

# The reproductive cycle, size at maturity and fecundity of garfish (*Belone belone*, L. 1761) in the eastern Adriatic Sea

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Received: 1 June 2010/Revised: 6 October 2010/Accepted: 8 October 2010/Published online: 22 October 2010  
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**Abstract** A recent study concerning the reproductive biology of the garfish (*Belone belone*, L. 1761) has been carried out in the eastern part of the Adriatic Sea along the Croatian coastline. Specimens of the fish ( $N = 3,393$ ) were collected over a 6-year period (2003–2008). Their length varied between 20.8 and 75.4 cm (mean  $\pm$  SD =  $38.3 \pm 7.94$ ). Female garfish were dominant in larger length groups being most apparent during the resting phase of sexual cycle and in the peak of the spawning period, occurring in April and May. The sexual ratio of all specimens was  $m/f = 0.98$ . Males were prevalent in March—at the beginning of the highest spawning activities. Fifty percentage of the garfish population sexually matured at 28.5 cm of total length. Males and females reached their sexual maturity at 28.0 and 31.5 cm of total length, respectively. Spawning began in January peaking during March to May. According to their maturity stages, gonad weight and the gonadosomatic index, males began to spawn one month earlier (April) than females (May). The mean batch fecundity of garfish was  $1,242.46 \pm 843.64$  of matured oocytes per ovary. Matured oocyte diameters ranged from 1.223 to 4.283 mm with the mean value of  $2.269 \pm 0.332$  mm.

**Keywords** Sex ratio · Spawning season · Length at maturity · Batch fecundity

## Introduction

Garfish, *Belone belone* (Linnaeus, 1761), is an epipelagic migratory species, widely distributed in the north-eastern Atlantic, Mediterranean as well as the Black Sea, and is generally considered of minor commercial importance (National fishery statistics). Three subspecies have been recognised (Colette and Parin 1986): *B. belone belone* (Linnaeus, 1761)—restricted to the north-eastern Atlantic, *B. belone gracilis* Lowe, 1839—distributed from the south of France in the Mediterranean Sea to the Canary Islands in the Atlantic and *B. belone euxini* Günther, 1866—which is found in the Black Sea and the Sea of Azov. Garfish are mainly found in offshore areas, except for the spawning period when they migrate into coastal regions where they also are susceptible to commercial exploitation (Jardas 1996). In spite of its wide distribution in the Adriatic Sea, the knowledge of biology of this species is still incomplete and scarce.

The understanding of fish reproduction is essential considering the fact that information on size at maturity, spawning season, fecundity and sex ratio is fundamental for accurate stock assessments from which biological reference points can be derived to determine reproductive potential and status of the exploited stocks (Caddy and Mahon 1995). A few studies concerning some aspects of the reproductive biology of garfish were carried out for populations that inhabited the north-eastern Atlantic (Dorman 1989, 1991), the Black Sea (Samsun et al. 2006) and Aegean Sea (Uçkun et al. 2004). The present study was undertaken to investigate reproductive traits like sex ratio, size at sexual maturity, spawning period and fecundity of garfish distributed in the Adriatic Sea.

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Communicated by Arne Malzahn.

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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 (Fig. 1), with the exception of June when no garfish were found.

Monthly samples of *B. belone* were collected during the night using seine net with stretched mesh size of 10 mm (the main net) to 34 mm (the net cod end). The seine net, which is about 10–30 m deep and 100 m long, generally operates near the coastline (200–300 m from the coastline) depending on bottom configuration. Preferred sea depth for this type of fishing gear is deeper than 20 m. When a garfish school is located, the seine is settled around the school. Afterwards, encircled fish are pulled up on the anchored boat using a mechanical winch. A total of 3,393 individuals, 1,166 males and 1,195 females, were analysed in the laboratory immediately after landing. Total length (TL) ( $\pm 0.1$  mm) and total body weight (W) ( $\pm 0.01$  g) of each fish were measured. Sex and gonad maturity stages were assessed macroscopically, using a modified maturity scale defined by Sinovčić (1978) and Sinovčić et al. (2008).

