette & Parin (1970) from the Black Sea and Sea of Azov. Recently the endemic garfish species in the Black Sea, the Sea of Azov and the Sea of Marmara was reported as *B. euxini* by Fricke *et al.* (2007) and Froese & Pauly (2014).

Belone euxini reach sexual maturity at 2 yr and 38.8 cm total length and spawning occurs in the warmer period between May and September in the Black Sea (Samsun *et al.*, 2006). The absolute fecundity of this species was reported as 10,196 and 48,908 oocytes per ovary by Yüce (1975) and 8460 and 51,694 oocytes per ovary by Samsun *et al.* (2006). Garfish species are carnivorous, feeding mainly on small fish, mostly clupeids and crustaceans, especially crab larvae (Yüce, 1975; Dorman, 1988; Sever *et al.*, 2009). Females of *B. euxini* generally reach a longer length than males of the same age (Yüce, 1975; Samsun *et al.*, 2006). Garfish migrate into coastal waters depending on water temperature for spawning, and after the spawning they leave the coastal area and go back to deeper open sea (Dorman, 1989; Zorica *et al.*, 2011). They live at the surface and are caught by casting or trawling with surface or near surface lures and in floating gill nets (Nédélec, 1975; Collette, 2003). The garfish is one of the most commercial pelagic fish species in the Black Sea artisanal fishery in Turkey and in recent decades the average annual catch has been about 442.2 ± 34.12 tons (232–661 tons) (TUIK, 2001–2012).

The first detailed study of the biological properties of *B. belone*, such as meristic characteristics, diet, age and length compositions, spawning time and gonad maturity stages, was carried out by Dorman in Courtmacsherry Bay in Southern Ireland (Dorman, 1988, 1989) and at Strömstad on the west coast of Västervick in the Baltic Sea (Dorman, 1991). After the studies of Dorman, age, growth, mortality (Zorica & Keč, 2013) and reproduction biology of *B. belone* such as spawning time, size at sexual maturity and fecundity (Zorica *et al.*, 2011) were studied between January 2003 and December 2008 in the eastern part of the middle Adriatic Sea. Embryonic and larval development of *B. belone* was also studied under laboratory conditions (Dulčić *et al.*, 2009; Kužir *et al.*, 2009). Feeding habits and growth of *B. belone* on Turkey's Aegean Sea coasts was studied by Uçkun *et al.* (2004) and Sever *et al.* (2009). Previous research into *B. euxini* growth and reproduction has been rather fragmentary on the Anatolian coast of the Black Sea (Samsun *et al.*, 1995, 2006; Samsun, 1996; Polat *et al.*, 2009).

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The most common pattern of animal growth is that growth rates continually decrease with time until finally the organism reaches a steady state in adulthood (Von Bertalanffy, 1951). Various growth models have been proposed to explain the growth pattern of individuals for a particular species. Non-linear models, such as exponential, Richards, Gompertz, von Bertalanffy, Morgan–Mercer–Flodin (MMF), Weibull and Janoschek models are generally used to describe a particular species' growth pattern during its lifetime (Fitzhugh, 1976; Quinn & Deriso, 1999; Henderson & Seaby, 2006; Haddon, 2011). Among all the growth models, the von Bertalanffy model generally provides the best fit and adequately describes the growth of most fish species rarely follows a sigmoid or S-shaped curve (Fitzhugh, 1976; Quinn & Deriso, 1999; Henderson, 2006; Haddon, 2011). Growth pattern of some fish species, such as black Scorpionfish, *Scorpaena porcus* (Demirhan & Can, 2009), sharptail mola, *Masturus lanceolatus* (Liu *et al.*, 2009), whitebrow skate, *Bathyraja minispinosa* (Ainsley *et al.*, 2011), and Atlantic saury, *Scomberesox saurus saurus* (Agüera & Brophy, 2012) are described by different growth models due to goodness of fit of the data, species body shape, growth properties, biological interpretation of parameters and comparison difficulties (Fitzhugh, 1976).

Belone euxini is a long and slender fish species with a laterally compressed body shape. So the above mentioned growth models were applied to this species to obtain reliable and suitable growth parameters to calculate the mortality ratio. Moreover, the objective of the present study was to contribute information on the catch per unit effort, to provide new findings on age and growth of this species, and also to present some detailed estimation on the present rate of mortality, necessary for the introduction of suitable management plans for garfish small scale fisheries on the Anatolian coast of the Black Sea, and to assess the differences in these parameters in other populations in different geographical regions.

MATERIALS AND METHODS

Study area and sampling

Samplings were conducted monthly between December 2011 and July 2013 except for August from the Rize coasts, in the south-east Black Sea (Figure 1). To calculate catch per unit effort, 17 samplings were conducted some months by garfish encircling nets with 21 mm mesh size during the study (2011: two samplings in December; 2012: two samplings in January and October, one sampling each in February, September, November and December; 2013: two samplings in January and March, three samplings in February). In other months, garfish specimens were obtained from garfish fishermen fishing with commercial garfish encircling nets with 21, 22 and 23 mm mesh sizes. In the warmer period (e.g. May, June and July) there is no garfish fishing due to the absence of schools in the study area (personal observations). Furthermore, because of the fact that the commercial garfish fishing was completely finished in the summer months in the study area, garfish specimens in May 2012 and May, June and July 2013 were obtained from fisheries for red mullet and whiting using bottom set trammel nets.

Catch per unit effort (CPUE)

When a garfish school was seen, the garfish encircling nets were settled around the garfish school and than encircled garfish specimens were frightened and directed into the nets by entering into encircled nets with the fishing boat. Later garfish encircling nets were taken to the boat and the individual garfish specimens and time spent in searching and catching of garfish were recorded to calculate the catch per unit effort (CPUE; individuals/km × h) for garfish (Erkoyuncu, 1995):

$$\mathrm{CPUE} = \frac{n}{\mathrm{NL} \times t}$$

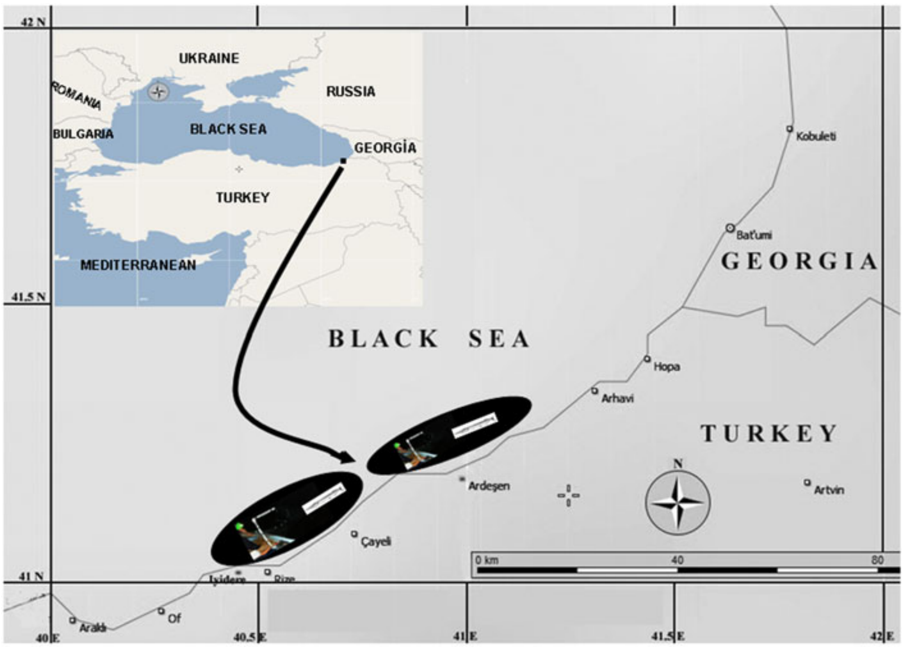

Fig. 1. Study site off Rize coast, Black Sea. Shaded areas indicate the sampling sites.

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where, n = number of caught fish, NL = length of garfish encircling nets (km), t = time spent in searching and catching of garfish (h).

A total of 1211 garfish specimens (618 female and 593 male) were taken to the laboratory and were measured (total length (TL)), weighed and sexed. The TL of each garfish was measured with a sensitivity of 1 mm. Specimens were weighed (wet weight) on a balance with a sensitivity of 0.001 g. Each pair of sagittal otoliths were also removed and stored in plastic Eppendorf tubes for aging.

Age determination

To obtain reliable results for reading sagittal otolith rings (hyaline and opaque zone), four different attempts were made on the sagittal otoliths of 50 fish of different length. Firstly, otoliths were cleaned with distilled water and ethanol 96% and read under the stereomicroscope. Secondly, the cleaned otoliths were placed in an oven for between 15 and 30 min at between 125 and 200°C. Afterwards the otoliths were cooled and rubbed with 96% ethanol and read under the stereomicroscope. Thirdly, the otoliths were cleaned with ethanol 96% and cut with a scalpel latitudinally, and burned with an alcohol flame and later read under the stereomicroscope. Finally, the otoliths were cleaned with distilled water, ethanol 96% and NaOH 4% (for 5–15 min) and read under the stereomicroscope. Thick otoliths were lightly abraded on sand paper for the growth rings to be clearly visible. False rings, hyaline and opaque zones of sagittal otoliths were the most visible and countable in the last attempt. The number of hyaline and opaque zones on the concave side of sagittal otoliths was counted using a Nikon SMZ1000 stereomicroscope at a magnification between ×0.8 and ×8.0, interfaced with a Nikon DSFI1 digital camera connected to a computer, using reflected light. We took into account the number of rings, the sampling date, the ring creation and the spawning period as between May and July (unpublished data). A total of 924 fish sagittal otoliths ring readings were successfully performed at two separate times.

