Journal of the Marine Biological Association of the United Kingdom, 2013, 93(2), 365–372.
doi:10.1017/S002531541200149X

Age, growth and mortality of the garfish, *Belone belone (L. 1761)* in the Adriatic Sea

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A sample of 3393 garfish, Belone belone *(Linnaeus, 1761) was captured using a seine net between January 2003 and December 2008, along the eastern Adriatic Sea. The range in total length was 20.8–75.4 cm and in weight was 12.21–639.25 g. Length–length equations for converting size measurements (standard length and fork length to total length (*TL*)) were linear. In the length–weight relationship, positive allometry was established (*$b = 3.4818$*). Age, determined from sagittal otoliths, ranged from 1+ to 8+ years. The estimated von Bertalanffy model growth parameters for garfish were* $L_\infty = 90.3$ *cm,* $K = 0.158$ *year*$^{-1}$*,* $t_o = -0.109$*. Otolith weight was endorsed as a possible age predictor, as it showed highly exponential correlation with total garfish length and age (*$W_o = 0.0012\ TL^{2.189}$*;* $W_o = 0.568t^{1.486}$*). These findings were used to examine mortality rates and exploitation in order to improve conservation and management of this pelagic species.*

Keywords: length–weight relationship, otolith, growth, mortality, garfish, Adriatic

Submitted 18 August 2012; accepted 21 August 2012; first published online 31 October 2012

INTRODUCTION

Garfish, *Belone belone* (Linnaeus, 1761), is widely distributed throughout the Mediterranean Basin and its adjacent seas, as well as in the eastern Atlantic. Three subspecies have been described along its area of distribution (Collette & Parin, 1986): *B. belone belone* (Linnaeus, 1761)—restricted to the north-eastern Atlantic; *B. belone gracilis* Lowe, 1839—distributed in the south of France to the Canary Islands and in the Mediterranean Sea; and *B. belone euxini* Günther, 1866, which is found in the Black Sea and the Sea of Azov. Garfish is an epipelagic species, which is found mainly in off-shore areas. It migrates towards coastal waters during the spawning period, where it is commercially exploited (Zorica *et al.*, 2011). In the Adriatic Sea, garfish is the main target of seine net (stretched mesh size 10–30 mm), but is also caught as a by-catch species in purse seine fisheries.

There are some published studies on its biology from the areas of its occurrence (Rosenthal & Fonds, 1973; Dorman, 1989, 1991; Bedoui *et al.*, 2002; Fehri-Bedoui & Gharbi, 2004; Uçkun *et al.*, 2004; Korzelecka-Orkisz *et al.*, 2005; Samsun *et al.*, 2006; Zorica *et al.*, 2011). In the Adriatic Sea, data concerning garfish biology are restricted to its reproduction traits (Zorica *et al.*, 2011), while knowledge about age and growth is lacking. Information concerning age and growth is essential for monitoring year-class strength, making stock assessments, documenting population recovery and constructing the demographic parameters fundamental to population models. Despite the fact that garfish is common in the Adriatic Sea, its total landings in Croatia are unknown (Croatian Bureau of Statistics), and its exploitation status is therefore undetermined. By improving understanding of the life history of the garfish population inhabiting the Adriatic Sea, fishery management will be provided with vital statistical and biological parameters that will allow definition of the present status and management strategy for this species.

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MATERIALS AND METHODS

Garfish specimens were collected monthly in the eastern part of the middle Adriatic Sea from January 2003 to December 2008 (Figure 1) with the exception of a small number of months when, due either to logistical problems or weather conditions, sampling was not possible. No samples were obtained in June throughout the investigation, even though sampling and fishing effort did not cease.

Samples of *Belone belone* were collected at night using seine net with stretched mesh of size 10 mm (the main net) to 34 mm (the net cod end). The seine net, which is approximately 10 to 30 m deep and 100 m long, is generally operated at 200 to 300 m from the coastline, depending on the sea floor configuration. Preferred sea depth for this type of fishing gear is deeper than 20 m. A total of 3393 individuals, 1166 males and 1195 females were analysed in the laboratory, immediately after landing. Total length (*TL*), standard length (*SL*) and fork length (*FL*) (± 0.1 mm), as well as total body weight (*W*) (± 0.01 g) of each specimen, were measured. Sex was macroscopically determined. The sagitta otoliths were removed by opening the otic bulla, washed in freshwater, dried, denoted and stored in plastic tubes prior to analysis.