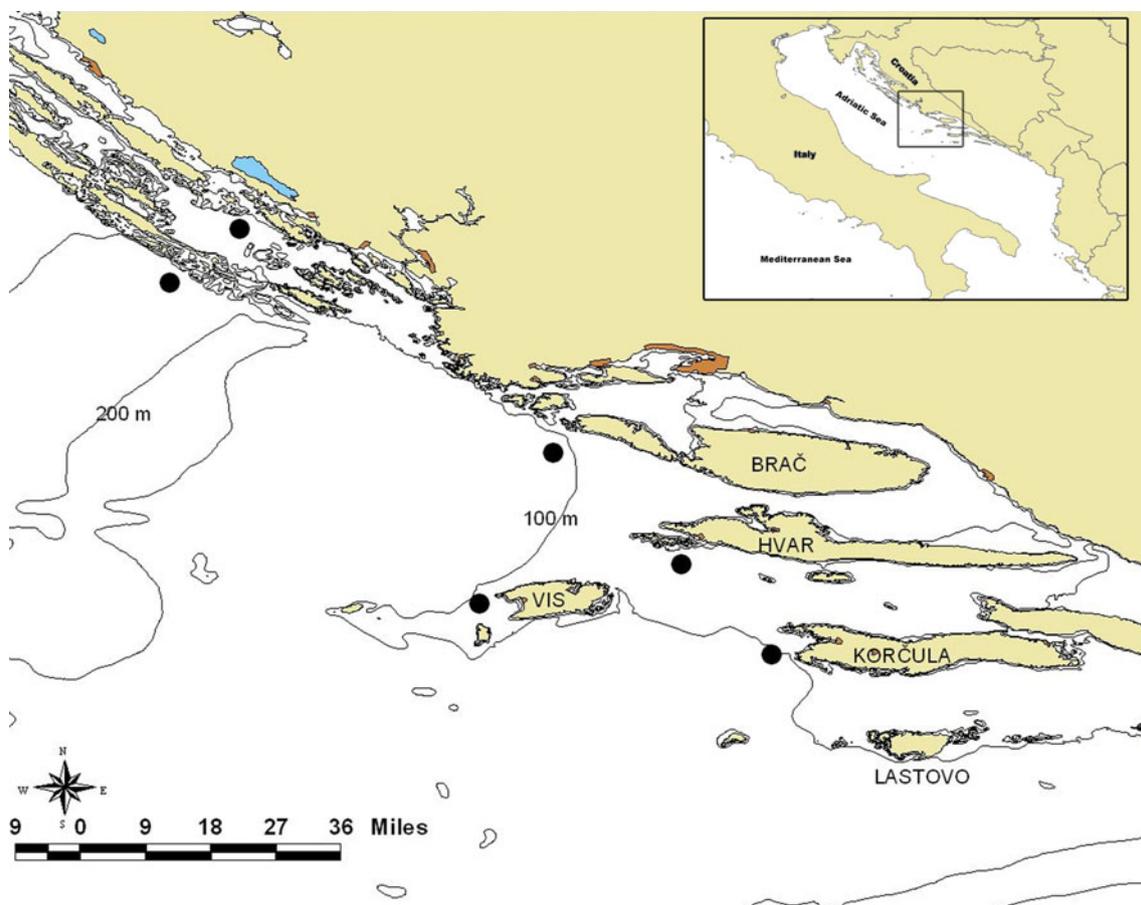
In order to reduce performed analyses, the stages were divided into four groups: immature (I and II), maturing (III and IV), ripe and spawning (V and VI), spent (VII and VIII). The overall sex ratio (males:females), sex ratio by size intervals (1.0 cm) and sex ratio by month were examined.

In order to determine size at maturity, only the matured individuals collected exclusively during spawning, with gonad maturity stages from ripe to spent, were taken into consideration. Size at maturity was determined by the proportion of spawning fish in each size class, fit into a logistic model:

$$P(x) = \frac{a}{1 + e^{b+cx}}$$

where  $P$  is the percentage of mature fish at length  $x$  and  $a$ ,  $b$  and  $c$  are constants.

Additional information on spawning seasonality was obtained by monthly changes in gonad weight, fluctuations of maturity stages and the gonadosomatic index. Values of gonadosomatic index were calculated by expressing the monthly gonad weight as a proportion of the total body



**Fig. 1** Study area, Middle Eastern Adriatic Sea with marked sampling sites

weight ( $GSI = \frac{100W_g}{W}$ , where  $W$  is the somatic fish weight and  $W_g$  is the gonad weight). During the spawning season, ripe and spawning gonads of garfish specimens ( $N = 50$ , in total) were taken for histological analysis. Histology was carried out not only to confirm macroscopically done stages of gonads but also to endorse garfish as batch spawners. They were fixed in 4% formaldehyde solution. After fixation, the gonads were dehydrated in alcohol and embedded in paraffin wax. Longitudinal or cross sections were made with a microtome. The section thickness was 10  $\mu\text{m}$ . Sections were stained with haematoxylin and eosin. Obtained histological sections of gonads were examined using a microscope. Oocytes were classified according to their morphology and the presence and position of lipid droplets, yolk vesicles and granules (Yamamoto and Yamazaki 1961). The spermatogenic cells were classified according to Grier (1981).

*Belone belone* is a batch spawner (Nikolsky 1954). To avoid biases when estimating batch fecundity, only ovaries with migrated nucleus oocytes and hydrated oocytes were used, while ovaries with recent postovulatory follicles were eliminated from fecundity calculations as their presence indicated that a part of the batch oocytes had already been released. Finally, 69 mature females were selected to estimate batch fecundity. Homogeneity distribution of the counted oocytes in an ovary was analysed by the use of three subsamples from different locations. Three pieces of ovary were sampled from the anterior, middle and posterior section of each gonad. Each subsample of gonad was weighed (accuracy  $\pm 0.01$  g) and subsequently put in Gilson's fluid (Agger et al. 1974) for 3–4 weeks to harden eggs and dissolve ovarian membranes and filamentous processes that cover the egg. After preservation, each subsample of gonad was observed under a binocular microscope (Olympus—magnification  $0.5 \times 3.5$ ) and its image was taken by a camera coupled to an Olympus binocular microscope and a PC. By image analysis and processing that was carried out using OLYMPUS DP-software, the number of matured oocytes (oocytes with migrated nucleus and hydrated ones) and the diameters of hydrated eggs (major axis;  $D$ ) were obtained. Batch fecundity ( $F$ , number of oocytes released per spawning) was estimated gravimetrically according to the method of Hunter et al. (1985), which was based on the number of matured oocytes in the ovary. Batch fecundity was determined as a product of scaling the average number of matured oocytes in subsamples to the weight of the whole ovary.