Growth

SIZE–FREQUENCY

Monthly size–frequency distributions for both sexes were calculated as 2 cm total length-class intervals. Size–frequency distribution analysis for females and males was conducted using the Kolmogorov–Smirnov two-sample test. Comparison of the mean total length between female and male was performed using t-test. Statistical analyses were considered significantly different at the level of $\alpha = 0.05$.

LENGTH–WEIGHT RELATIONSHIP

Least squares regression analysis with MS Excel software was used to calculate the length–weight relationship parameters. The length–weight relationship was estimated as:

$$W = a\,\mathrm{TL}^b$$

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.

For comparison of the difference of slope value from $b = 3$ both female and male, Pauly's t-test was performed (Pauly, 1984). Pauly's t-test statistic was calculated as:

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

where $\mathrm{Sd}_{\log\mathrm{TL}}$ is the standard deviation of the log TL values, $\mathrm{Sd}_{\log W}$ is the standard deviation of the log W values, n is the number of garfish used in the computation. The value of b is different from $b = 3$ if t value is greater than the tabled t values for $n - 2$ degrees of freedom (Pauly, 1984).

The sex-ratio of the garfish was analysed using a χ^2 test. A least significant difference (LSD) test was applied for comparison of total length and month for females and males.

GROWTH MODELS

To obtain reliable estimates of garfish growth curve parameters, seven growth models (Gompertz, logistic or Richards curve, Janoschek, exponential, Morgan–Mercer–Flodin (MMF), von Bertalanffy and Weibull) were applied for females and males separately. The formulations of the models were as follows:

$$L_t = L_\infty e^{e^{-k(t-I)}}\text{: (Gompertz (1825, 1832))}$$

$$L_t = \frac{L_\infty}{1+e^{-k(t-I)}}\text{: (logistic or Richards curve (Richards, 1959))}$$

$$L_t = L_\infty - (L_\infty - \beta)e^{(-kt^\delta)}\text{: (Janoschek (1957))}$$

$$L_t = L_\infty - (L_\infty - \beta)e^{(-(kt))}\text{: exponential (Everhart et al., 1975)}$$

$$L_t = L_\infty - \frac{L_\infty - \beta}{1+(kt)^\delta}\text{: (Morgan–Mercer–Flodin (MMF) (Morgan et al., 1975))}$$

$$t = \left[\frac{\delta - 1}{\delta + 1}\right]^{1/\delta}\text{: (the point of inflection of MMM equation)}$$

$$L_t = L_\infty(1 - e^{-K(t-t_o)})\text{: (von Bertalanffy (1938))}$$

$$L_t = L_\infty - (L_\infty - \beta)e^{(-(kt)^\delta)}\text{: (Weibull (1951))}$$

$$\left(\frac{1}{K}\right)\left(\frac{\delta - 1}{\delta}\right)^{1/\delta}\text{: (the point of inflection of MMM equation of Weibull)}$$

where, t is time (age), L_t is length at age t, L_∞ is the upper asymptotic total length to which the garfish grows (cm), K = the growth rate parameter (yr^{-1}), t_o is the nominal age at which the length is zero, I is the age at the inflection point (as I increases in magnitude, the curve moves to the right), β is the lower asymptotic total length (cm), δ is a parameter that controls the x-ordinate (time, age) for the point of inflection.

Analysis of growth models parameters were fitted to age length data using the Growth-II (Pisces Conservation Ltd, Lymington, UK) procedure in the PC-based computer package (Henderson & Seaby, 2006). Growth-II is designed by Henderson & Seaby (2006) to fit a variety of common growth curves to data. Growth-II offers a measure of the suitability of a model as a fit for data. The Akaike information criterion (AIC) (Akaike, 1974) is a measure to help in the selection between candidate models. Using this criterion, the best model is the one with the lowest AIC results. This criterion takes into account both the closeness of fit of the points to the model and the number of parameters used by the model (Henderson & Seaby, 2006). AIC was calculated as:

$$\mathrm{AIC} = N \log(\mathrm{WSS}) + 2M,$$

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where N is the number of data points, WSS is the weighted sum of squares of residuals, and M is the number of model parameters. WSS was calculated as:

$$\mathrm{WSS} = \sum_{i=1}^{i=n} \frac{1}{\mathrm{SD}_i^2} (Y_{\mathrm{obs},i} - Y_{\mathrm{calculated},i})^2,$$

where SD = standard deviations was estimated for the mean size at age.

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 was computed as:

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

Mortality

Total instantaneous mortality rate, Z, was estimated using the catch curve method for both sexes (Pauly, 1984). Catch curve analysis assumes that the decrease in observed numbers of individuals across the age structure of the population is the result only of mortality. The calculated Z is the slope (b) of the fitted regression line plotted to log-transformed numbers at age t. Catch curve (Pauly, 1984) was used to estimate Z as:

$$\ln(N_t) = a + bt$$

where N_t is the frequency in age-class t, t is the age, a is the intercept and b is the slope corresponding to Z with the sign changed. The Z values were estimated from the right side of the linearized catch curve based on age composition without extreme age groups are not fully recruited. Moreover, male' age 6 was only one individual indicated that natural logarithm of the number of fish in age group 6 was equal to zero, and so between 2 and 5 age groups were used for Z estimation for male.

Garfish growth pattern was analysed by seven mathematical growth models to obtain the most accurate L_∞ and K parameters and then to calculate the M rate which required L_∞ and K as input of growth model. To obtain reliable estimates of the instantaneous natural mortality rate, M, four empirical equations of Pauly (1980), Djabali *et al.* (1993), Alagaraja (1984) and Srinath (1998) were applied:

$$\log M = 0.8(-0.0066 - 0.279 \log \mathrm{TL}_\infty + 0.6543 \log K + 0.4634 \log T) \text{ (Pauly, 1980)}$$

$$\log M = 0.8(-0.736 - 0.114 \log \mathrm{TL}_\infty + 0.522 \log K + 0.583 \log T) \text{ (Djabali et al., 1993)}$$

$$M = 1.680\,K \text{ (Srinath, 1998)}$$

$$M = 1.535\,K \text{ (Alagaraja, 1984)}$$

where T is the mean annual surface water temperature (T) of 15°C at the study area (Bat *et al.*, 2007), K = the growth rate parameter (yr^{-1}) and TL_∞ is the asymptotic total length (cm) to which the garfish grow. This empirical equation assumes that the length is measured as total length (TL) in cm (Gayanilo *et al.*, 2005).

Fishing mortality rate, F, estimated by subtracting instantaneous natural mortality, M, rates (obtained from empirical equations of Pauly (1980), Djabali *et al.* (1993), Alagaraja (1984) and Srinath (1998)) from the total instantaneous mortality rate (Z). Fishing mortality rate, F, was estimated as:

$$F = Z - M.$$

The rate of exploitation, E, was estimated from Ricker (1975) as:

$$E = F/Z.$$

Fishing mortality rate, instantaneous natural mortality rate and exploitation rate were calculated according to input parameters (e.g. L_∞ and K) of seven growth models parameters for females and males, separately.

RESULTS

Population structure

From the 17 fishing surveys a total of 1828 individual garfish weighing a total of 89.4 kg were caught by garfish encircling nets. Garfish specimens were not obtained in two surveys in December 2011. Monthly CPUE values showed that garfish are fished only in winter and autumn seasons. Mean CPUE (individuals/km × h) value was calculated as 13.7 ± 8.1 with a peak of 66.9 and 65.1 in February and November, respectively (Figure 2). It was recognized that garfish catch falls to the lowest levels in spring, especially after May, and was completely finished by the summer months in the study area.

Length structure

A total of 1211 garfish (618 female, 593 male) were examined between January 2012 and July 2013. The total length of females ranged between 24.7 and 65.1 cm (mean 39.10 ± 0.248 cm) and the total length of males ranged between 22.2 and 55.3 cm (mean 35.2 ± 0.209 cm). The mean total length of females was significantly (t-test: $P = 9.41 \times 10^{-31}$) greater than the mean total length of males. Size–frequency distributions were also significantly different (Kolmogorov–Smirnov two-sample test: $d = 0.29178$, $P = 3.95 \times 10^{-23}$) between females and males. Looking at the overall size–frequency distribution (Figure 3), the dominant length interval was found to be 36–44 cm for females (32.3%) and 32–40 cm for males (35.0%).

Monthly distribution of the total length of collected garfish females and males is illustrated in Figure 4. Monthly length frequency distribution shows that the amount of the garfish under the size of sexual maturity calculated from our available data (unpublished data: 33.3 cm TL for males and 34.4 cm for females) was found to be important (about 25%), especially for those fish captured in two periods, firstly between February and March and secondly between June and July, indicating groups of small individuals were to be found in the study areas (Figure 4).