Conversions between length measures were accomplished with linear regression models using the least squares method (Sokal & Rohlf, 1981), while possible significant differences in length–length relationships among sexes were determined by parametric or non-parametric tests ($P < 0.05$), depending on data normality. The length–weight relationship for both sexes and overall was calculated by applying the exponential regression $W = aTL^b$, where

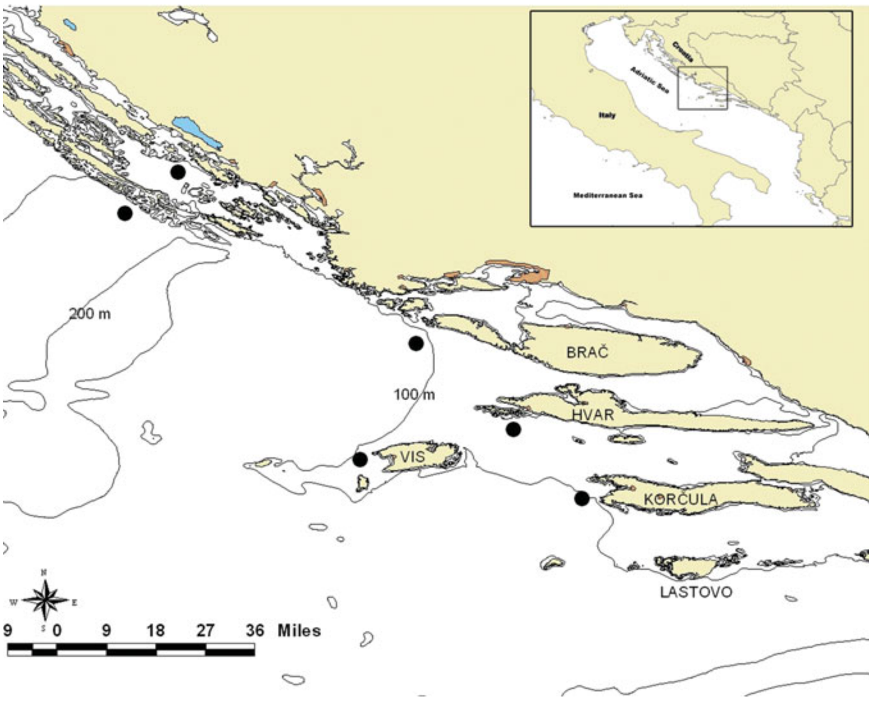

Fig. 1. Study area with marked sampling station.

W = total fish weight in g; TL = total length in cm; a = proportionality constant; and b = allometric growth parameter. The hypotheses of isometric growth, and abbreviation between male and female allometric growth parameter, were tested using a Student's t-test ($P < 0.05$).

Age was determined by reading the otoliths. The entire otolith was immersed in ethanol solution and examined against a black background with reflected light, using a binocular microscope with amplifications between 1.6×25.6 and 1.6×51. Hyaline and opaque rings were counted in the dorsoventral part of the concave side of the otoliths. The number of hyaline (translucent) rings was recorded over the rostrum area. Otolith reading was performed on two separate occasions, two months apart. Where there was an age discrepancy between two otolith readings, these otoliths were excluded from further analysis and determined as unreadable, due to false rings. The von Bertalanffy growth equation $TL = L_\infty[1 - e_o^{(-K)(t-t)}]$ was fitted to length-at-age data, separately for each sex and overall, using non-linear least-squares parameter estimation, where TL = the length at time t, L_∞ = the asymptotic length, K = the growth constant, t_o = the 'age' at which $TL = 0$ (Gulland, 1983). The growth performance index phi-prime (φ'; $\varphi' = lnK + 2lnL_\infty$) was calculated using the equation described by Munro & Pauly (1983) in order to compare growth parameters obtained in our study with those reported by other authors. The weights of the undamaged and cleaned otoliths (W_o) were measured on a Mettler analytical balance (nearest 0.01 mg). The weights of left and right otolith (for 83 otolith pairs) were not significantly different (Mann–Whitney U-test, $Z = 0.157$; $P = 0.876$); 82% of otolith pairs had a weight within 0.0002 g of each other. Hence, only one otolith from subsequent pairs was weighed and used in further analysis. Independently of sex, the relationships of otolith weight to total length (W_o–TL) and otolith weight to age (W_o–t) were analysed using the power function $W_o = aTL^b$ and $W_o = at^b$, respectively.

Natural mortality rate (M) was defined using the general regression equations below:

- $logM = -0.0066 - 0.279log\ L_\infty + 0.6543logK + 0.4634logT$ (Pauly, 1980), where L_∞ and K are the parameters of the von Bertalanffy growth equation and parameter T is the mean value of the water temperature (17.35°C) in the investigated area (Grbec *et al.*, 2007);
- $M = 1.521/X0{,}72 - 0{,}155$ (Rikhter & Efanov, 1976), where X refers to age 2+ at which most of the garfish specimens reach maturity, according to Zorica *et al.* (2010);
- $M = 0.996/A0.95$ (Taylor, 1959), where $A\ 0.95$ is the age at length of 95% L_∞. (18.85 years);
- $ln(M) = 0.55 - 1.6ln(L) + 1.44ln(L_\infty) + ln(K)$ (Gislason *et al.*, 2010), where L is average length at age, L_∞ is the asymptotic length and K is the growth constant.