A one-factorial ANOVA was performed to analyse variability in fecundity between different locations within each ovary. No significant difference in fecundity estimates between the three different locations within the ovary

( $P < 0.001$ ) was noticed. Relative fecundity was expressed as the number of matured eggs per gram of total fish somatic weight. The absolute fecundity of garfish was recorded as the overall number of eggs in the ovaries. The relation between batch fecundity and total length and total somatic weight of the fish as well as ovarian weight were described using exponential and linear models.

Statistical analyses were performed with SPSS 5.5 software package, and a level of significance of  $\alpha = 0.05$  was accepted.

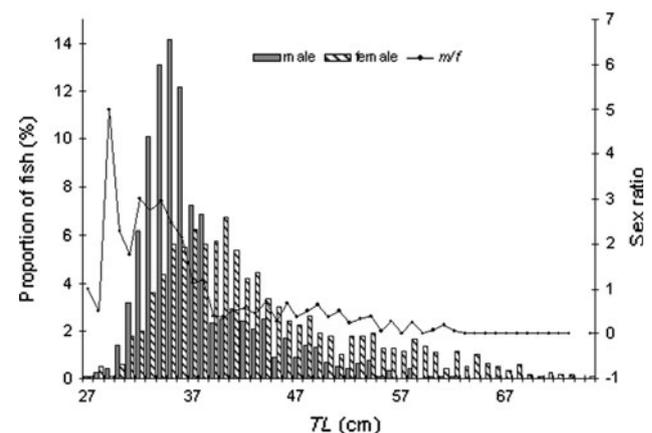
## Results

### Length structure

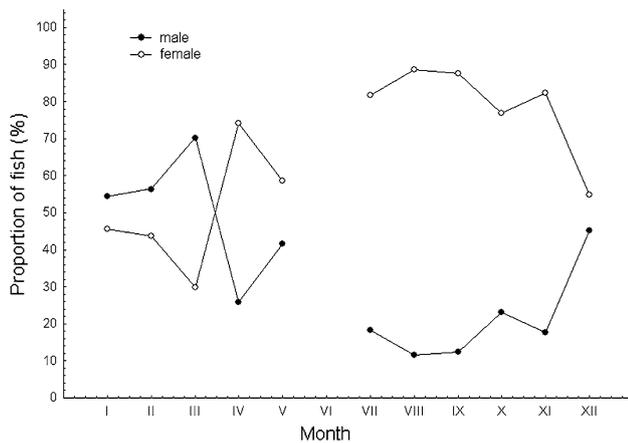
All observed specimens varied in total length from 20.8 to 75.4 cm (mean  $\pm$  SD:  $38.3 \pm 7.94$  cm) and between 12.21 and 639.25 g (mean  $\pm$  SD:  $70.33 \pm 68.53$  g) in total body weight. Males varied from 27.7 to 62.6 cm (mean  $\pm$  SD:  $37.4 \pm 5.37$  cm), and females varied from 27.2 to 75.4 cm (mean  $\pm$  SD:  $43.6 \pm 9.12$  cm) (Fig. 2). The total weight of males varied between 17.41 and 392.53 g (mean  $\pm$  SD:  $58.14 \pm 39.74$  g), whereas for females, it varied between 18.03 and 639.25 g (mean  $\pm$  SD:  $109.77 \pm 93.63$  g). No statistically significant difference between length distribution of male and female garfish specimens collected during the whole investigated period was detected (Kolmogorov–Smirnov test,  $P < 0.05$ ), although all specimens with  $TL > 62.5$  cm were exclusively female.

### Sex ratio

The sex ratio fluctuated with size—males were represented as smaller length sizes, while females were dominant at



**Fig. 2** Length frequency distribution of both sexes and the oscillations of sex ratio value with size of garfish specimens, Adriatic Sea, 2003–2008



**Fig. 3** Mean monthly sex ratio of garfish *Belone belone*, Adriatic Sea, 2003–2008

larger length classes (Fig. 2). Namely, the sex ratio of garfish specimens in length classes between 27.0 and 38.0 cm was in favour of males; the mean value was  $m/f = 2.18$ . The proportion of females increased in length class of 39.0 cm, while all garfish specimens  $TL > 63.0$  cm were females. Monthly variations of sex ratio, which are shown in Fig. 3, revealed the prevalence of males only during the first 3 months of the year. Afterwards, sex ratio was dominated by the female which attained its maximum value during August ( $m/f = 0.14$ ). The overall sex ratio ( $m/f = 0.98$ ) did not significantly deviate from the hypothetical distribution of 1:1 ( $\chi^2 = 0.332$ ,  $df = 1$ ,  $P < 0.05$ ).