The fluctuation of the sex-ratio of females:males with size is shown in Figure 5. The overall female:male ratio (1.04) of garfish is skewed towards females ($\chi^2 = 603.6755$, $P < 0.001$). Moreover, female:male ratio (0.67) with size was towards males up to 38 cm length-class ($\chi^2 = 457.1833$, $P < 0.001$). In individuals greater than 38 cm, the female:male

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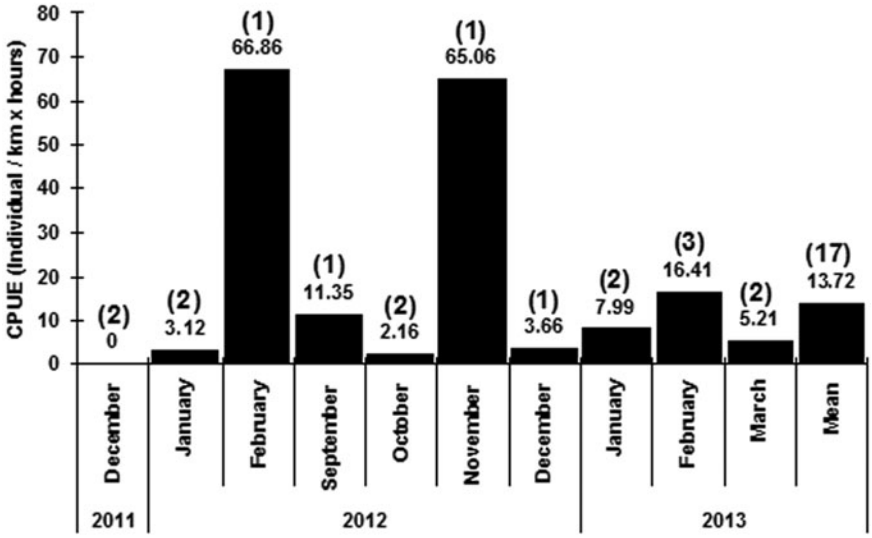

Fig. 2. Monthly catch per unit efforts (CPUE) of *Belone euxini* off Rize coast, Black Sea. The number in parentheses is the number of sampling.

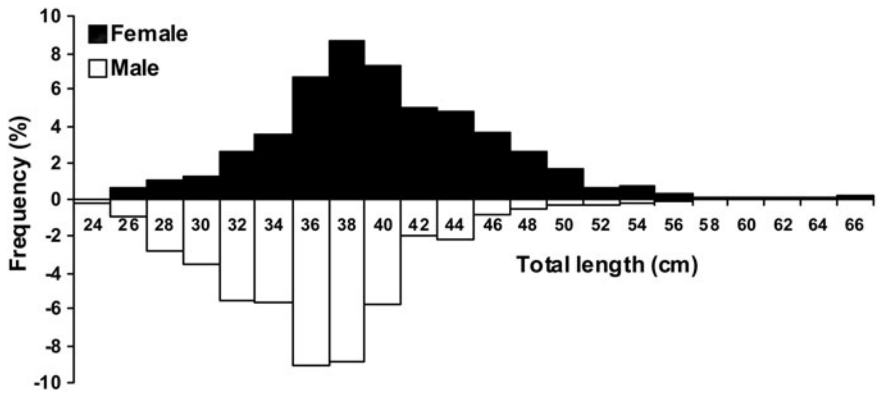

Fig. 3. Length–frequency distribution (%) of females and males of *Belone euxini* between February 2002 and January 2004.

ratio (3.08) was this time skewed towards females ($\chi^2 = 191.6688$, $P < 0.001$). Moreover, monthly sex-ratio of females: males was found to be biased towards females, except in February (0.59; $\chi^2 = 61.630$), September (0.60; $\chi^2 = 43.895$), October (0.77; $\chi^2 = 117.383$), December (0.90; $\chi^2 = 54.379$) 2012 and February (0.61; $\chi^2 = 83.076$) and March (0.83; $\chi^2 = 40.745$) 2013.

Length–weight relationship

The length–weight relationships for female and male were estimated as follows:

Female: $W = 0.0005\text{TL}^{3.1802}$ ($r^2 = 0.9208$, $n = 618$, $\text{Sd}_{\log\ \text{TL}} = 0.0678$, $\text{Sd}_{\log W} = 0.2248$, $P < 0.05$)
Male: $W = 0.0007\text{TL}^{3.0904}$ ($r^2 = 0.8967$, $n = 593$, $\text{Sd}_{\log\ \text{TL}} = 0.0628$, $\text{Sd}_{\log W} = 0.2048$, $P < 0.05$)

The slope of the length–weight relationship regression lines for females (Pauly's *t* test = 4.794) and males (Pauly's *t* test = 2.095) were significantly different from the isometric growth curve slope ($P < 0.05$). These results show that both females and males have positive allometric growth characteristics.

Age composition

Of the 1211 total garfish specimens, 287 specimens were discarded due to deformation and amorphous structure of otoliths and unclear age reading. Successful age determination was achieved on a total of 924 garfish otoliths (478 female and 446 male). The age–length key for both sexes is shown in Table 1. Total lengths of aged specimens ranged from 24.7 to 61.1 cm (mean: 39.3 ± 0.28 cm) for females and from 22.2 to 53.4 cm (mean: 35.4 ± 0.25 cm) for males. The age range estimated was up to 7 yr for both females and males. The dominant age group was 3 yr for females (17.5%) and 2 yr for males (20.2%). Aged specimens of both sexes showed an approximately 85% ratio between 2 and 4 yr age groups for both females (44.1%) and males (40.7%) (Figure 6).

Growth models

Growth parameters estimated by different models for females and males are shown in Table 2. According to the AIC, the exponential and von Bertalanffy curve attained a better fit of the data than the other models in females, and these models are considered as the most suitable growth models for

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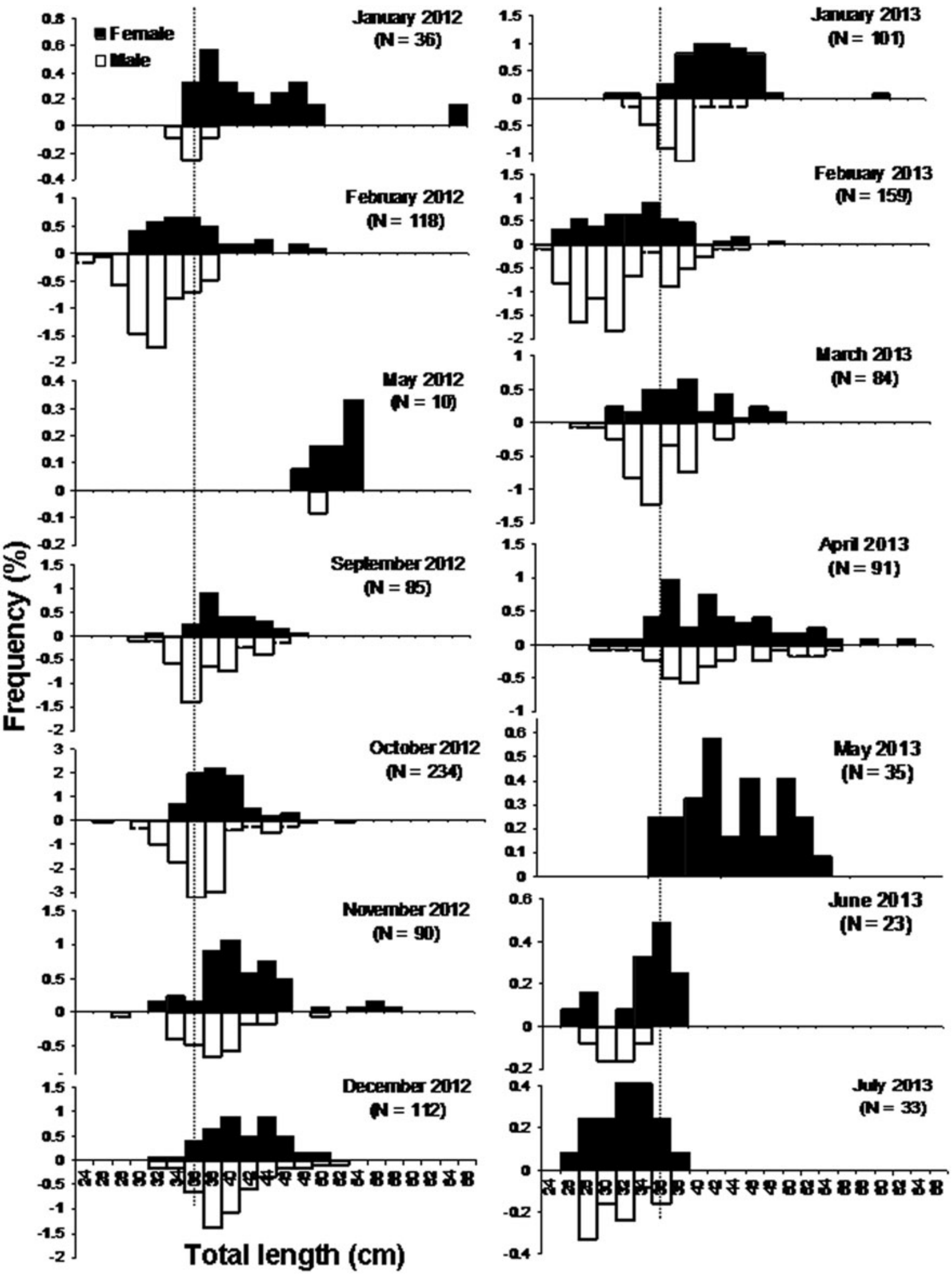

Fig. 4. Monthly length–frequency distribution (%) of female and male of *Belone euxini* between January 2012 and July 2013. Dotted line at 35 cm drawn to illustrate recruitment of immature and small individuals to the population.

females (Figure 7). On the other hand, the results of the growth model AIC values for males were fairly similar to each other, and a 'best' model was not selected.

