Journal of Applied Ichthyology

J. Appl. Ichthyol. 26 (2010), 436–440

ISSN 0175–8659

Received: December 27, 2008
Accepted: August 20, 2009
doi: 10.1111/j.1439-0426.2009.01382.x

Age, growth and sexual development of solenette, *Buglossidium luteum* (Risso, 1810), in the central Aegean Sea

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Summary

Age, growth, spawning period and maturity of the solenette (*Buglossidium luteum* Risso, 1810) were studied in the central Aegean Sea to provide fisheries managers with essential data for science-based management. A total of 1220 samples were collected by trawl hauls from July 2004 to June 2007 in İzmir Bay (Turkey). Sample sizes ranging from 5.3 to 11.6 cm total length were composed of 46% females, 32% males and 22% immature individuals, with a female to male ratio of 1 : 0.7. Age composition stages of the females were from I to IV, and males between I and III. The length–weight relationship was calculated as $W = 0.0101L^{3.008}$ for all samples. Estimated von Bertalanffy growth parameters were $L_\infty = 13.30$ cm, $t_o = -0.440$ year and $k = 0.481$ year^{-1}, with a growth performance index of 1.93 (φ'). The spawning period began in April and continued until July. Lengths at first maturity of females and males were 8.1 and 7.9 cm total length, respectively. Both sexes matured at the age of 2 years.

Introduction

The solenette (*Buglossidium luteum* Risso, 1810) is the smallest species of the Soleidae, usually reaching only 10–13 cm total length (Wheeler, 1969); maximum total length reported was 15 cm (Bauchot, 1987). The family comprises closely related and poorly defined species, which makes their classification difficult (Massutí et al., 2002). Solenette is a demersal marine fish that lives at depths of 5–450 m (Muus and Nielsen, 1999) but usually is found between 10 and 40 m (Quéro et al., 1986). Geographic range for this species is from the eastern Atlantic (Iceland and Scotland southward) to the North Sea, Kattegat and the Baltic as well as the Mediterranean Sea (including the Adriatic, Sea of Marmara, and Bosporus) (Froese and Pauly, 2009). Solenette is rarely found inshore and does not make any pronounced migrations (Wheeler, 1969). Although flatfish have generally specific preferences for bottom substrate, the distribution and abundance of solenette are not related to sediment type (Amezcua and Nash, 2001).

The solenette is not a commercial or attractive fish species but appears in by-catch and as discards. Like many non-commercial fish species, little is known about the characteristics of the solenette populations. The species biology, such as growth, feeding, reproduction and fecundity aspects are partially known. Biological characteristics of the solenette have been studied by Nottage and Perkins (1983) in Solway Firth (England); growth, feeding and distribution by Amara et al. (2004) along the coasts of the French Atlantic, eastern English Channel and Southern Bight of the North Sea. Deniel (1984) reported some information on reproduction and fecundity in Douarnenez Bay (Brittany, France). Baltus and Veer (1995) presented data on nursery areas of the species in the southern North Sea. Morais (2006) studied its growth and spawning season in the western Mediterranean. For the Aegean Sea only the length–weight relationship of the species has been studied (Bayhan et al., 2008); no information is available concerning its age, growth, population structure or reproduction for this area.

The present paper aims to provide new findings on age and population parameters such as length distribution, sex ratio, length–weight relationship, growth, spawning period, first maturity age and length of the solenette for the central Aegean Sea, and to provide data that could be useful for management.

Materials and methods

Solenette samples for the study were collected from trawl hauls in İzmir Bay (38º40′N 26º31′E and 38º2′N 26º8′E) by R/V 'Egesüf' (26.8 m length, 463 HP engine and 110 gross tonnes). The sampling period was carried out midday and collected in monthly intervals from July 2004 through June 2007. Trawl surveys were performed using a conventional bottom trawl in 30–70 m depths on sandy and muddy bottoms. Towing duration was one hour for all hauls and average towing speed was 2.3 knots (ranging from 2.2 to 2.4). The cod-end was knotless diamond shaped mesh and made of polyamide (PA) material with 22 mm stretched mesh size.

All captured samples were collected and transported in ice to the laboratory for analysis whereby total length (LT) was measured in the natural body position to the nearest mm. Total weight (W) and gonad weight (W_g) were measured to the nearest 0.01 g, and the sexes were recorded. Sagittal otolith pairs were removed for each length group.