#### Size at maturity

Garfish specimens with the most advanced stages of gonads (ripe, spawning and spent, with semi-hydrated and hydrated oocytes) were collected during peak of spawning (March–May). They were used for calculating maturity ogives and size at maturity. The smallest male and female sexually matured specimen was 28.0 and 30.0 cm long, respectively. The total length at which 50% of garfish population attain maturity was estimated by logistic regression at 28.5 cm of total length ( $r^2 = 0.929$ ), males at lower size (28.0 cm;  $r^2 = 0.915$ ) than females (31.5 cm;  $r^2 = 0.897$ ) (Fig. 4).

#### Spawning season

The monthly changes of different maturation stages are shown separately for male and female garfish individuals (Fig. 5). According to the monthly percentage composition of gonad maturity stages, immature garfish specimens were observed from the end of summer till the beginning of winter, with the maximum portion obtained during

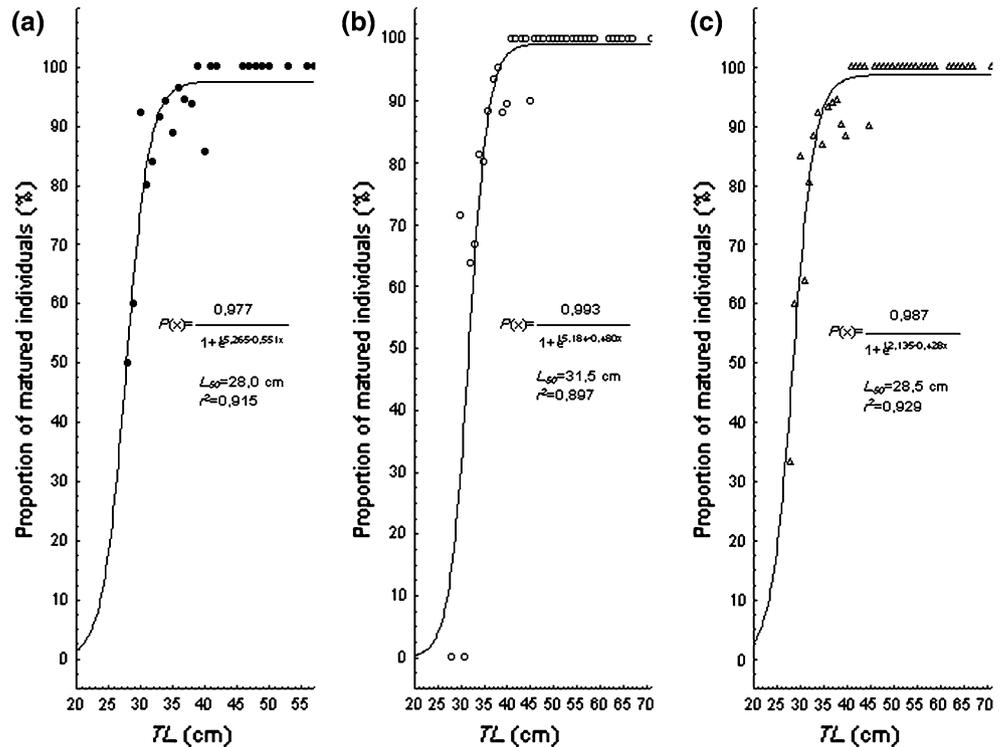
September. Maturing gonads appeared from September, but were most frequent at the end of autumn and at the beginning of winter. Ripe gonads occurred in December and dominated from March to May, when a major discrepancy between male and female garfish maturity stage was observed—the highest percentage of mature males was noticed in April (69.3%), while mature females dominated in May (69.0%). Gonads specified as spent and resting started appearing from May with the highest percentage obtained in July.

Seasonal alternations in mean monthly gonadosomatic indices as well as mean monthly values of gonad weight of males, females and overall analysed garfish specimens are shown in Fig. 6. A monthly variation in *GSI* (Fig. 6a) followed that of maturity stages of gonads (Fig. 5). A slight increase in gonadosomatic indices appeared in December (male:  $GSI = 0.515 \pm 0.285$ , female:  $GSI = 1.742 \pm 0.695$ , overall:  $GSI = 1.216 \pm 0.825$ ), after very low values during July–November period, peaking in April (males;  $GSI = 3.687 \pm 4.631$ ) and May (females  $GSI = 14.078 \pm 4.979$ ; overall  $GSI = 9.423 \pm 6.772$ ). Afterwards, a sharp decline in the *GSI* occurred.