According to the growth models the asymptotic length (L_∞) of females was estimated higher than males, and the L_∞ varied between 64.1 and 158.6 cm for females and between 57.3 and 73.8 cm for males. The L_∞ values of females were also estimated to be higher than male except by the Richards model. Moreover, the growth rate (K) of males derived from different models was estimated higher than females. The K values ranged between 0.0478 and 0.3561 yr^{-1} for females and between 0.1447 and 0.4181 yr^{-1} for males.

The age at inflection point of the growth curve (I) was estimated as 1.7 yr by the Richards model and 0.6 yr by the

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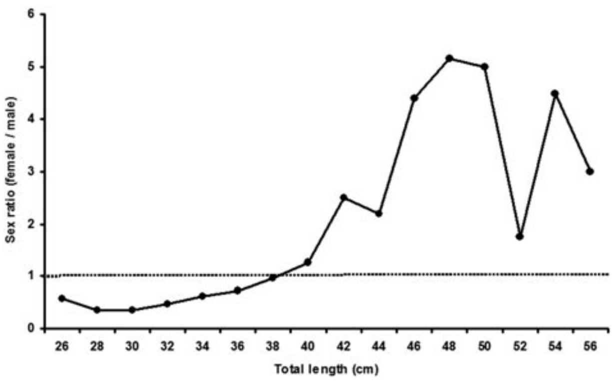

Fig. 5. Sex-ratio (female:male) fluctuation of *Belone euxini*. Dotted line at 1 drawn to illustrate 1:1 sex-ratio.

Gompertz model for females. For males, *I* was estimated as 1.2 yr by the Richards model and 0.3 yr by the Gompertz model. Therefore, the parameter that controls the point of the growth curve (δ) was estimated as 0.8 yr by the Weibull model and 0.9 yr by both the Janoschek and Morgan–Mercer–Flodin models for females. For males δ was estimated as 1.4 yr by the Morgan–Mercer–Flodin model and 1.3 yr by both the Janoschek and Weibull models. Besides all these, exponential and von Bertalanffy growth models selected more biologically suitable models to characterize growth of both sexes of garfish.

Growth performance index, Φ′, derived from seven growth methods was ranged between 2.92 and 3.17 and had a mean of 3.02 ± 0.04 for females. For males Φ′ ranged between 2.70 and 3.14 and had a mean of 2.94 ± 0.05.

Mortality

The linearized catch curve based on age composition data showed a recruitment age for the garfish fishery of 3 yr for females and 2 yr for males. Males age 1 and females age 1 and 2 were excluded from the regression line as they were not fully recruited (Figure 8). From this regression, *Z* was estimated as 1.04 yr^{-1} for females and 1.24 yr^{-1} for males.

Estimated mean instantaneous natural mortality ratio was higher for males than for females obtained by four empirical equations of Pauly (1980), Djabali *et al.* (1993), Alagaraja (1984) and Srinath (1998), which required L_∞ and *K* as

Table 1. Age–length key of both female and male of *Belone euxini*, in the Black Sea.

Length (cm)	Age														
	Female							Male							
	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	All
23								1							1
24								2							2
25	1							1							2
26	6							9							15
27	7							20							27
28	5							14							19
29	2	2						8	9						21
30	3	5						6	9						23
31		18						1	19						38
32		9							21						30
33		13							20						33
34		14	1						32						47
35		24	5						27	6					62
36		17	7						23	12					59
37		19	15						15	15					64
38		8	23						12	32					75
39		1	34							39					74
40			29							25					54
41			12	3						7					22
42			23	9						10	4				46
43			8	9						8	3				28
44			5	35						1	13				54
45				21							7				28
46				20	1						2				23
47				8	2						3				13
48				6	12						1	1	1		21
49				3	8						1			1	13
50				1	7							2			10
51					2	2						2			6
52					1	1									2
53						2									2
54					1	4	1							1	7
56						1	1								2
62							1								1
All	24	130	162	115	34	10	3	62	187	155	34	5	1	2	924

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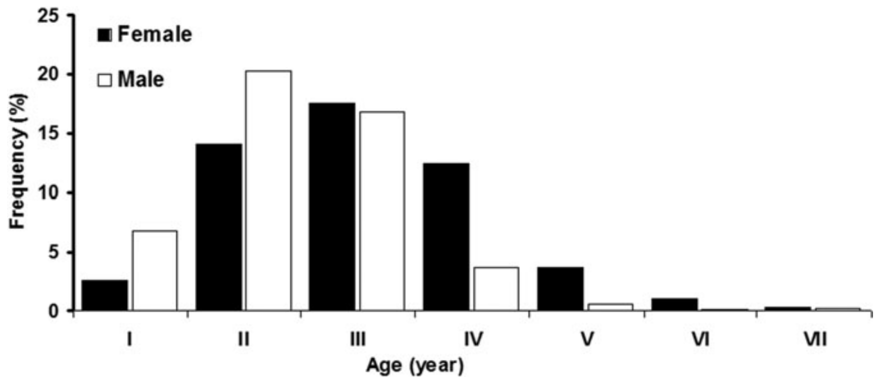

Fig. 6. Age–frequency distribution (%) of female and male *Belone euxini*.

Table 2. Results of growth models parameters, Akaike information criterion (AIC) and growth performance index. L_∞=the upper asymptote, K = the growth rate, t_o = the time when L = 0, b = lower asymptote (the size at t = 0), I = the age at the inflection point, b = lower asymptote (the size at t = 0), δ = a parameter that controls the point of inflection (as d decreases in magnitude, the point of inflection moves to the right and the curve becomes less steep), Φ′ = growth performance index.

Growth models	L_∞ (cm)	K (yr^{-1})	t_o (yr)	β (cm)	I (yr)	δ (yr)	AIC	Φ′
Female								
Gompertz	68.0	0.2495			0.626		3658.45	3.06
Richards	64.1	0.3561			1.744		3660.31	3.17
Janoschek	106.6	0.0975		19.130		0.896	3656.87	3.04
Exponential	88.3	0.1075		20.471			3655.52	2.92
MMF	158.6	0.0478		19.361		0.925	3656.87	3.08
VBGF	81.6	0.1248	−2.245				3656.12	2.92
Weibull	127.3	0.0527		18.508		0.843	3656.7	2.93
Male								
Gompertz	62.1	0.2804			0.340		3399.22	3.03
Richards	57.3	0.4181			1.244		3398.06	3.14
Janoschek	58.9	0.1447		22.231		1.292	3400.91	2.70
Exponential	71.9	0.1508		19.714			3400.48	2.89
MMF	73.8	0.1921		22.325		1.376	3402.07	3.02
VBGF	71.9	0.1507	−2.127				3400.48	2.89
Weibull	58.9	0.2240		22.231		1.292	3400.91	2.89

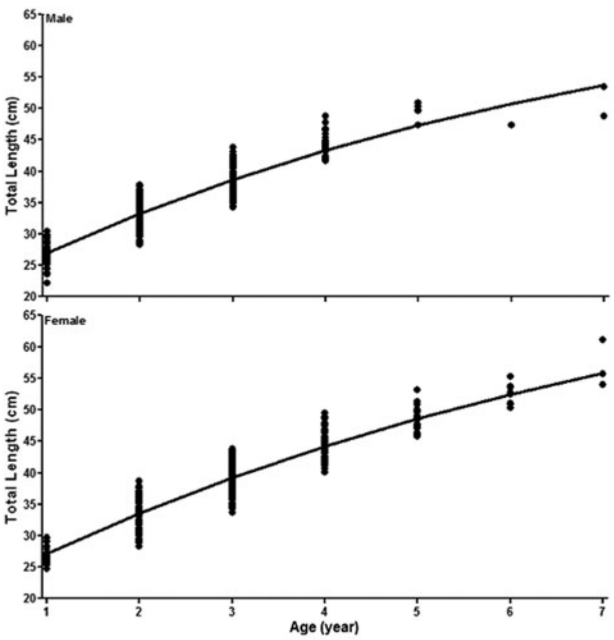

Fig. 7. The von Bertalanffy growth curves for female and male *Belone euxini*.