Individuals were sexed by macroscopic inspection of the gonads as females, males or immature. Maturity stages were assessed according to Gunderson's (1993) scale: stage I, immature; stage II, resting; stage III, developing; stage IV, ripe; and stage V, spent. The sex ratio (female : male) was calculated as the number of males divided by the number of females. The chi-square (χ^2) test was used to detect differences in the sex ratio and one-way ANOVA was done to analyze differences in mean length of the sexes.

The relationship between length and weight was established as $W = aL^b$, where W is total body weight (g), L is total length (cm), and a and b are coefficients (Ricker, 1973). The parameters a and b of length–weight relationships were estimated by linear regression analysis on log-transformed data. The association degree between variables was calculated by the determination coefficient (R^2). Prior to the determina-

tion of length–weight relationship the data was checked for outliers (Barnett and Lewis, 1994). The growth type was identified by Student's *t*-test.

Sagittal otoliths were used for age determination. A total of 336 individuals were selected randomly to represent all length groups, and the sagittal otolith pairs were removed, cleaned and stored in dry conditions inside the U-plate. Considering their physical and chemical characteristics, some otoliths were prepared for age readings by profiling, rubbing and polishing. They were imbedded in polyester molds, cut by an Isomet low-speed saw, polished with sandpaper (type 400, 800, and 1200), and finally polished with 3, 1, and ¼ μ particulate alumina (Metin and Kınacıgil, 2001). Age determination was performed using a stereoscopic zoom microscope under reflected light against a black background. Opaque and transparent rings were counted: one opaque zone together with one transparent zone was considered to be the annual growth indicator. Age estimations were made by two independent readers.

Growth was analyzed by fitting the von Bertalanffy growth function to size-at-age data using standard nonlinear optimization methods (Sparre and Venema, 1998). The function $L_t = L_\infty[1–e^{-k(t–to)}]$ was applied to the data, where L_t is the fish length (cm) at the time t (year), L_∞ is the asymptotic length (cm), k is the growth coefficient (year^{-1}), and t_o (year) is the hypothetical time at which the length is equal to zero. Accuracy of the growth parameters was tested using Munro's growth performance index ($\varphi' = \log(k)+2\log(L_\infty)$) and *t*-test (Pauly and Munro, 1984).

The spawning period was established by monthly variations of the gonadosomatic index (*GSI*) from the equation $GSI = [W_g/(W\text{-}W_g)]*100$, where W_g is the gonad weight (g), and W is the total weight (g) of the fish (Ricker, 1975).

Length at first maturity (L_m) was defined as the length at which 50% of the population investigated is near-spawning (King, 1996). LogLog function was used to assess the proportion of the mature individuals by size class using a nonlinear regression. The equations $r(l) = \exp(-\exp(-(a+bl)))$ and $L_m = (-\ln(-\ln(0.5)) - a)/b$ were applied, where $r(l)$ is the proportion of mature fish in each length class (%), l is the fish length (cm), L_m is the mean length at sexual maturity (50%, cm), a is the intercept and b is the slope.

All statistical analyses were prepared with the 'R 2.8.0' package (R Development Core Team, 2008).

Results

In this study, a total of 1220 individuals were sampled during the study period. The minimum size observed was 5.3 cm (1.50 g) in April while the maximum size was in November with a 11.6 cm (16.04 g) total length. Average total length and total weight of the individuals were calculated as 8.52 ± 0.02 cm and 6.45 ± 0.05 g ($\bar{x} \pm se$), respectively. It was determined that 46.1% of the samplings were females (n = 563), 32.4% males (n = 395) and 21.5% immature (n = 262), and the sex ratio was calculated as 1 : 0.70 (F : M). The average length and weight of the females was 8.70 ± 0.03 cm, 6.83 ± 0.07 g; and for males 8.33 ± 0.03 cm, 6.03 ± 0.07 g. The ANOVA and chi-square analyses showed that average body length and weight between sexes ($F_L = 62.7$, $F_W = 54.6$, $P < 0.05$) and the sex ratio are statistically significant ($x^2 = 29.5$, $P < 0.05$).