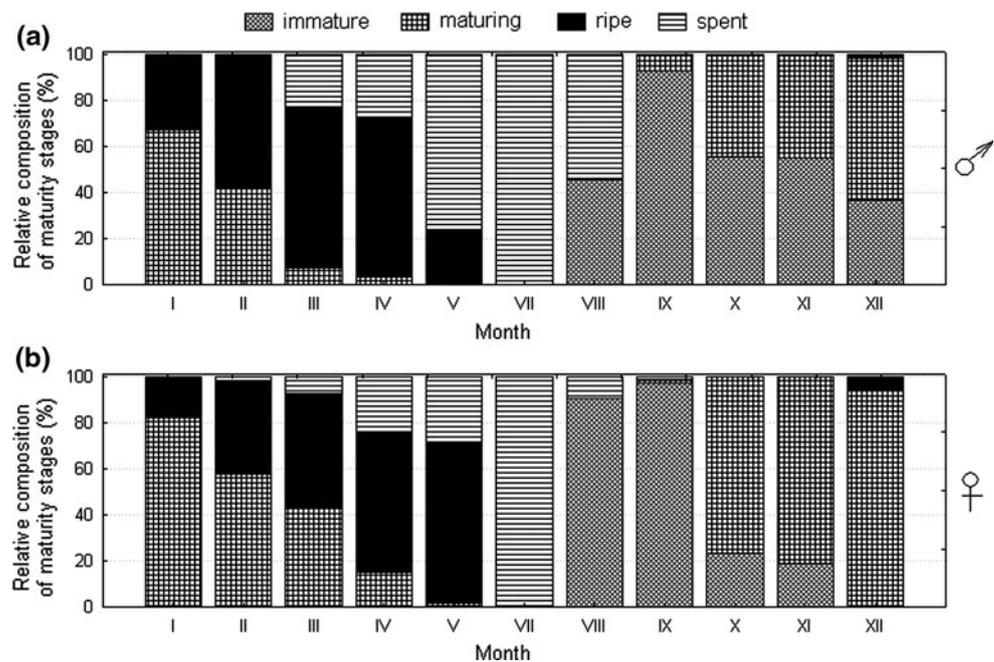
Monthly changes in testicular weight (Fig. 6b) followed the patterns of macroscopic stages and *GSI* values. Highest testicular weights were noticed from January ( $Wg = 1.12 \pm 0.87$  g) to April ( $Wg = 3.78 \pm 9.20$  g), when a peak was reached. The weight of testis declined sharply by July and only showed minor variation until December. A minimum value was obtained in September ( $Wg = 0.27 \pm 0.32$  g). As opposed to males, values of ovarian weight did not completely follow the same pattern of *GSI* values and monthly fluctuation of macroscopic maturity stages. Namely, over a growth period of gonadosomatic indexes (February–May) and during the dominance of ripe females, a sharp decline of ovarian weight was noted, precisely in March ( $Wg = 7.69 \pm 6.35$  g; Fig. 6b). The maximal ovarian weight was obtained in April ( $Wg = 16.02 \pm 15.68$  g), while the highest *GSI* value was in May. Afterwards, mean monthly values of ovarian weight, as well as *GSI* values, decreased and fluctuated at very low values till the beginning of January. The decline of ovarian weight was caused by the lack of bigger garfish individuals in the samples. In fact, monthly length frequency distribution of garfish specimens pointed out that samples collected in March and May, during the whole investigated period, contained only two specimens of total length higher than 50 cm. Out of samples collected in February and April, 118 garfish specimens had a total body length of more than 50 cm. Oscillations of combined male and female gonad weight were highly affected by ovarian weight and thus showed the same monthly pattern.

Male gonad weights ranged from 0.03 to 49.07 g, attaining an average 2.4% of the total body weight. The gonad weight of ripe males (maturity stage V and VI) did

**Fig. 4** Length at maturity for **a** male, **b** female and **c** overall specimens of *B. belone*, Adriatic Sea, 2003–2008



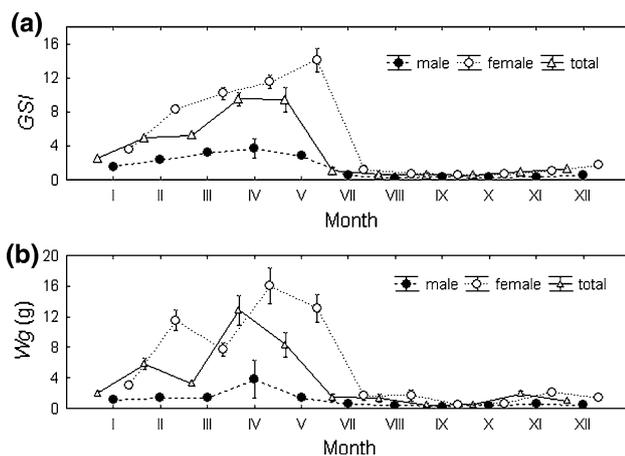
**Fig. 5** Monthly variations of **a** male and **b** female gonad maturity stages of *B. belone*, Adriatic Sea, 2003–2008



not show positive correlation with the weight of male garfish ( $W_g = 0.046 W - 0.904$ ;  $r^2 = 0.265$ ,  $N = 701$ ). Unlike males, gonad weight of active females was positively correlated with the total body weight ( $W_g = 0.112 W - 0.692$ ;  $r^2 = 0.674$ ,  $N = 455$ ). Ovaries were extremely high in weight ( $W_g$  range: 0.01–97.23 g) and attained up to 25.4%  $W$ .