An estimate of instantaneous total mortality rate (Z) was obtained using the linearized length-converted catch curve (Pauly, 1984) in the FISAT program (Gayanilo *et al.*, 1994). The natural logarithm of the ratio between the number of fish in each length-class, and the time needed for the fish to grow through the length-class ($ln\ Ni/Dti$), was plotted against their corresponding relative age (t); total mortality was estimated from the descending slope b. Total mortality rates were calculated separately for males, females and overall garfish specimens. The fishing mortality was estimated by subtracting an average M from Z. The exploitation ratio (E) was calculated as $E = F/Z$ (Beverton & Holt, 1957), while the survival rate (S) was estimated by the formula $S = e^{-Z}$ (Ricker, 1975).

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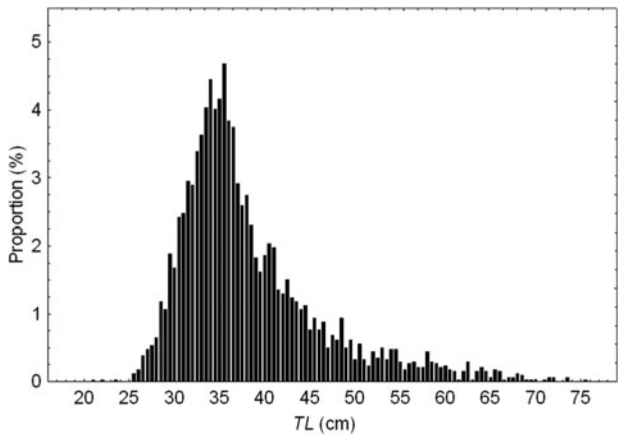

Fig. 2. Size–frequency distribution of garfish specimens collected in the eastern Adriatic Sea, 2003–2008.

Table 1. The length–length relationships between total length (*TL*) and fork length (*FL*) and total (*TL*) and standard length (*SL*) separately given for males, females and overall garfish specimens, in the Adriatic Sea, January 2003–December 2008.

Relationship	Sex	N	Equation	r^2
	♂	920	$FL = 0.951TL + 0.345$	0.999
FL–TL	♀	1013	$FL = 0.960TL + 0.050$	0.999
	Total	2613	$FL = 0.958TL + 0.145$	0.999
	♂	824	$SL = 0.937TL - 0.030$	0.999
SL–TL	♀	1069	$SL = 0.942TL - 0.155$	0.999
	Total	2583	$SL = 0.940TL - 0.066$	0.999

N, number; r^2, coefficient of determination.

RESULTS

Length–frequency distribution

Garfish from the eastern Adriatic ranged from 20.8 to 75.4 cm (mean ± standard deviation (SD): 38.3 ± 7.94 cm) in total length and 12.21 and 639.25 g (mean ± SD: 70.33 ± 68.53 g) in total body weight (Figure 2). Total length range of males was somewhat narrower ($27.7 < TL < 62.6$ cm; mean ± SD: 37.4 ± 5.37 cm) than that obtained for females ($27.2 < TL < 75.4$ cm; mean ± SD: 43.6 ± 9.12 cm). Accordingly, measurable range as well as mean total body weight of males ($17.41 < W < 392.53$ g; mean ± SD: 58.14 ± 39.74 g) was lower than for females ($18.03 < W < 639.25$ g; mean ± SD:109.77 ± 93.63 g). There was no statistically significant difference detected between length distribution of male and female garfish specimens collected during the whole investigation (Kolmogorov–Smirnov test, $P < 0.05$), although all specimens with $TL > 62.5$ cm were exclusively female.

Length–length relationship

Conversions between total (*TL*) and fork (*FL*) length and total (*TL*) and standard (*SL*) length for each sex and overall are given in Table 1. All obtained length–length regressions were statistically significant ($P < 0.05$) with a high value of the coefficient of correlation ($r > 0.99$).

Length–weight relationship

Length–weight relationships for males, females and all individuals combined are shown on Figure 3. Positive allometrical growth was observed in all three cases: for each, a statistically