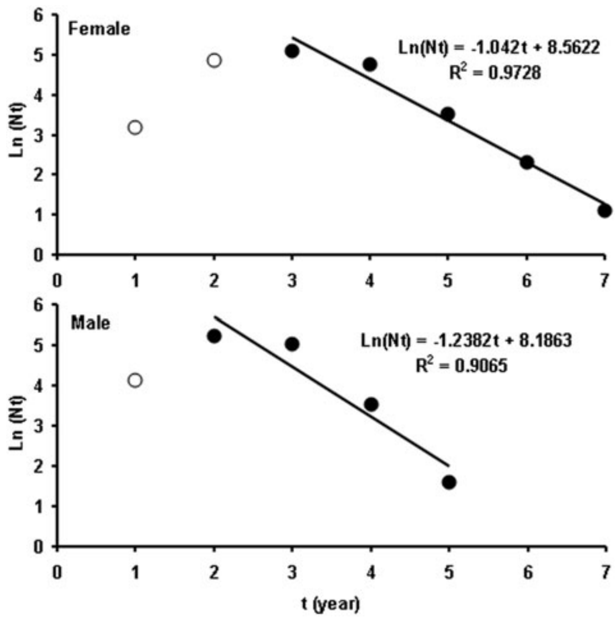

Fig. 8. Linearized catch curve based on age composition showing the recruitment age for female at 3 yr old and for male at 2 yr old and obtained regression equation.

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Table 3. Four empirical instantaneous natural mortality ratio, *M*, results obtained from results of different growth models input parameters for female and male.

Growth models	Input parameters						
	L_∞ (cm)	K (yr^{-1})	Pauly (1980)	Djabali *et al.* (1993)	Srinath (1998)	Alagaraja (1984)	$\bar{M}\pm$standard error (SE)
Female							
Exponential	88.3	0.108	0.31	0.24	0.18	0.17	0.22 ± 0.03
Gompertz	68	0.250	0.51	0.35	0.42	0.38	0.41 ± 0.04
Janoschek	106.6	0.098	0.28	0.23	0.16	0.15	0.20 ± 0.03
Richards	64.1	0.356	0.62	0.41	0.60	0.55	0.54 ± 0.05
MMF	158.6	0.048	0.18	0.16	0.08	0.07	0.12 ± 0.03
VBGF	81.6	0.125	0.34	0.26	0.21	0.19	0.25 ± 0.03
Weibull	127.3	0.053	0.20	0.17	0.09	0.08	0.13 ± 0.03
		$\bar{M}\pm$SE	0.35 ± 0.06	0.26 ± 0.03	0.25 ± 0.07	0.23 ± 0.07	
Male							
Exponential	71.9	0.151	0.39	0.28	0.25	0.23	0.29 ± 0.03
Gompertz	62.1	0.280	0.55	0.37	0.47	0.43	0.46 ± 0.04
Janoschek	58.9	0.145	0.39	0.28	0.24	0.22	0.29 ± 0.04
Richards	57.3	0.418	0.69	0.44	0.70	0.64	0.62 ± 0.06
MMF	73.8	0.192	0.44	0.31	0.32	0.29	0.34 ± 0.03
VBGF	71.9	0.151	0.39	0.28	0.25	0.23	0.29 ± 0.03
Weibull	58.9	0.224	0.50	0.34	0.38	0.34	0.39 ± 0.04
		$\bar{M}\pm$SE	0.48 ± 0.04	0.33 ± 0.02	0.37 ± 0.06	0.34 ± 0.06	

Table 4. Exploration ratio, *E*, results obtained from results of seven growth models and four empirical natural mortality rates for female and male.

Growth model	Pauly (1980)	Djabali *et al.* (1993)	Srinath (1998)	Alagaraja (1984)	$\bar{E}\pm$standard error (SE)
Female					
Exponential	0.70	0.77	0.83	0.84	0.79 ± 0.03
Gompertz	0.51	0.67	0.60	0.63	0.60 ± 0.03
Janoschek	0.73	0.78	0.84	0.86	0.80 ± 0.03
Richards	0.40	0.61	0.43	0.47	0.48 ± 0.04
MMF	0.83	0.85	0.92	0.93	0.88 ± 0.02
VBGF	0.67	0.75	0.80	0.82	0.76 ± 0.03
Weibull	0.81	0.84	0.92	0.92	0.87 ± 0.02
$\bar{E}\pm$SE	0.67 ± 0.06	0.75 ± 0.03	0.76 ± 0.07	0.78 ± 0.06	
Male					
Exponential	0.69	0.77	0.80	0.81	0.77 ± 0.02
Gompertz	0.55	0.70	0.62	0.65	0.63 ± 0.03
Janoschek	0.68	0.77	0.80	0.82	0.77 ± 0.03
Richards	0.44	0.65	0.43	0.48	0.50 ± 0.04
MMF	0.65	0.75	0.74	0.76	0.73 ± 0.02
VBGF	0.69	0.77	0.80	0.81	0.77 ± 0.02
Weibull	0.60	0.73	0.70	0.72	0.69 ± 0.03
$\bar{E}\pm$SE	0.61 ± 0.04	0.74 ± 0.02	0.70 ± 0.05	0.72 ± 0.05	

input for seven growth modes (Table 3). Moreover, mean exploitation ratio, which required *F* and *Z* as input derived from each empirical natural mortality ratio which calculated input parameters of seven growth models, was lower for males than for females (Table 4). The exploitation rate of the both sexes was also higher than the optimum exploitation ($E = 0.5$) criterion (Gulland, 1971), which is indicative of overfishing in the garfish population.

DISCUSSION

Population structure

There are seasonal fluctuations in abundance in the *B. euxini* population in the south-east Black Sea coastal area. The highest catches occurred in the autumn (November) and winter (February). Garfish abundance decreased to its lowest levels in the spring months, especially after May, and it was completely finished by the summer months, which is similar to the observations of Dorman (1989). This is also a general characteristic of garfish small scale fisheries in the Black Sea (personal observation).

Length composition

Our data showed a larger length range than previous studies conducted in the Black Sea (Samsun *et al.*, 1995, 2006; Samsun, 1996), Aegean Sea (Uçkun *et al.*, 2004) and Mediterranean (Fehri-Bedoui & Gharbi, 2004; Ghailen *et al.*, 2010) but the length range was lower than the Adriatic Sea (Dulčić & Soldo, 2006; Zorica & Keč, 2013). While the largest individual of *B. euxini* determined in the present study was 65.1 cm total length in the Black Sea, 103.5 cm is the greatest length ever reported to date (Dulčić & Soldo, 2006), and 75.4 cm (Zorica & Keč, 2013) for *B. belone* in the Adriatic Sea. The differences of length composition between various geographical regions and within regions may be due to different strength of the year-class, different mortality rates and growth. Warm and calm seawater conditions in summer months, protection from predators and quality and quantity of the amount of prey of garfish (e.g. Dorman (1988) reported that postlarval garfish feed on small neustonic organisms, particularly copepods and crustaceans, especially crab larvae, and juvenile fish, mostly clupeids were also dominant in the diet of adults) affects positively the survival of juveniles and hence the strength of the garfish year class and growth should be effected (Dorman, 1989).

Monthly length–frequency distribution shows that small and under the size at sexual maturity individuals at ages 1 and 2 yr mostly appeared in samplings in February 2012, February and March 2013 and June and July 2013, which may imply hatching in June or July 2010, 2011, 2012, respectively. Gürcan (2012) reported 10 mm total length garfish larvae as being first found in June 2012 off the Sinop coast in the Black Sea. Dorman (1989) also reported that garfish spawning occurred in June, and juveniles reached about 34 mm total length one month later, and by the end of August young garfish reached about 15 cm total length in the Courtmacsherry Bay. This rapid growth rate of garfish continues into the second year, but slows in the third, associated with the size at sexual maturity (Dorman, 1989).

Sex-ratio

Sex-ratio and size of *B. euxini* implies that males are dominant at lower size up to 38 cm total length-classes, while sex-ratio was towards female after 38 cm total length. Similar difference in sex-ratio and size was reported for *B. belone* in the eastern part of the middle Adriatic Sea (Zorica *et al.*, 2011) and from Strömstad on the west coast to Västervick in the Baltic Sea (Dorman, 1991). The sex-ratio and changed size of *B. euxini* is the same with *B. belone* reported from the Adriatic Sea. We agree with the exploration of Zorica *et al.* (2011) on the probable reasons of garfish sex ratio fluctuation at size, e.g. sexual dimorphism in size, gear selectivity, sampling strategies and spawning migrations. Moreover, monthly fluctuation of sex-ratio of *B. euxini* may be complicated by differential sex mortality rates and migration patterns. Namely, garfish migrate into the coastal area depending on water temperature in summer months for the purpose of spawning (Dorman, 1989; Zorica & Keč, 2013).

Age and growth

Comparisons of mean length at age of garfish obtained from previous studies are shown in Table 5. Zero year old of garfish have not been reported so far, so it is not known what length is attained in the early stages of life (Table 5). This may be most probably due to fishing gears selectivity. *Belone euxini* specimens attained age very fast in the first year, being approximately 50% of their ultimate total length, and a similar fast growth property was obtained from early study for garfish populations in the Black Sea (Polat *et al.*, 2009), although this growth property for *B. belone* was relatively lower (about 35%) in the Adriatic Sea (Zorica & Keč, 2013).