**Histology**

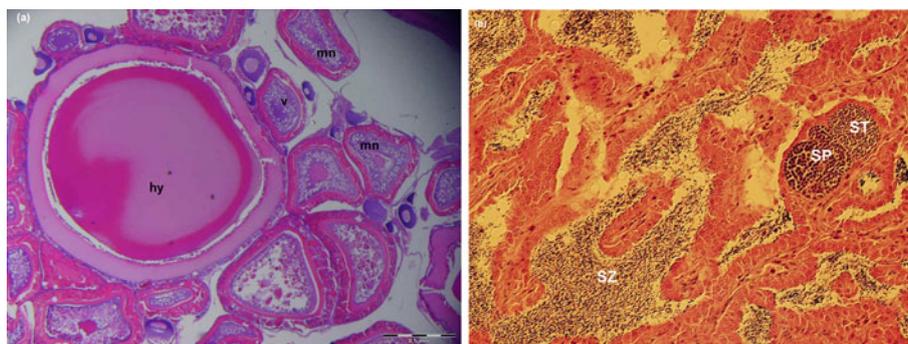
Histological examination of ovaries collected during the spawning season indicated a clear distinction between few groups of large oocytes (oocytes in the stage of vitellogenesis or migratory nucleus stages as well as the hydrated ones), and a more heterogeneous group of smaller oocytes



**Fig. 6** Monthly mean (mean  $\pm$  0.95 conf. interval) fluctuations of **a** gonadosomatic index—GSI and **b** gonad weight—Wg for male, female and overall garfish specimens, Adriatic Sea, 2003–2008

is possible (Fig. 7a). Histological analysis of ovaries that were macroscopically staged as ripe (maturity stage V or VI) indicated the presence of oocytes in the stage of vitellogenesis and postovulatory follicles.

Analysis of histological sections of the testes collected during the spawning period revealed that inside seminiferous tubules, the cysts were occurring. The cysts were formed of the spermatogenic cells in the same stages of spermatogenesis. In maturing and ripe testis, cysts of spermatocytes and spermatids, as well as sparse spermatogonia, were placed in the periphery, while the lobules lumen was congested with spermatozoa (Fig. 7b). The presence of germ cells at different developmental stages in tubules indicated extended gonad maturation and spawning.



**Fig. 7** Images of garfish gonad tissue: **a** ripe female (marked oocytes of three different development stages were v—maturing oocytes or oocytes in the stage of vitellogenesis in which the yolk granules that appeared first in the periphery of the cytoplasm increased in size and number dispersing within the cytoplasm, mn—ripe oocytes in which the fusion of several oil droplets resulted in the formation of a large oil droplet, which migrated towards animal pole together with the

## Fecundity

Batch fecundity ( $N = 69$ ) varied from 353.33 (fish  $TL = 37.8$  cm) to 4,711.09 (fish  $TL = 73.7$  cm) (mean:  $1,242.46 \pm 843.64$ ) matured oocytes per ovary. Relative batch fecundity was between 5.29 and 32.00 matured oocytes per gram of garfish body weight (mean:  $11.00 \pm 4.28$ ). The mean value of absolute fecundity was 23,595.62 oocytes per ovary, with the minimum and maximum value of 8,319.77 and 53,534.40 oocytes per ovary, respectively. Batch fecundity showed a significant positive exponential relationship with the total garfish length, total body weight and ovarian weight (Fig. 8).

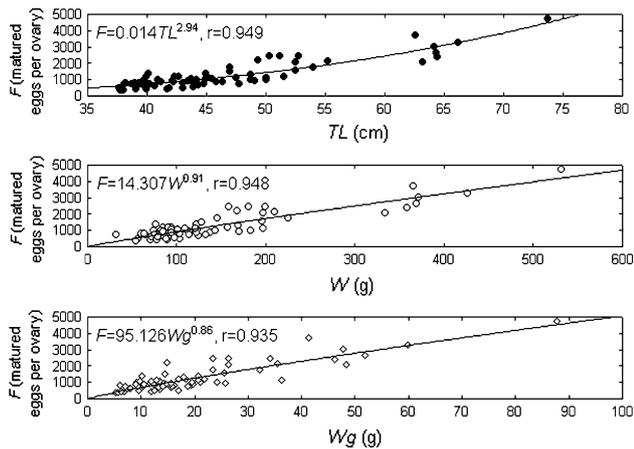
The diameter range of matured oocytes ( $N = 1,900$ ) was from 1.223 to 4.283 mm after preservation, with a mean of  $2.269 \pm 0.332$  mm. Statistically significant negative correlation was established between the diameter of matured oocytes and batch fecundity ( $F = 30,714-10,400D$ ,  $r = 0.6195$ ,  $P < 0.05$ ). Absolute fecundity slightly increased with the diameter of matured oocytes, but the increment was not statistically significant ( $r = 0.1978$ ).