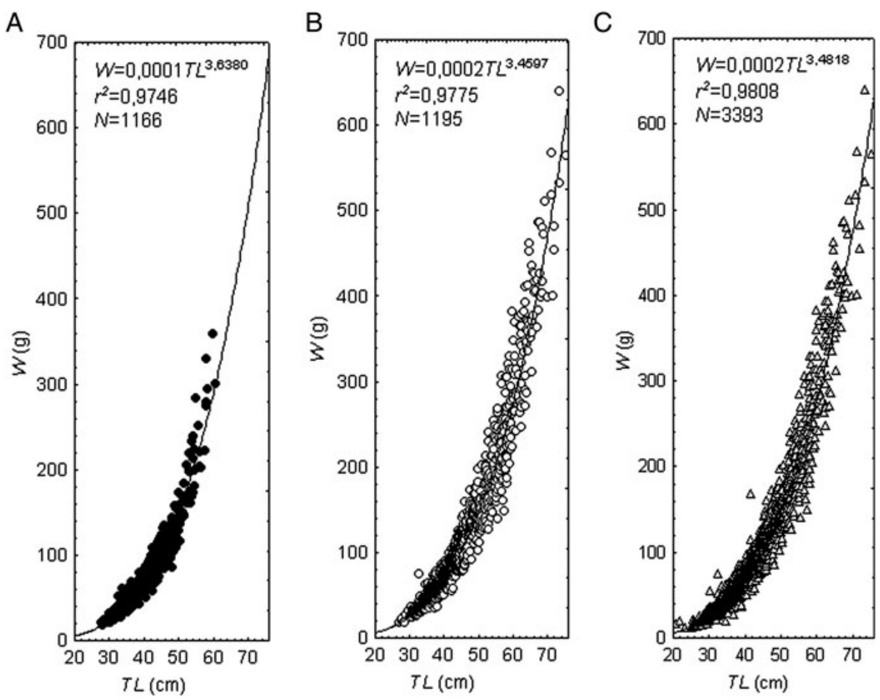

Fig. 3. Length–weight relationships of garfish males (A), females (B) and overall (C).

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significant difference from isometric value ($b = 3$) was obtained ($P < 0.05$). Although for both sexes positive allometry was established, statistically significant differences in slopes between males and females was noted ($t = 137.128$; df = 2359, $P < 0.05$).

Age and growth

Otoliths of 468 garfish specimens, with total length ranging from 23.3 cm to 75.4 cm, were used for aging. Out of 468 otoliths pairs 440, were successfully aged. According to the otolith reading, six age-classes were established for each sex (males: 2+ to 7+; females: 3+ to 8+), while in pooled material eight age-classes (1+ to 8+) were determined (Table 2). In the observed garfish population, specimens of 3+ to 4+ years old were the most numerous, while juvenile specimens (0+) were generally missing for the six years of our sampling period. Females dominated in the older age-classes (>7+).

The von Bertalanffy growth curves (Figure 4) fitted well to the available length at age data. The estimated parameters of the equation were: $L_\infty = 85.2$ cm (TL), $K = 0.159$, $t_o = -0.3223$, $r^2 = 0.9317$ males; $L_\infty = 89.5$ cm (TL), $K = 0.166$, $t_o = -0.063$, $r^2 = 0.9476$ females; $L_\infty = 90.3$ cm (TL), $K = 0.158$, $t_o = -0.109$, $r^2 = 0.9500$ overall. In our consideration of obtained growth parameters, φ' was calculated as 3.062, 3.124 and 3.110 for males, females and pooled material, respectively.

Weights of 208 undamaged garfish otoliths were noted. Garfish otolith weight ranged from 1.26 mg ($TL = 28.2$ cm; $W = 18.9$ g) to 18.12 mg ($TL = 73.6$ cm; $W = 639.25$ g), while the mean value of otolith weights was 4.66 ± 2.89 mg. The age–otolith weight key is given in Table 3. Within each age-class, considerable variation of otolith weight was noticed, which created some overlaps between the different age-classes. Significant exponential relationships between otolith weight and total length and mean otolith weight and

Table 2. Age-class distribution of male, female and all examined garfish specimens with specified total length range and mean value for each age class, in the Adriatic Sea, January 2003–December 2008.

Age-class	Males			Females			Total		
	N	Range TL (cm)	$\bar{x}$ + SD (cm)	N	Range TL (cm)	$\bar{x}$ + SD (cm)	N	Range TL (cm)	$\bar{x}$ + SD (cm)
0+	–	–	–	–	–	–	–	–	–
1+	–	–	–	–	–	–	1	23.3–23.3	23.3 ± 0.00
2+	3	28.3–30.0	29.3 ± 0.89	–	–	–	13	25.8–31.0	28.3 ± 1.50
3+	94	28.8–40.8	34.6 ± 2.18	55	30.5–41.1	36.0 ± 2.59	202	28.8–41.1	34.6 ± 2.62
4+	24	38.6–48.3	43.3 ± 2.75	55	37.9–49.0	43.4 ± 2.98	84	37.9–49.0	43.2 ± 2.91
5+	20	41.7–55.2	48.4 ± 4.05	50	41.6–58.7	50.4 ± 4.70	75	41.5–58.7	49.5 ± 4.73
6+	4	49.0–57.8	53.3 ± 3.76	17	50.1–60.1	55.5 ± 2.85	21	49.0–60.1	55.0 ± 3.07
7+	5	54.7–60.8	58.4 ± 2.32	18	55.7–64.1	61.4 ± 2.14	23	54.7–64.1	60.7 ± 2.47
8+	–	–	–	21	63.2–75.4	67.8 ± 3.12	21	63.2–75.4	67.8 ± 3.12
Total	150	28.3–60.8	39.0 ± 7.34	216	30.5–75.4	48.0 ± 10.58	440	23.3–75.4	42.5 ± 10.44

N, number; $\bar{x}$, mean TL; SD, standard deviation.