Fisheries assessments are generally based upon mathematical models of the production processes and the populations being fished (Haddon, 2011). Mean total length and length–frequency distribution between females and males are statistically different, and so growth parameters were estimated for both sexes separately. The AIC value is a useable tool to choose a growth model among candidate growth models which is best supported by the data (Henderson & Seaby, 2006). Moreover, to obtain biologically sensible interpretations concerning how a fish grows from a model, then model selection cannot solely depend upon the quality of statistical fit of the data. The suitable growth model selection should be also based on the fish biology and reflect the

Table 5. Comparison of mean total length at age of garfish species obtained from other populations of the different geographical localities.

Study	Locality	Species	Sex	Mean length at age (cm)							
				I	II	III	IV	V	VI	VII	VIII
Zorica & Keč (2013)	Adriatic Sea	*B. belone*	♀			36	43.4	50.4	55.5	61.4	67.8
Zorica & Keč (2013)	Adriatic Sea	*B. belone*	♂		29.3	34.6	43.3	48.4	53.3	58.4	
Zorica & Keč (2013)	Adriatic Sea	*B. belone*	♀ + ♂	23.3	28.3	34.6	43.2	49.5	55	60.7	67.8
Fehri-Bedoui & Gharbi (2004)	Mediterranean	*B. belone*	♀ + ♂	21.5	25.6	28.5	32.2	35.6	38.1	40.9	
Uçkun *et al.* (2004)*	Aegean Sea	*B. belone*	♀ + ♂	27.6	35	40.5	44.7	48.9			
Yüce (1975)*	Bosporus	*B. euxini*	♀	34.6	37.9	42.2	46.8	51.6	55.9		
Yüce (1975)*	Bosporus	*B. euxini*	♂	34.3	37.8	39.9	41.6	47.4	49.2		
Yüce (1975)*	Bosporus	*B. euxini*	♀ + ♂	34.4	37.7	40.6	44.2	49.5	52.6		
Samsun *et al.* (1995)	Black Sea	*B. euxini*	♀ + ♂	36.2	40.3	45.0	48.5	50.5			
Samsun (1996)	Black Sea	*B. euxini*	♀ + ♂	34.1	40.1	44.3	48.2	50.0	50.9		
Samsun *et al.* (2006)	Black Sea	*B. euxini*	♀	34	39	43.6	47.7	49.3	53.9		
Samsun *et al.* (2006)	Black Sea	*B. euxini*	♂	33.6	38	43.1	46.2				
Samsun *et al.* (2006)	Black Sea	*B. euxini*	♀ + ♂	33.9	38.7	43.5	47.7	49.3	53.9		
Polat *et al.* (2009)*	Black Sea	*B. euxini*	♀ + ♂	24.3	34.7	41.2	49	57.2			
Present study	Black Sea	*B. euxini*	♀	27.0	33.8	39.0	44.3	48.5	52.8	56.9	
Present study	Black Sea	*B. euxini*	♂	27.0	33.4	38.4	44.0	49.6	47.4	51.1	
Present study	Black Sea	*B. euxini*	♀ + ♂	27.0	33.5	38.7	44.2	48.6	52.3	54.6	

*, studies measured size as fork length.

Table 6. Comparison of von Bertalanffy growth curve parameters, growth performance index (φ′), size range and slope of the length–weight regression line (*b*) of garfish obtained from other populations of the different locality. L_∞ is the upper asymptotic total length to which the garfish growth (cm), K = the growth rate parameter (yr^{-1}), t_o is the nominal age at which the total length is zero.

Study	Locality	Sex	$L_{min-max}$ (cm)	$L_{mean \pm SE}$ (cm)	*b*	L_∞	*K*	t_o	φ′
Zorica & Keč (2013)	Adriatic Sea, southern Croatia	♀	27.2–75.4	43.6 ± 0.26	3.470	89.5	0.166	−0.063	3.124
Zorica & Keč (2013)	Adriatic Sea, southern Croatia	♂	27.7–62.6	37.4 ± 0.16	3.638	85.2	0.159	−0.322	3.062
Zorica & Keč (2013)	Adriatic Sea, southern Croatia	♀ + ♂	20.8–75.4	38.3 ± 0.14	3.482	90.3	0.158	−0.109	3.110
Dulčić & Soldo (2006)	Adriatic Sea, eastern Croatia	?	103.5						
Sinovčić *et al.* (2004)	Adriatic Sea, eastern Croatia	♀	33.5–44.8		3.160				
Sinovčić *et al.* (2004)	Adriatic Sea, eastern Croatia	♂	32.4–43.3		2.710				
Sinovčić *et al.* (2004)	Adriatic Sea, eastern Croatia	♀ + ♂	31.5–44.8		3.010				
Fehri-Bedoui & Gharbi (2004)	Mediterranean, Gulf of Gabes	♀ + ♂	23.7–52.0			61.4	0.109	−2.889	2.614
Ghailen *et al.* (2010)	Mediterranean, Gulf of Gabes	♀	26.0–32.0	41.9 ± 0.54	3.102				
Ghailen *et al.* (2010)	Mediterranean, Gulf of Gabes	♂	24.8–52.4	40.6 ± 0.64	3.095				
Ghailen *et al.* (2010)	Mediterranean, Gulf of Gabes	♀ + ♂	24.8–52.4	40.1 ± 0.45	3.132				
Uçkun *et al.* (2004)*	Aegean Sea, İzmir Bay	♀	26.0–54.5		3.460	62.2	0.249	−1.422	2.984
Uçkun *et al.* (2004)*	Aegean Sea, İzmir Bay	♂	27.5–47.7		3.070	54.3	0.336	−1.252	2.996
Uçkun *et al.* (2004)*	Aegean Sea, İzmir Bay	♀ + ♂	26.0–54.5		3.400	62.7	0.237	−1.566	2.969
Samsun *et al.* (2006)	Black Sea, Sinop Peninsula	♀		39.1 ± 0.16					
Samsun *et al.* (2006)	Black Sea, Sinop Peninsula	♂		36.1 ± 0.16					
Samsun *et al.* (2006)	Black Sea, Sinop Peninsula	♀ + ♂	29.0–58.0		3.137	74.6	0.130	−3.670	2.859
Samsun (1996)	Black Sea, Sinop Peninsula	♀ + ♂	31.2–52.2	37.6 ± 0.17	3.178	56.01	0.325	−1.864	3.008
Samsun *et al.* (1995)	Black Sea, Sinop Peninsula	♀ + ♂	31.9–56.9	40.2 ± 0.15	3.223	62.8	0.193	−3.382	2.881
Polat *et al.* (2009)*	Black Sea, Samsun Gulf	♀ + ♂	23.7–60.3	36.1 ± 0.27	3.245	79.1	0.198	−1.420	3.093
Present study	Black Sea, Rize coasts	♀	24.7–65.1	39.1 ± 0.25	3.180	81.6	0.125	−2.245	2.920
Present study	Black Sea, Rize coasts	♂	22.2–55.3	35.2 ± 0.21	3.090	71.9	0.151	−2.127	2.892
Present study	Black Sea, Rize coasts	♀ + ♂	22.2–65.1	37.2 ± 0.17	3.138	84.6	0.116	−2.344	2.919

*, studies measured size as fork length.

theoretical viewpoint of growth (Haddon, 2011). Our results showed that non-linear von Bertalanffy and exponential growth models attained better fit for females, and Richards, von Bertalanffy and Gompertz models were a better fit for males than the other models (see Table 2). So, the von Bertalanffy model was believed to be more biologically realistic to characterize the *B. euxini* growth pattern. This model fitted well, and estimated L_∞ was reasonable and gave the best results with the lowest AIC value and biologically reasonable growth parameters among the applied growth models.

Growth of some fish species from different geographical areas is described by different growth models due most probably to the goodness of fit length at age data, growth properties of species, biological interpretation of growth parameters and so on. Sharptail mola, *Masturus lanceolatus* growth model was calculated using three growth mpdels; von Bertalanffy, Gompertz and Robertson were used to model the observed length at age data and the von Bertalanffy was suggested as the better model to describe growth of this fish species (Liu *et al.*, 2009). Whitebrow skate *Bathyraja minispinosa* and Atlantic saury *Scomberesox saurus saurus* growth functions were calculated to be better described by the Gompertz model than by the von Bertalanffy model (Ainsley *et al.*, 2011; Agüera & Brophy, 2012). Moreover, three growth models; the von Bertalanffy, the logistic and the Schnute and Richards models were applied to estimate black Scorpionfish, *Scorpaena porcus* growth, and the von Bertalanffy growth curve did not reach an asymptote within the observed range of data, and the L_∞ estimate appeared to be an overestimate. Although the logistic model fitted well and estimated L_∞ was reasonable, the Schnute and Richards models approach gave the best results with the lowest residual sum of squares and biologically reasonable growth parameters among the applied growth models (Demirhan & Can, 2009).