## Discussion

### Length structure

In the present study, all 3,393 garfish specimens from the eastern part of the Adriatic Sea were analysed between January 2003 and December 2008 in order to determine reproductive biology of *Belone belone*. In comparison with the previous studies (Yüce 1970; Bedoui et al. 2002; Fehri-Bedoui and Gharbi 2004; Sinovčić et al. 2004; Uçkun et al. 2004; Samsun et al. 2006), the length range of

nucleus and hy—“hydrated oocyte” in which the yolk granules fused forming a continuous mass of fluid yolk and with its formation the spawning is initiated), **b** ripe male (marked cells were SP—Spermatocytes—small oval cells; ST—Spermatids—cells with larger and rounded nucleus and SZ—Spermatozoa—the cells developed from spermatids when they were rejected into the cyst cavity as the spermatogenesis was coming to an end)



**Fig. 8** Exponential relationship between batch fecundity ( $F$ ) and total garfish length ( $TL$ ), weight ( $W$ ) and ovarian weight ( $Wg$ ) with associated coefficients of correlation ( $r$ )

garfish specimens in the present study is the widest reported till now for garfish specimens inhabiting the Adriatic Sea, Mediterranean and Black Sea. Garfish length frequency distribution reported in this study, as well as in the earlier studies, addresses the scarcity of young garfish specimens, even though the mesh size of fishing gear (10–34 mm) and fishing technique that cover the water column from waterline up to 20 m should ensure a successful collection of smaller garfish specimens. Thus, this study endorses Dorman (1991) that smaller and probably immature specimens do not accompany their elders.

### Sex ratio

Analysis of sex ratio at the size of garfish pointed out that the proportion of female fish increased gradually with the fish length; males were dominant at smaller total length values (Fig. 2). A similar trend of sex ratio at size was observed for a garfish population from the Atlantic (Dorman, 1991). Namely, Dorman reported male domination at smaller and female at higher length classes ( $TL > 80.0$  cm). The observed difference in sex ratio at size is probably due to sexually dimorphic growth patterns (Moreno and Morales-Nin 2003). Additionally, higher difference in sex ratio at size could also be attributed to fishing gear and its vulnerability and selectivity.

Monthly alternations of sex ratio are probably associated with spawning migrations. In the majority of studies focusing on eggs and larvae of this species (Demel 1937; Gąsowska 1962; Rosenthal and Fonds 1973; Dorman 1991; Korzelecka–Orkisz et al. 2005), garfish are reported to migrate towards coastal areas for spawning. There they become much more exposed to fishery. After spawning, garfish specimens leave the costal area and get back to deeper, open sea waters. This type of spawning migration

was also observed in this study and in some way, it could be confirmed by the fact that during this 6-year period of investigation, despite fishing efforts, samples of garfish were not collected in June.

Regardless of sex ratio fluctuations in relation to size and month, overall sex ratio did not differ significantly from the hypothetical distribution of 1:1. In general, the sex ratio in a population is a key demographic parameter, and an equilibrium sex ratio of 1:1 known as ‘Fisherian’ is the only evolutionarily stable strategy (Hamilton 1967). From an ecological point of view, a female-biased sex ratio is certainly more desirable because the reproductive potential of fish species is determined by the number of matured females and their capacity to produce viable eggs and larvae (Murua et al. 2003). This balanced sex ratio was also reported by Yüce (1970) for a garfish population caught in the Aegean Sea. Other scientists who studied this species reported dominance of females in the catches: Bedoui et al. (2002)— $m/f = 0.82$ ; Fehri-Bedoui and Gharbi (2004)— $m/f = 0.69$ ; Uçkun et al. (2004)— $m/f = 0.45$  and Samsun et al. (2006)— $m/f = 0.52$ . Only Dorman (1991) recorded prevalence of males ( $m/f = 1.59$ ) in a population from the Atlantic. Mentioned differences in sex ratio could also be a matter of sampling strategies that covers different periods of the spawning/migration cycle.

### Size at maturity

The estimated maturity size of garfish reported in this paper is lower than those published by other researchers (Table 1). Nevertheless, garfish specimens analysed in this study were the smallest specimens ever collected and reported for comparable studies; observed differences between lengths at sexual maturity in divergent geographical areas suggest that this species is not resistant to environmental changes; hence, its reproductive parameters do not remain stable during unfavourable conditions (Domínguez-Petit et al. 2008). Changes in maturity ogives could be associated with sample size and/or their level of exploitation as it is known that during a collapse of the population due to over exploitation, age at maturity diminished, whereas size at maturity increased slightly, probably as a compensatory response (Morales-Nin et al. 2002; Engelhard and Heino 2004).