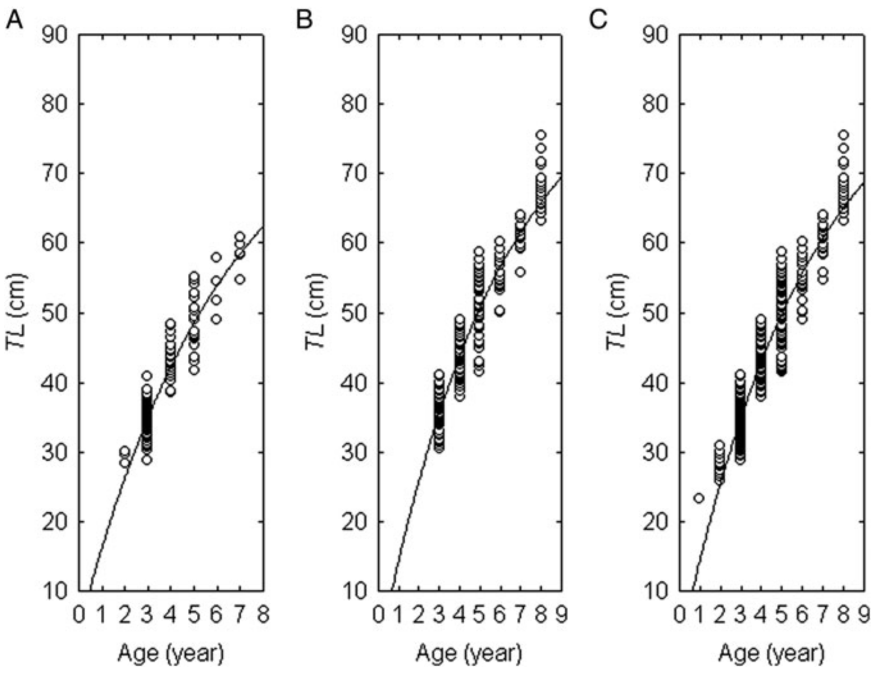

Fig. 4. The von Bertalanffy growth curves and its equations for male (A), female (B) and overall (C) garfish specimens, in the Adriatic Sea, 2003–2008.

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Table 3. Age–otolith weight key for garfish individuals collected from the Adriatic Sea, January 2003–December 2008.

Otolith weight range (W_O, mg)	Age (year)							Total
	2 +	3 +	4 +	5 +	6 +	7 +	8 +	
1.0–1.9	5	8						13
2.0–2.9	3	58	7					68
3.0–3.9		20	11					31
4.0–4.9		6	7	5				18
5.0–5.9		3	8	10				21
6.0–6.9		3	4	6	2			15
7.0–7.9			1	6	3	2		12
8.0–8.9			1	3	2	1		7
9.0–9.9			1		1	3	2	7
10.0–10.9				2		1		3
11.0–11.9						1	1	2
12.0–12.9						1		1
13.0–13.9							2	2
14.0–14.9							1	1
15.0–15.9							1	1
16.0–16.9								
17.0–17.9								
18.0–18.9							1	1
N	8	98	40	32	8	9	8	203
Min *Wo* (mg)	1.26	1.30	2.03	4.01	5.99	7.41	9.02	1.26
Max *Wo* (mg)	2.76	6.94	9.01	10.25	9.43	12.04	18.12	18.12
$W_o \pm$ SD (mg)	1.83 ± 0.50	2.94 ± 1.01	4.63 ± 1.54	6.44 ± 1.59	7.72 ± 1.12	9.61 ± 1.67	13.05 ± 3.10	4.66 ± 2.89

N, number; SD, standard deviation.

age were established (Figure 5); larger garfish specimens have heavier otoliths than smaller ones of the same age.

Mortality

Natural mortality rates obtained by Rikhter & Efanov (1976: $M_{♂} = 0.590$ yr^{-1}; $M_{♀} = 0.548$ yr^{-1}; $M = 0.520$ yr^{-1}), Gislason *et al.* (2010: $M_{♂} = 0.417$ yr^{-1}; $M_{♀} = 0.378$ yr^{-1}; $M = 0.451$ yr^{-1}) and Pauly (1980: $M_{♂} = 0.321$ yr^{-1}; $M_{♀} = 0.326$ yr^{-1}; $M = 0.315$ yr^{-1}) seems reasonable for this pelagic fish species, whilst estimates of *M* derived from Taylor (1959: $M_{♂} = 0.054$ yr^{-1}; $M_{♀} = 0.055$ yr^{-1}; $M = 0.0053$ yr^{-1}) were too low for a species that links low and high trophic levels. So, for further analysis natural mortality rate was define as an average value of values provided by Rikhter & Efanov (1976), Pauly (1980) and Gislason *et al.* (2010). All mortality rates (*M, Z* and *F*) for males, females and pooled material, as well as exploitation ratio (*E*) and survival rate (*S*), are given in Table 4. Total mortality rates (Z) were assessed by using the length converted catch method, but without garfish specimens that were not fully recruited (0–2+ years): this is shown in Figure 6.