In the present study, female garfish reach a larger size then males. Namely, the asymptotic total length changed between 64.1 and 158.6 cm for females and between 57.3 and 73.8 cm for males (Table 6). Similar results were obtained in a previous study of *B. belone* in the Aegean Sea (Uçkun *et al.*, 2004) and in the Adriatic Sea (Zorica & Keč, 2013). The other studies from Black Sea did not contain growth parameters for both sexes separately, and we did not compare our result with them. Solely, we calculated selected growth models (von Bertalanffy) parameters for combined sexes to compare previous studies and realized that the asymptotic total length of *B. euxini* was longer than in other parts of the Black Sea (Samsun *et al.*, 1995, 2006; Samsun, 1996; Polat *et al.*, 2009). This may probably be due to the larger length composition and age range obtained in our study (see Table 6). In addition, the *K* values estimated using all models for males of *B. euxini* were estimated higher than females, and ranged between 0.048–0.356 yr^{-1} for females and 0.145–0.418 yr^{-1} for males. A similar result was obtained for *B. belone* in the Aegean Sea (Uçkun *et al.*, 2004). But, Zorica & Keč (2013) reported higher *K* value of *B. belone* in males (0.159) than females (0.166) in the Adriatic Sea. In the previous study, estimated *K* values of *B. euxini* were generally close to each other, but sometimes the *K* value was estimated to be higher. For example, the *K* value was estimated as 0.193 (Samsun *et al.*, 1995), 0.130 (Samsun *et al.*, 2006), 0.198 (Polat *et al.*, 2009) and 0.325 (Samsun, 1996) in different parts of the Black Sea. While garfish are generally identified as a slow growing species (Zorica & Keč, 2013), *K* can be affected by year and geographical region and may be due to different

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Table 7. Comparison of mortality and exploitation rates of garfish obtained from different studies in the Black Sea (*Belone euxini*) and Adriatic Sea (*Belone belone*). *Z* is total mortality rate (yr^{-1}), *M* is natural mortality rate (yr^{-1}), *F* is fishing mortality rate (yr^{-1}), *E* is exploitation rate (yr^{-1}).

Study	Locality	Season	Sex	*Z*	*M*	*F*	*E*
Zorica & Keč (2013)	Adriatic Sea	2003–2008	♀	0.800	0.417	0.383	0.479
Zorica & Keč (2013)	Adriatic Sea	2003–2008	♂	1.100	0.443	0.657	0.597
Zorica & Keč (2013)	Adriatic Sea	2003–2008	♀ + ♂	0.880	0.429	0.451	0.513
Samsun *et al.* (2006)	Black Sea	2000–2001	♀ + ♂	1.240	0.230	1.010	0.815
Samsun (1996)	Black Sea	1995–1996	♀ + ♂	1.160	0.520	0.640	0.552
Samsun *et al.* (1995)	Black Sea	1994–1995	♀ + ♂	1.070	0.360	0.710	0.664

length composition, age range and different biotic (e.g. prey availability, predators, genetic variation) and abiotic factors (e.g. salinity, temperature, habitat structure).

Growth performance index is a good tool for averaging growth parameters for a particular species (Sparre & Venema, 1992) and useful for the evaluation of growth under a variety of environmental stresses (Pauly, 1991). The growth performance indices, calculated from different studies are shown in Table 6. Our results of Φ' for females were a bit greater than for males, indicating that females grew relatively faster and reached a larger asymptotic total length at age compared to males. When studies from different regions are compared, the Φ' of *B. belone* and *B. euxini* are close to each other in the Black Sea (Samsun *et al.*, 1995, 2006; Samsun, 1996; Polat *et al.*, 2009), Aegean Sea (Uçkun *et al.*, 2004) and in the Adriatic Sea (Zorica & Keč, 2013).

The age at inflection point of the growth curve (I) is the age corresponding to reproductive maturity in the growth curve, or described as the theoretical time of maximum growth. I also generally coincides with the onset of reproductive maturity in animals (Fitzhugh, 1976; Karkach, 2006). Zorica *et al.* (2011) estimated 50% total length at sexual maturity for *B. belone* as 28.0 cm for females and 31.5 cm for males, corresponding to about age 2 yr (Zorica & Keč, 2013). Similarly, Dorman (1989) mentioned that the rapid growth rate of *B. belone* continues into the second year, associated with the size at sexual maturity. In the Black Sea, *B. euxini* reached 50% size at sexual maturity at age 2 yr and 38.8 cm (Samsun, *et al.*, 2006). The age at inflection point was estimated from the present study as 1.7 yr for females and 1.2 yr for males by the Richards model. These results approximately suggest that the age at inflection point of the growth curve of garfish specimens coincide biologically with the age at sexual maturity calculated from previous study.

Mortality

Mortality rate is one of the most important parameters for fisheries management, and the most accurate estimates of mortality are difficult. The results of mortality rates and exploitation rates of garfish obtained from previous studies from the Black and Adriatic Seas are shown in Table 7. Total instantaneous mortality rate of *B. euxini* was estimated to be lower for females (1.042 yr^{-1}) than for males (1.238 yr^{-1}). Natural mortality rate for this species was estimated using four empirical equations using input parameters of seven growth models, showing that natural mortality of males was also higher than for females (Table 3). A similar result was obtained for *B. belone* stock in the Adriatic Sea (Zorica & Keč, 2013). Higher natural mortality estimation for males may be due to sexual dimorphism in size (e.g. sex-ratio fluctuation with size was represented up to 38 cm total length by male than by female), fishing gear selectivity, sampling strategies and spawning migration patterns. Moreover, fishing mortality rate was higher than in the Adriatic Sea, and in the Black Sea fishing mortality rate changed between years (see Table 7), maybe due to different fishing pressure and biotic and abiotic factors affecting the garfish stock, e.g. strength of the garfish year-class and growth. On the one hand, larger size usually leads to greater mating success, greater fertility, lower vulnerability to environmental hazards, and thus lower mortality (Karkach, 2006). Therefore, the differences in the estimates may arise either from the stock being at equilibrium and a constant mortality for different sizes, or the data do not represent the true population.

Gulland (1971) suggested that in a stock that is optimally exploited, fishing mortality should be about equal to natural mortality, or $F_{opt} \approx M$ which correspond to $E_{opt} \approx 0.5$ (Pauly, 1984). The exploitation rates of *B. euxini* for both sexes obtained using input parameters from four empirical natural mortality rates and seven growth models showed that garfish stock was overexploited in the Black Sea ($E >$ 0.5). The severity of exploitation on the garfish stock off the Sinop coast in the middle Black Sea also changed year to year, and was estimated as 0.7, 0.6 and 0.8 in the previous studies by Samsun *et al.* (1995, 2006) and Samsun (1996), respectively. These fishing levels have been contentious on the Turkish Black Sea coast.

According to Duzgunes & Erdogan (2008), fishing regulation is based on the following criteria in the Turkish Seas: minimum mesh and fish size; closed season and area; species under full conservation (e.g. cetaceans, salmon, sturgeon); completely banned fishing methods and fishing gears; gear restriction for identified species and gear or fishing method restrictions; and some restrictions concerning pollutants. None of these regulations apply to the garfish fishery. Therefore, a stock assessment and management of this species in the Black Sea is urgently needed. To protect garfish stock and to build sustainable garfish fisheries in the Black Sea, some management measures such as total allowable catch and landing quotas, exclusive regional fishing permits or closed area (e.g. coastal garfish spawning area), minimum fish size (e.g. 35 cm total length) and closed season (e.g. May–July) should be applied as soon as possible by a competent body (the Ministry of Food, Agriculture and Livestock). The results of this study should be used as biological input parameters for further evaluation of the garfish stock in the Black Sea and regarded as a reference for management of other stocks of this species.

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REFERENCES

Agüera A. and Brophy D. (2012) Growth and age of Atlantic saury, *Scomberesox saurus saurus* (Walbaum), in the northeastern Atlantic Ocean. *Fisheries Research* 131–132, 60–66.

Ainsley S.M., Ebert D.A. and Cailliet G.M. (2011) Age, growth, and maturity of the whitebrow skate, *Bathyraja minispinosa*, from the eastern Bering Sea. *ICES Journal of Marine Science* 68, 1426–1434.

Akaike H. (1974) A new look at the statistical model identification. *Automatic Control, IEEE Transactions* 19, 716–723.

Alagaraja K. (1984) Simple methods for estimation of parameters for assessing exploited fish stoks. *Indian Journal of Fisheries* 31, 177–208.

Bat L., Şahin F., Satılmış H.H., Üstün F., Birinci Özdemir Z., Kıdeys A.E. and Shulman G.E. (2007) The changed ecosystem of the Black Sea and its impact on anchovy fisheries. *Journal of Fisheries Sciences* 1, 191–227.

Collette B.B. (2003) Family Belonidae Bonaparte 1832—needlefishes. *California Academy of Sciences Annotated Checklists of Fishes* 16, 22.

Collette B.B. and Parin N.V. (1970) Needlefishes (Belonidae) of the eastern Atlantic Ocean. *Atlantide Report*, 11, 7–60.

Dalyan C. and Eryılmaz L. (2006) Two new fish records from Turkish coast of the Eastern Mediterranean: the garfish, *Belone svetovidovi* Collette and Parin, 1970; the Spiny gurnard, *Lepidotrigla dieuzeidei* Audoin in Blanc and Hureau, 1973. *Journal Black Sea/ Mediterranean Environment* 12, 155–158.

Demirhan S.A. and Can M.F. (2009) Age, growth and food composition of *Scorpaena porcus* (Linnaeus, 1758) in the southeastern Black Sea. *Journal of Applied Ichthyology* 25, 215–218.

Djabali F., Mehailia A., Koudil M. and Brahmi B. (1993) Empirical equations for the estimation of natural mortality in Mediterranean teleosts. *Naga, the Iclarm Quarterly* 16, 35–37.