### Spawning season

According to monthly changes of maturity stages,  $GSI$  and gonad weight, garfish exhibit an annual spawning cycle that extends over 6 months in the early winter–spring period (December–May) (Fig. 5). Male gonads attained ripeness 1 month before female gonads; male peak spawning took place in April, while the spawning peak for

**Table 1** Spawning season and length at first maturity of *B. belone* from various geographical regions

Author	Geographical area	Spawning season	Length at maturity ( $L_{50}$ ) (cm)
This study	Adriatic Sea	January–May	28.5
Colette and Parin (1986)	Mediterranean (Spain)	February–May	
Bedoui et al. (2002)	Mediterranean (Tunis)	March–May	36.46
Colette and Parin (1986)	Black Sea	April–September	
Samsun et al. (2006)	Black Sea	May–September	38.8
Yüce (1970)	Aegean Sea	April–August	
Uçkun et al. (2004)	Aegean Sea	April–August	
Rosenthal and Fonds (1973)	Atlantic	May–June	
Colette and Parin (1986)	Atlantic	May–June	65.0
Dorman (1989, 1991)	Atlantic	May–June	

females was attained in May. In general, monthly variations of maturity stages, *GSI* values and gonad weight had almost the same pattern. Only a slight deviation was noticed during March–May period in the fluctuation of ovarian weight that directly affected overall variation of gonad weight.

Data concerning the spawning season of fish species differ depending on the geographical area, food accessibility and redundancy, as well as abiotic factors (temperature and salinity) (Westernhagen 1974). Concerning the differences in spawning periods as well as size at maturity for different garfish populations (Table 1), it is obvious that the spawning season of garfish populations in the Mediterranean is quite similar—from winter till the end of spring, while in other areas, spawning starts in the middle of spring and peaks in summer.

### Histology

Histological examination of gonad tissue confirmed anticipation that garfish is a batch spawner with group-synchronous oocyte development and indetermined fecundity (Murua et al. 2003). With the extended spawning season (January–May) and batch spawning, garfish ensured itself with a higher probability to find suitable conditions for larval survival. In that way, recruitment level could be increasing as James et al. (2003) reported earlier for other fish species.

### Fecundity

A paper published earlier on fecundity of this species carried out quite similar values of absolute fecundity. Thus, Yüce (1970) reported the range of absolute fecundity 10,196–48,903 oocytes per ovary, while Samsun et al. (2006) estimated the average absolute fecundity of 24,088 oocytes per garfish ovary. Range values of garfish batch fecundity were given by Dorman (1991) who reported the

range of 2,193–10,804 hydrated oocytes per ovary; then, Uçkun et al. (2004) estimated the range between 1,066 and 20,446 hydrated oocytes per ovary. Stated ranges were wider than those reported in this study. The discrepancy was probably caused by the difference in temperature regime from the Adriatic Sea, Mediterranean and Atlantic. Namely, according to Kjesbu et al. (2010), the differences in temperature are probably a major driving force for the differences that are noticed in size at maturity and fecundity. It is known that fecundity varies annually (Sinovčić 1983–1984; Rijnsdorp 1991; Kjesbu et al. 1998). As it is a size-dependent parameter, it is possible that the differences concerning fecundity could be explained by the size of garfish in each region. Differences obtained in fecundity values could also result from responses to different environmental conditions (temperature, available food) to which the species is trying to adapt (Witthames et al. 1995; Murua et al. 2003; Ganius 2009). Relatively low values of garfish fecundity are associated with quite large eggs (average diameter of matured oocytes =  $2.269 \pm 0.332$  mm). Namely, it was established that as the diameter of matured oocytes increase the batch fecundity significantly decrease. Obtained diameter of matured garfish oocytes is in accordance with previously reported findings. Thus, Dorman (1991) reported that the range of matured oocytes diameter was between 0.1 and 3.0 mm with a mean value of 2.0 mm. Uçkun et al. (2004) found that the average diameter of matured oocytes was 1.84 mm, while the minimum and maximum diameter was 0.4 and 4.0 mm, respectively. For the garfish population that inhabits the Baltic Sea, average egg diameter  $3.27 \pm 0.15$  mm (range: 2.95–3.70 mm) is reported by Korzelecka–Orkisz et al. (2005).

The exponential relationships between batch fecundity and total body length, weight and ovarian weight have been established (Fig. 8). It has been noted that batch fecundity was almost equally related to those three parameters; the coefficient of correlation for all of them was  $\geq 0.94$ . Obtained relationships indicated that batch fecundity

depends on the total body length, total body weight and ovarian weight—larger and heavier garfish individuals with weightier gonads produce more eggs. That was also confirmed by the obtained regression equation between ovarian weight and the total garfish weight during the spawning season ( $Wg = 0.112 W - 0.692$ ;  $r = 0.821$ ). An exponential relationship between absolute fecundity and total body length of garfish was also approved by Samsun et al. (2006). Dorman (1991) attained linear relationship between batch fecundity and the total body length for garfish inhabiting the Atlantic.

These results concerning the reproduction pattern of the garfish population inhabiting the Adriatic Sea contribute to a better understanding of basic reproductive biology of the investigated species, but further research needs to be done, particularly of the juvenile garfish.

**Acknowledgments** 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)”. Referees’ comments and suggestions are greatly appreciated.

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