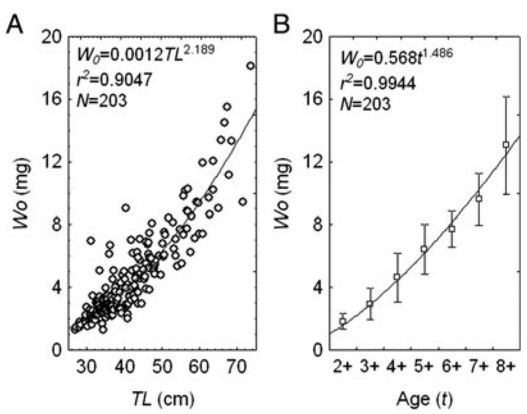

Fig. 5. Garfish exponential relationship of: (A) otolith weights (*Wo*)–total body lengths (*TL*) and (B) mean otolith weight with its standard deviations (*Wo* ± SD)–age-classes (*t*) with associated equations and coefficients of determination.

DISCUSSION

Length–frequency distribution

Over the study period (2003–2008) samples from the garfish population inhabiting the eastern Adriatic were collected in order to study the life history of this species. Data concerning garfish reproduction patterns have been published (Zorica *et al.*, 2011), while data describing its age and growth are presented here. During the sampling period, the length-range of analysed garfish specimens was considerably wider in comparison with earlier studies.

Table 4. Mortality and exploitation rates of garfish specimens given separately for each sex and overall, in the Adriatic Sea, January 2003–December 2008.

Mortality and exploitation	Males	Females	Total
Natural mortality (*M*)	0.443	0.417	0.429
Fishing mortality (*F*)	0.657	0.383	0.451
Total mortality (*Z*)	1.100	0.800	0.880
Exploitation ratio (*E*)	0.598	0.478	0.513
Survival rate (*S*)	0.334	0.450	0.416

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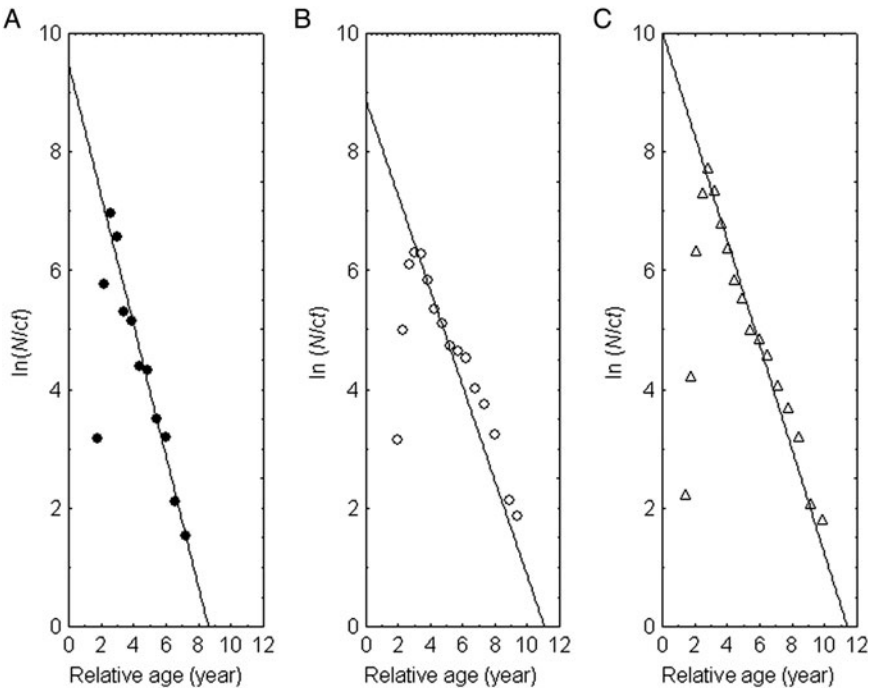

Fig. 6. Length converted catch curve for males (A), females (B) and all (C) garfish specimens collected from the eastern Adriatic Sea, 2003–2008.

Length–length relationships

Length–length relationships were linear with $r^2 > 0.990$ (Table 1). Estimated conversions among morphological measurements and proportional increases during the garfish growth were in accordance with those previously reported for the Adriatic Sea (Sinovčić *et al.*, 2004) and Mediterranean (Fehri-Bedoui & Gharbi, 2004).

Length–weight relationship

In general, positive allometry was established for garfish inhabiting the Adriatic Sea. Male garfish specimens gained in weight significantly more than females over their lifespan. This was also supported by the fact that average body weight of males was higher than those noted for females from the same length-classes (53.0 cm $< TL < 62.0$ cm; $W_{♂} = 238.01 \pm 58.721$ g; $W_{♀} = 228.86 \pm 54.154$ g). An overview of the literature for garfish allometrical coefficients (b) given in Table 5 generally corresponds with findings obtained in this paper. Slight allometric coefficient deviations between different geographical areas could be due to sampling strategy, degree of stomach fullness, gonad maturity, sex, size-range, health and general fish condition and preservation techniques (Tesch, 1971).