Because there was a significant statistical difference between values of male and female individuals, the length–weight regression was calculated separately for females, males and all samples. The overall length–weight equation was $W = 0.0101L^{3.00}$, for females $W = 0.0093L^{3.04}$, and for males $W = 0.0094L^{3.04}$ (Fig. 1). The *b*-values showed no significant difference from isometric growth for both sexes (for females 95% CI of b (CI_b) = 2.99–3.10; for males CI_b = 2.97–3.11) and all fishes (CI_b = 2.97–3.04, *t*-test, P > 0.05).

Monthly average gonadosomatic index (GSI) values of females and males are given in Fig. 2. In both sexes, gonads start to mature in January. A maximum average GSI value was shown in April for females (2.48) and in March for males (0.62). It was observed that reproduction began in April and continued until July. Furthermore, a second smaller peak of GSI was shown in September for females; however, this was not observed in males.

According to results of otolith readings, age distribution of individuals varied between I and IV. Age group II (74.8%) was dominant, followed by age groups I (23.6%), III (1.5%) and IV (0.2%). Solenette achieve a mean length of approximately 6.7 cm the first year; 9.3 cm the second; 10.7 cm the third; and

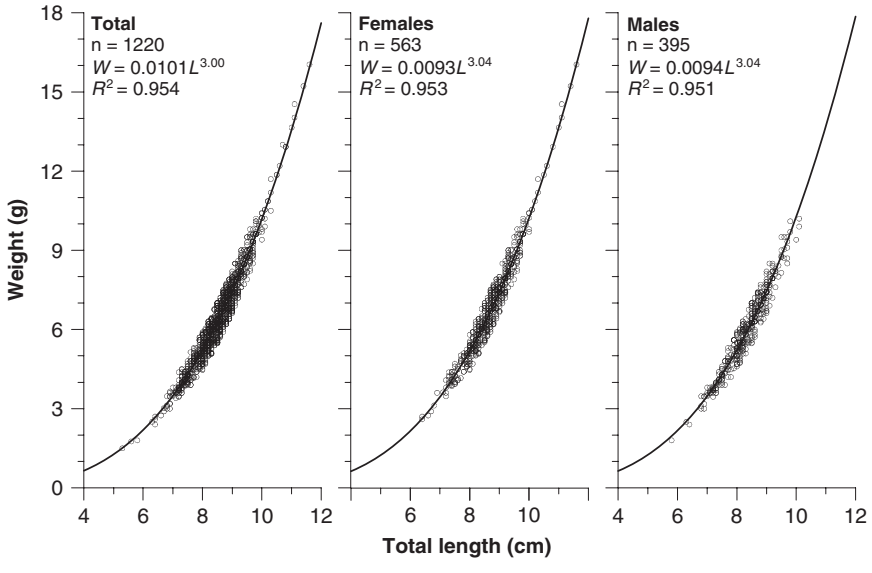

Fig. 1. Length–weight relationships of solenette (*Buglossidium luteum*): total, females and males, central Aegean Sea

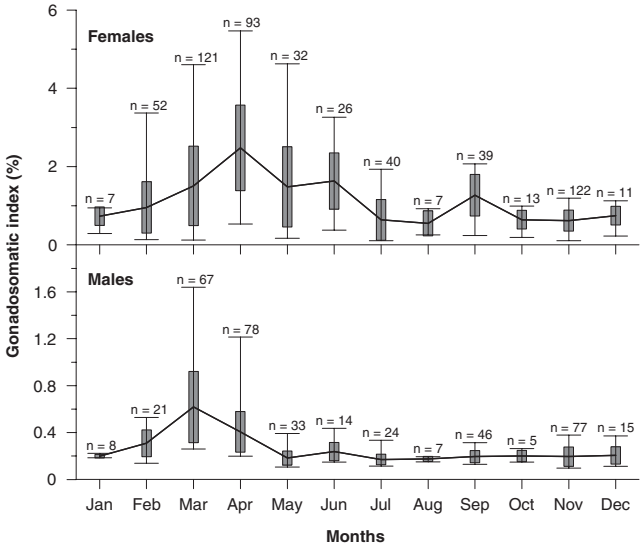

Fig. 2. Monthly average gonadosomatic index (GSI) values (%) with number of fish analyzed, minimum-maximum range and standard error per month for solenette (*Buglossidium luteum*) females and males, central Aegean Sea

11.6 cm in the fourth year. The infinite length (L_∞) 13.30 cm, infinite weight (W_∞) 22.93 g, and theoretical age of the fish prior to hatching from the egg was (t_o) –0.440 year; the growth coefficient (k) was 0.481 year^{-1} (R^2 = 0.988). For all fish, the growth model was $L_t = 13.3[1-e^{-0.481(t+0.44)}]$.

