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Age, growth and otolith morphometrics of *Serranus hepatus* (L., 1758) in two areas of the Eastern Mediterranean

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Research Article

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Abstract

Serranus hepatus is a bycatch species in the Mediterranean trawl fishery for which knowledge on biological features such as otolith morphology is generally poor in the Mediterranean Sea. In the present study, the weight–length relationship, age, growth and ten otolith morphometric variables of this species were investigated in two distant areas, the Eastern Ionian and southwestern Aegean Seas. Isometric growth in weight was defined in both areas. Growth parameters also did not differ between the two study areas. Six of the otolith variables (radius, otolith length, otolith width, otolith area, perimeter and ellipticity) showed a significant relationship with size without significant differences between the two areas. Significant differences between the two areas were only defined for five of the morphometric variables (otolith length, width and area being the most important). Further studies to discriminate between potential stocks of *S. hepatus* seem to be necessary, information that is needed for stock identification, stock assessment and fisheries management.

Introduction

The brown comber, *Serranus hepatus* (Linnaeus, 1758), is a small-sized demersal fish that belongs to the family Serranidae. It occurs in the Eastern Atlantic, Mediterranean and Black Seas. The species inhabits sandy and muddy bottoms with seagrass and rocks at depths ranging from 5 to 200 m (Smith, 1981; Whitehead *et al*., 1986; Jardas, 1996). *Serranus hepatus* is caught mainly by bottom trawl and discarded at sea (Labropoulou *et al*., 1998; Dulčić *et al*., 2007; Bilecenoğlu, 2009), while two congeneric species, *S. cabrilla* and *S. scriba*, are both commercial species albeit of rather low economic value.

Several studies have been conducted on various aspects of the species biology in the Mediterranean Sea. More specifically, age and growth have been studied by Wagué and Papaconstantinou (1997), Labropoulou *et al.* (1998), Dulčić *et al.* (2007), Bilecenoğlu (2009), Yapici *et al.* (2012), Soykan *et al.* (2013) and Erdoğan and Torcu-Koc (2016); weight–length relationship (*WLR*) by Merella *et al.* (1997), Wagué (1997), Abdallah (2002), Lamprakis *et al.* (2003), Valle *et al.* (2003), Çiçek *et al.* (2006), Dulčić and Glamuzina (2006), Sangün *et al.* (2007), Bilecenoğlu (2009) and Başusta *et al.* (2017); feeding habits by Bilecenoğlu (2009) and Yapici *et al.* (2012); reproduction by Truslé (1983), Soykan *et al.* (2013) and Erdoğan and Torcu-Koc (2016). Finally, Altin and Ayyildiz (2017) and Bilge *et al.* (2018) studied the relation between the body size and four otolith parameters of this species.

It is well recognized that information on age, growth and *WLR* is necessary in stock assessment and population dynamics. Moreover, otolith morphology is used to distinguish fish species at taxonomic, phylogenetic, paleontological, geographical and dietary level (Lombarte and Lleonart, 1993; Tuset *et al*., 2006; Škeljo and Ferri, 2011; Disspain *et al*., 2016; Jawad *et al*., 2017), providing useful data in species biology, and stock identification studies. Such knowledge is essential if different approaches are required to be implemented for distinct stocks in fisheries management. Information on these topics is also necessary for discarded species, for which the existing excessive lack of adequate data may lead to inaccurate conclusions in stock assessment and management (FAO, 2020). No published work on the above-mentioned biological features of *S. hepatus* is known in the Eastern Ionian and southwestern Aegean Seas so far, where considerable abundance for this discarded species is known (Labropoulou, 2007; Mytilineou *et al*., 2022).

The present study aims to contribute to the knowledge of the life history of *S. hepatus* by providing updated information on age, growth and otolith morphometrics, information presented for the first time for this species in the E. Ionian and SW Aegean Seas. An additional objective encompasses the comparison of the above-mentioned life-history characteristics to define potential differences between the two study areas, which may be indicative of stock-related differences, information useful in fisheries management and stock identification studies.

Materials and methods

Study areas and data collection

Samples of *S. hepatus* were collected during experimental bottom trawl surveys conducted in the E. Ionian (October 2014) and SW Aegean Seas (September 2014 and May 2015) (Figure 1). Samples were collected at depths ranging between 43 and 71 m in the former area and 71 and 99 m in the latter one.