Age and growth

Garfish estimation of age, using sagittal otoliths, was successful considering that only 6% of sampled otoliths were excluded from further analysis due to occurrence of false rings, which were difficult to interpret. In analysed material, age-class 3+ was dominant (45.9%). Specimens of age-class 0+ were absent, and a decreasing trend in numbers of older age-classes was noticed. This is probably correlated with selectivity of fishing gear and the fact that smaller and younger garfish specimens do not accompany their elders (Dorman, 1991; Zorica *et al.*, 2010). The von Bertalanffy growth function provided an accurate description of somatic garfish growth at the ages encountered. The lack of small specimens may be a possible limitation of this study. Growth parameters (L_∞, K and t_o) and growth performance index phi-prime (φ') from

Table 5. Total length (*TL*) or fork length (*FL*) range, allometric parameter (*b*) and von Bertalanffy growth parameters of *Belone belone* from various geographical regions.

Author	Geographical area	Length range (cm)	b	L_∞	K	t_o	φ'
This paper	Adriatic Sea	20.8–75.4 (*TL*)	3.482	90.3 (TL)	0.158	−0.109	3.11
Sinovčić *et al.* (2004)	Adriatic Sea	31.5–44.8 (*TL*)	3.010	–	–	–	–
Yüce (1970)	Aegean Sea	30.0–57.5 (*FL*)	–	–	–	–	3.01
Uçkun *et al.* (2004)	Aegean Sea	26.0–54.5 (*FL*)	3.400	62.71 (FL)	0.237	−1.566	2.97
Fehri-Bedoui & Gharbi (2004)	Mediterranean (Tunis)	23.7–52.0 (*TL*)	3.485	61.4 (TL)	0.109	−2.889	2.61
Samsun *et al.* (1995)	Black Sea	–	–	62.8 (TL)	0.193	–	2.88
Samsun (1996)	Black Sea	31.2–52.2 (*TL*)	–	56.1 (***TL***)	0.325	–	3.01
Samsun *et al.* (2006)	Black Sea	29.0–58.0 (*TL*)	3.137	74.64 (TL)	0.130	−3.670	2.86

L_∞, asymptotic length; K, the growth constant; t_o, the ‘age’ at which $TL = 0$.

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the present study and previously published studies are given in Table 5. There were also some data concerning the age–frequency distribution of the garfish population inhabiting the Atlantic (Dorman, 1989, 1991) but as no length-range data or growth parameters were given, results were not comparable. Nevertheless, the values of growth constant (K) obtained in this study were very close to values estimated for the Mediterranean and Black Sea, which in general identified garfish as a slow-growing fish species. For our study, the highest value was recorded most probably due to wider length- and age-range. Garfish growth performance index (φ') varied within a narrow limit over its area of distribution. Observed discrepancy of the performance index could be explained by the different sea temperatures between geographical areas, which affect the otolith growth and result in different formation of the annulus (Morales-Nin & Ralston, 1990). We also produced growth curves separately by sex. Namely, as females were more abundant in older age-classes they attained somewhat higher values of K and L_∞ than males. This sex-related growth pattern was similar to one reported by Uçkun *et al.* (2004); males grow more slowly and reach a lower L_∞ value than females.

Recent investigations of otolith weights confirmed them as potential age predictors, as it is known that their weight increases throughout the lifespan of an individual. Throughout this study garfish otolith weights were noted and statistically significant exponential relationships between otolith weight–total body length and otolith weight–age were established (Figure 5). Hence, the previously mentioned assumption—otolith weight as age predictor—was also confirmed also for this species. Only one other study dealing with garfish otolith weight has been published (Zorica *et al.*, 2011), which reported linear correlation between otolith weight and total garfish length ($W_o = 0.25TL - 5.85$, $r^2 = 0.904$). Further differences might be observed if different sample size, in particular age/length distribution, is used.

Mortality

With a basic and reliable knowledge about age and growth characteristics, fundamental practice for good management can be established. Here, obtained estimates of natural mortality, mortality from fishing, and total mortality of garfish (Table 4) can only be compared with the values previously given by Samsun (1996: $M = 0.38$; $E = 0.66$) and Samsun *et al.* (2006: $M = 0.23$; $Z = 1.24$; $E = 0.81$) on garfish populations inhabiting the Black Sea. Mortality values in these two mentioned studies pointed out that garfish in the Adriatic had a higher natural mortality value, but lower values for fishing mortality and total mortality than garfish in the Black Sea. Observed discrepancy between natural mortality rates is probably due to use of indirect methods that unfortunately generates some bias in natural mortality estimates as they employ different von Bertalanffy growth parameters and the age at which garfish are considered to reach maturity. In addition, different fishing gears are used in different geographical regions: fishing pressure is therefore unequal, resulting in dissimilar mortality rates. Fishing mortality was slightly higher than natural mortality ($F > M$) and the estimate of the exploitation rate was almost optimal ($E = 0.513$). According to Gulland (1971), fish stock is optimally exploited when its exploitation ratio is lower than 0.5. Garfish populations in the Adriatic can therefore be considered endangered.

ACKNOWLEDGEMENTS

This study was supported by the Ministry of Science, Education and Sports of the Republic of Croatia, as a part of the research project 'Biodiversity and Management of Pelagic and Demersal Resources of the Adriatic Sea (001-0013077-0532)'. The referees' comments and suggestions are greatly appreciated.