It was observed that the smallest female was 6.4 cm (1-year-old) and the male 5.8 cm total length (1-year-old). Gonad maturity in 50% of the individuals was at 8.12 cm total length for females and 7.89 cm for males (Fig. 3). $r_f = \exp(-e^{-(-22.219+2.736l)})$ (R^2 = 0.810), $r_m = \exp(-e^{-(-19.001+2.408l)})$ (R^2 = 0.752). The sexual maturity age was found to be at age 2 for both sexes.

Discussion

Solenette is the smallest sole species among sole in Turkey. Therefore the fishing gear and its features used in sampling are very important. In this study, a bottom trawl was used for sampling, while Nottage and Perkins (1983) and Amara et al. (2004) used a beam trawl. For proper sampling with towed fishing gear the most important feature is the mesh size of the cod-end. The present study and Nottage and Perkins (1983) used 22 mm stretched mesh size, but Amara et al. (2004) used a 20 mm cod-end for the sampling. The data set of this study ranged between 5.3 and 11.6 cm, while the Nottage and Perkins (1983) and Amara et al. (2004) sample ranges were 5.9–13.0 and 2.3–12.5 cm total length, respectively. This variation in the length range could be attributed to the fishing gear, as well as to selectivity of the gear.

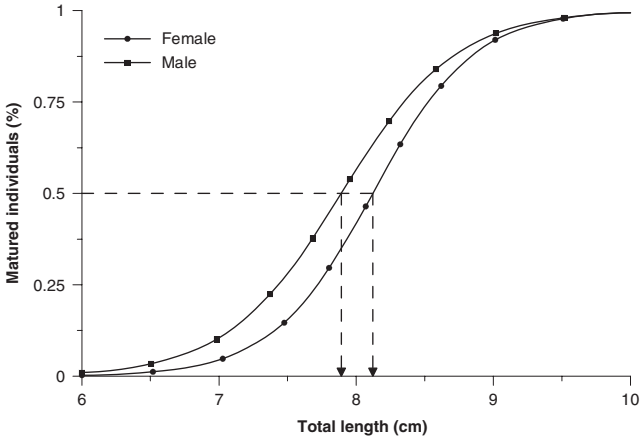

Fig. 3. Length at first maturity estimation of female and male solenette (*Buglossidium luteum*), central Aegean Sea

Although the length ranges of sexes and the sex ratio were different, the curves of the length–weight relationships were quite similar, and the growth type was isometric for females, males and all samples. Pereda and Villamor (1991) and Bayhan et al. (2008) also reported a similar growth type for Cantábrico as well as the same study area as in the present study. In contrast, negative allometric growth was reported for the South Atlantic coast of Spain (Mata et al., 2008) and positive allometric growth was reported for Douarnenez Bay by Deniel (1984) (Table 1). The b-values are often 3.0 and range between 2.5 and 3.5, and each fish population may differ according to the species, sex, age, sexual maturity of fish, season and fish feeding (Ricker, 1975). Furthermore, the data include early juveniles, which in most fishes have not yet obtained adult body shape (Safran, 1992); also included are very old specimens, which often have distorted body forms with unusually high proportions of fat (Froese, 2006); additionally, insufficient sample sizes which have a very narrow length size, can influence growth type determination.

The sagittal otoliths were used to identify the age. For large sized samples the otoliths were prepared for age readings by cross-section, because of their physical structure. For the same reason Nottage and Perkins (1983) used both otolith and vertebrae for age determination. We found that the solenette ranged up to age group IV. However, Nottage and Perkins (1983) reported the maximum age as X. This is a pretty big difference and probably due to the regional differences in environmental factors. Related to this, Ross (1988) noticed that cool waters produce larger, older and later-maturing individuals of a species than do warm waters. Female individual total length ranged between 6.4 and 11.6 cm, and the maximum age was IV. But males ranged from 5.8 to 10.1 cm total length, and the maximum age was III. This result indicates that females have a relatively long life span compared to male individuals. Greater longevity might also explain the sex ratio (1 : 0.70) in favor of females. Female dominance was also reported by Nottage and Perkins (1983) as 1 : 0.75 for Solway Firth.