Dorman J.A. (1988) Diet of the garfish, *Belone belone* (L.), from Courtmacsherry Bay, Ireland. *Journal of Fish Biology* 33, 339–346.

Dorman J.A. (1989) Some aspects of the biology of the garfish *Belone belone* (L.) from southern Ireland. *Journal of Fish Biology* 35, 621–629.

Dorman J.A. (1991) Investigations into the biology of the garfish, *Belone belone* (L.) in Swedish waters. *Journal of Fish Biology* 39, 59–69.

Dulčić J. and Soldo A. (2006) A new maximum length for the garpike *Belone belone* (Belonidae). *Cybium* 30, 382.

Dulčić J., Baždarić B., Grubišić L. and Dragičević B. (2009) Embryonic and larval development of garpike from the Adriatic Sea. *Integrative Zoology* 4, 272–276.

Duzgunes E. and Erdogan N. (2008) Fisheries management in the Black Sea countries. *Turkish Journal of Fisheries and Aquatic Sciences* 8, 181–192.

Erkoyuncu İ. (1995) *Fisheries biology and population dynamics*. Sinop: University of Ondokuz Mayıs Press.

Everhart W.H., Eipper A.W. and Youngs W.D. (1975) *Principles of fishery sciences*. Ithaca, NY: Cornell University Press.

Fehri-Bedoui R. and Gharbi H. (2004) Contribution a l'étude de la croissance et l'éage de. *Belone belone* (Belonidae) des côtes Est de la Tunisie. *Rapports de la Commission Internationale pour la Mer Méditerranée* 37, 1–352.

Fitzhugh H.A. (1976) Analysis of growth curves and strategies for altering their shape. *Journal of Animal Science* 42, 1036–1051.

Fricke R., Bilecenoglu M. and Sarı H.M. (2007) Annotated checklist of fish and lamprey species (Gnathostomata and Petromyzontomorphi) of Turkey, including a Red List of threatened and declining species. *Stuttgarter Beiträge zur Naturkunde* 706, 1–169.

Froese R. and Pauly D. (eds) (2014) *FishBase*. Available at: http://www.fishbase.org (version 04/2014).

Gayanilo F.C.J., Sparre P. and Pauly D. (2005) *FAO-ICLARM Stock Assessment Tools II (FISAT II). User's guide. FAO Computerized Information Series (Fisheries). No. 8, Revised version*. Rome: FAO.

Ghailen H., Abdallah H., Hassan A., Mourad C., Abderrahmen B. and Othman J. (2010) Length–weight relationships for 13 fish species from the Gulf of Gabes (Southern Tunisia, Central Mediterranean). *African Journal of Biotecnology* 9, 6177–6181.

Gompertz B. (1825) On the nature of the function expressive of the law of human mortality and on a new mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society of London* 115, 515–585.

Gompertz B. (1832) On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society* 123, 513–585.

Gulland J.A. (1971) *The fish resources of the oceans*. West Byfleet: FAO Fishing News (Books) Ltd, 210 pp.

Gürcan E.S. (2012) *The ichthyoplankton dynamics of the Sinop coasts*. Msc thesis. Sinop University, Science and Technology Institute, Turkey.

Haddon M. (2011) *Modeling and quantitative methods in fisheries*. 2nd edition Boca Raton, FL: Chapman and Hall/CRC Press.

Henderson P.A. and Seaby R.M. (2006) *Growth II*. Lymington: Pisces Conservation Ltd.

Janoschek A. (1957) Das reaktionskinetische Grundgesetz und seine Beziehungen zum. *Wachstums und Ertragsgesetz Stat Vjschr* 10, 25–37.

Karkach A.S. (2006) Trajectories and models of individual growth. *Demographic Research* 15, 347–400.

Kužir S., Kozarić Z., Gjurčević E., Baždarić B. and Petrinec Z. (2009) Osteological development of the garfish (*Belone belone*) larvae. *Anatomia Histologia Embryologia* 38, 351–354.

Liu K.M., Lee M.L., Joung S.J. and Chang Y.C. (2009) Age and growth estimates of sharptail mola, *Masturus lanceolatus*, in waters of eastern Taiwan. *Fisheries Reseaarch* 95, 154–160.

Morgan P.H., Mercer L.P. and Flodin N.W. (1975) General model for nutritional response of higher organisms. *Proceedings of the National Academy of Sciences of the United States of America* 72, 4327–4331.

Nédélec C. (1975) *Catalogue of small-scale fishing gear*. West Byfleet: Food and Agriculture Organization of the United Nations/Fishing News.

Pauly D. (1980) On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 stocks. *Journal du Conseil International pour ı'Exploration de la Mer* 39, 175–192.

Pauly D. (1984) Fish population dynamics in tropical waters: a manual for use with programmable calculators. *Makati, Metro, Manila, Philippines.* ICLARM Contribution, no. 143, 325 pp.

Pauly D. (1991) Growth performance in fishes: rigorous description of patterns as a basis for understanding causal mechanisms. *Aquabyte* 4, 3–6.

Pauly D. and Munro J.L. (1984) Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte* 2, 21.

Polat N., İnceismail Y., Yılmaz S. and Bostancı D. (2009) Age determination, age–length and length–weight relationships of garfish. (*Belone belone L*., 1761) in the Black Sea (Samsun). *Journal of Fisheries Sciences* 3, 187–198.

Quinn T.J. and Deriso R.B. (1999) *New quantitative fish dynamics*. New York: Oxford University Press, Biological Resource Management Series.

Richards F.J. (1959) A flexible growth functions for empirical use. *Journal of Experimental Botany* 10, 290–301.

Ricker W.E. (1975) *Computation and interpretation of biological statistics of fish populations*. Ottawa: Department of the Environment Fisheries and Marine Service.

Salekhova L.P., Kostenko N.S., Bogachick T.A. and Minibaeva O.N. (1988) Composition of ichthyofauna in the region of the Karadag State Reserve (Black Sea). *Journal of Ichthyology* 28, 16–23.

Samsun O. (1996) Sinop (Karadeniz) Zargana (*Belone belone euxini*, Günther, 1866) balığı populasyonuna ilişkin (1995–1996) büyüme karakteristikleri değişimlerinin İzlenmesi. *Ege Üniversitesi Su Ürünleri Dergisi* 12, 347–355.

Samsun O., Özdamar E. and Erkoyuncu İ. (1995) *Sinop yöresinde avlanan zargana (*Belone belone euxini, *Günther, 1866) balığının bazı balıkçılık biyolojisi parametreleri ile et veriminin araştırılması.* Doğu Anadolu Bölgesi II. Su Ürü. Semp., Atatürk Üniversitesi, Ziraat Fakültesi, Su Ürünleri Bölümü, Erzurum, 14-16 Haziran.

Samsun O., Samsun N., Bilgin S. and Kalaycı F. (2006) Population biology and status of exploitation of introduced garfish, *Belone belone euxini* Günther, 1866 in The Black Sea. *Journal of Applied Ichthyology* 22, 353–356.

Sever T.M., Bayhan B., Bilge G. and Taşkavak E. (2009) Diet composition of *Belone belone* (Linnaeus, 1761) (Pisces: Belonidae) in the Aegean Sea. *Journal of Applied Ichthyology* 25, 702–706.

Sinovčić G., Franičević M., Zorica B. and Čikeš-Keč V. (2004) Length–weigth and length–length relationships for 10 pelagic fish species from the Adriatic Sea (Croatia). *Journal of Applied Ichthyology* 20, 156–158.

Sparre P. and Venema S.C. (1992) *Introduction to tropical fish stock assessment. Part 1. Manual.* FAO Fisheries Technical Paper.

Srinath M. (1998) Emprical relationships to estimate the instantaneous rate of natural mortality. *Indian Journal of Fisheries* 45, 7–11.

TUIK (2001–2012) *Fishery statistics*. Ankara, Turkey: Turkish Statistical Institute.

Uçkun S., Akalin E. and Toğulga M. (2004) Some biological characteristics of the garfish (*Belone belone* L., 1761) in İzmir Bay, Aegean Sea. *Journal of Applied Ichthyology* 20, 413–416.

Von Bertalanffy L. (1938) A quantitative theory of organic growth (Inquiries on growth laws. II). *Human Biology* 10, 181–213.

Von Bertalanffy L. (1951) Metabolic types and growth types. *American Naturalist* 85, 111–117.

Weibull W. (1951) A statistical distribution function of wide applicability. *Journal of Applied Mechanics, Transactions of the ASME* 18, 293–297.

Yüce Y. (1975) Zargana balığı *Belone belone* (L)'nın biyolojisi. *Istanbul University, Hidrobiology Institue* 2, 1–25.

Zaitsev Y. and Mamaev V. (1997) *Marine biological diversity in the Black Sea*. New York: United Nations Publications.

Zorica B. and Keč V.Č. (2013) Age, growth and mortality of the garfish, *Belone belone* (L. 1761) in the Adriatic Sea. *Journal of the Marine Biological Association of the United Kingdom* 93, 365–372.

and

Zorica B., Sinovčić G. and Keč V.C. (2011) The reproductive cycle, size at maturity and fecundity of garfish (*Belone belone*, L. 1761) in the eastern Adriatic Sea. *Helgoland Marine Research* 65, 435–444.

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