REFERENCES

Bedoui R., Garbi H. and El Abed A. (2002) Période de reproduction et maturité sexuelle de *Belone belone gracilis* (Belonidae) des côtes Est et Sud de la Tunisie. *Vémes Journées de l'ATSMer* 7, 1–4.

Beverton R.J.H. and Holt S.J. (1957) *On the dynamics of exploited fish populations.* Fishery Investigations Series II, Marine Fisheries, Great Britain Ministry of Agriculture, Fisheries and Food 19, 533 pp.

Collette B.B. and Parin N.V. (1986) Belonidae. In Whitehead P.J.P., Bauchot M.L., Hureau J.C., Nielsen J. and Tortonese E. (eds) *Fishes of the north-eastern Atlantic and the Mediterranean. Volume 2.* Paris: UNESCO, pp. 604–609.

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.

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

Gayanilo F.C. Jr, Sparre P. and Pauly D. (1994) *The FAO–ICLARM Stock Assessment Tools (FiSAT) user's guide. No. 8.* FAO: Rome, 124 pp. [FAO Computerized Information Series (fisheries).]

Gislason H., Daan N., Rice J.C. and Pope J.G. (2010) Size, growth, temperature and the natural mortality of marine fish. *Fish and Fisheries* 11, 149–158.

Grbec B., Vilibić I., Bajić A., Morović M., Beg Paklar G., Matić F. and Dadić V. (2007) Response of the Adriatic Sea to the atmospheric anomaly in 2003. *Annales Geophysicae* 25, 835–846.

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

Gulland J.A. (1983) *Fish stock assessment: a manual of basic methods.* Rome: FAO and Wiley Publications.

Korzelecka-Orkisz A., Formicki K., Winnicki A., Bonisławska M., Szulc J., Biernaczyk M., Tański A. and Wawrzyniak W. (2005) Peculiarities of egg structure and embryonic development of garfish (*Belone belone* (L.)). *Electronic Journal of Ichthyology* 2, 42–53.

Morales-Nin B. and Ralston S. (1990) Age and growth of *Lutzanus kasmira* (Forsskal) in Hawaiian waters. *Journal of Fish Biology* 36, 191–203.

Munro J.L. and Pauly D. (1983) A simple method for comparing growth of fishes and invertebrates. *ICLARM Fishbyte* 1, 5–6.

Pauly D. (1980) *A selection of simple methods for the assessment of tropical fish stocks.* FAO Fisheries Circular 729, 54 pp.

Pauly D. (1984) *Fish population dynamics in tropical waters: a manual for use with programmable calculators*. ICLARM Studies and Reviews 8, 325 pp.

Ricker W.E. (1975) Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 191, 382 pp.

Rikhter V.A. and Efanov V.N. (1976) *One of the approaches to estimation of natural mortality of fish populations*. ICNAF Research Document 79 (8), 12 pp.

Rosenthal D.F. and Fonds M.H. (1973) Biological observations during rearing experiments with the garfish *Belone belone*. *Marine Biology* 21, 203–218.

Samsun O. (1996) Sinop (Karadeniz) Zargana (*Belone belone euxini*, Günther, 1866) Balığı Populasyonuna İlişkin (1995–1996). *Büyüme Karakteristikleri Değişimlerinin İzlenmesi. Ege Üniversitesi Su Ürünleri Dergisi* 12, 347–355. [In Turkish.]

Samsun O., Özdamar E. and Erkoyuncu İ. (1995) Sinop Yöresinde Avlanan Zargana (*Belone belone euxini*, Günther, 1866). *Balığının Bazı Balıkçılık Biyolojisi Parametreleri İle Et Veriminin Araştırılması. Doğu Anadolu Bölgesi II. Su Ürünleri Semp. Atatürk. Üniversitesi, Zir. Fak., Su Ür. Böl* 14–16 Haziran, 1–14. [In Turkish.]

Samsun O., Samsun N., Bilgin S. and Kalayci 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.

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

Sokal R.R. and Rohlf F.J. (1981) *Biometry—the principles and practice of statistics in biological research*. San Francisco, CA: W.H. Freeman.

Taylor C.C. (1959) Temperature and growth—the Pacific razor clam. *Journal du Conseil International pour l'Exploration de la Mer* 25, 93–101.

Tesch F.W. (1971) Age and growth. In Ricker W.E. (ed.) *Methods for assessment of fish production in fresh waters*. Oxford: Blackwell Scientific Publications, pp. 99–130.

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

Yüce R. (1970) Zargana Baliği *Belone belone* (L.) nin Biolojisi. *Hidrobiyol Arasti Enstit Yayinl* 75, 1–25. [In Turkish.]

Zorica B., Sinovčić G. and Čikeš Keč V. (2010) 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.

and

Zorica B., Sinovčić G. and Čikeš Keč V. (2011) Preliminary data on the study of otolith morphology of five pelagic fish species from the Adriatic Sea (Croatia). *Acta Adriatica* 51, 89–97.

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https://doi.org/10.1017/S002531541200149X Published online by Cambridge University Press