The theoretical maximal length value was calculated as being greater than the size of the largest fish, and the growth coefficient value indicated a relatively high attainment of maximal size. The equation also shows that most growth occurs in the first year of life. Solenette attained 50.4% of the asymptotic size in the first year of life. Similar results were also reported by Nottage and Perkins (1983) and Amara et al. (2004). It was observed that the estimated infinite length was higher than at Douarnenez Bay, but lower than in the western Adriatic Sea. Differences were also shown in the growth coefficient and lowest k value calculated for this study. The differences in growth can probably be attributed to variations in habitat. The growth performance index (φ') was calculated as 1.93 for this study; this parameter was calculated as between 1.76 and 2.2 in previous studies. As the infinite length was not given by Nottage and Perkins (1983) or Amara et al. (2004), the growth performance index value could not be calculated for the west coast of Britain (Solway Firth) or the northeastern

Table 1
Comparison of study results on solenette (*Buglossidium luteum*) sampling size, range and age; length–weight relationship; growth parameters and performance index

Study area	n	L	t	a	b	L_∞	k	t_o	φ'	References
Solway Firth (United Kingdom)	403	5.9–13.0	1–10	–	–	–	–	–	–	Nottage and Perkins (1983)
Northeast Atlantic (English Channel, Southern Bight and Biscay Bay)	–	2.3–12.5	–	–	–	–	0.49[a] 0.64[b]	–	–	Amara et al. (2004)
Cantábrico (Spain)	16	6.0–12.0	–	0.00738	3.092	–	–	–	–	Pereda and Villamor (1991)[c]
South Atlantic (Spain)	222	5.5–9.5	–	0.001	2.54	–	–	–	–	Mata et al. (2008)
İzmir Bay (Turkey)	28	7.3 – 9.6	–	0.0240	2.566	–	–	–	–	Bayhan et al. (2008)
Douarnenez Bay (Brittany)	357	–	–	0.00548	3.267	–	–	–	–	Deniel (1984)[c]
Douarnenez Bay (Brittany)	–	–	–	–	–	11.7[a] 9.8[b]	0.54[a] 0.606[b]	−0.504[a] −0.447[b]	1.87[a] 1.76[b]	Deniel (1990)[c]
Western Adriatic Sea	–	–	–	–	–	14.5	0.76		2.20	Giovanardi and Piccinetti (1981)[c]
İzmir Bay (Turkey)	1220 563[a] 395[b]	5.3–11.6 6.4–11.6[a] 5.8–10.1[b]	1–4 1–4[a] 1–3[b]	0.0101 0.0093[a] 0.0094[b]	3.00 3.04[a] 3.04[b]	13.30	0.481	−0.440	1.93	Present study

n = sample size; L = length range; t = age range; a and b = intercept and slope of the length–weight relationship; L_∞, k and t_o = parameters of von Bertalanffy growth equation; φ' = Munro's growth performance index.
[a]Female.
[b]Male.
[c]From Froese and Pauly (2009).

Atlantic (English Channel, Southern Bight and Biscay Bay). The *t*-test showed no significant differences between the growth performance indexes in the other areas ($P > 0.05$).

The monthly average GSI reached the highest value of 2.48 in April for females and 0.62 in March for males. The spawning period of solenette started in April and continued until July. The reproduction period was reported by Nottage and Perkins (1983) to be between March and April in Solway Firth and by Quéro et al. (1986) to be from July to August in western Ireland and the western part of the English Channel. The spawning period has a close relationship to the ecological characteristics of the water system in which the species live. The lengths at first maturity of females and males were 8.12 and 7.89 cm total length, respectively. These values coincided at about age-2 in both sexes. Nottage and Perkins (1983) reported maturity at age-3 in females and males. This difference can be explained as being in differing bio-ecological conditions.

This work determined the length distribution, sex ratio, length–weight relationship, age, growth, spawning period, first maturity age and length features of solenette; these findings provide information necessary for successful fisheries management. Although this study increases our understanding of the species, further research is needed on factors where knowledge is lacking, such as that of fecundity and feeding.

Acknowledgements

The present study was carried out with financial support from The Scientific and Technological Research Council of Turkey (TUBITAK) project 103Y132, and Ege University Science and Technology Center (EBİLTEM) project 2005 ⁄ BİL ⁄ 003. We would like to thank Marga McElroy for revising the English text.

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