From each specimen, total length (*TL*) was recorded to the nearest mm and total weight (*TW*) to the nearest g. Sex was determined based on the macroscopic inspection of the gonads. Sagittal otoliths were removed from the cranial cavity, cleaned

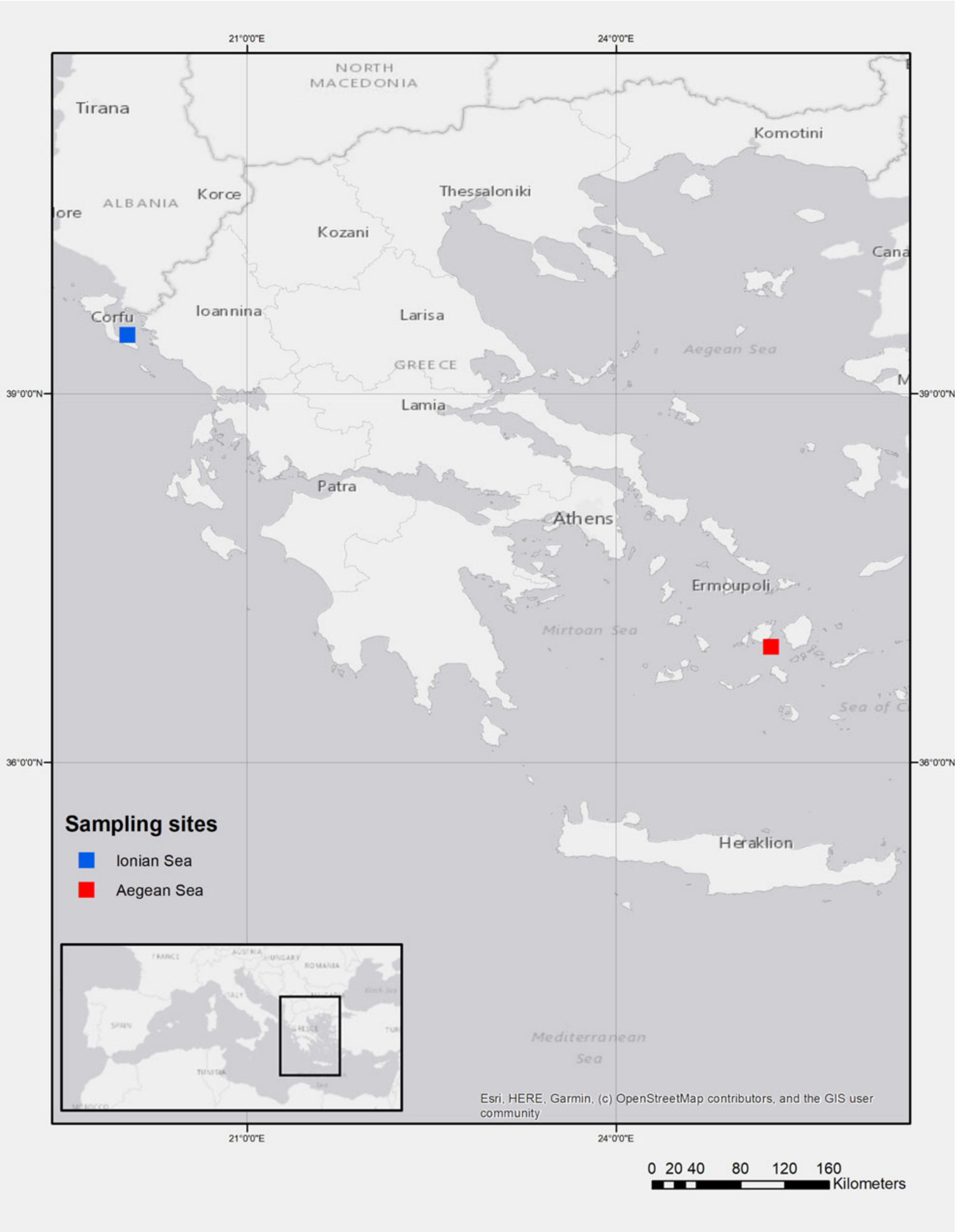

Figure 1. Map of the sampling stations in the Ionian (blue) and Aegean Seas (red).

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in water to remove the organic material and stored dry. Each right otolith was placed, with its proximal side down on a glass Petri dish filled with water and photographed under transmitted light against a black background with the Image-Pro Plus software (Version 4.5.0.29) under the magnification ×12.5.

Age estimation was based on counting the annual growth rings, considered as alternating opaque and translucent zones, along the right sagittal otolith axis, from the core to the post-rostrum edge. Otoliths were read by three readers. To compare the age readings between the different readers, the formulas of percent agreement (PA), coefficient of variation (CV) and average percent error (APE) were calculated (see relevant formulas in Supplementary materials). Broken or damaged otoliths were excluded from the ageing procedure and the analysis of the morphometric parameters. Regardless of the actual spawning date of the species, date of birth was set at 1st January as commonly established by the majority of fish age determination laboratories around the world (ICES, 2018; NOAA, 2020).

The otolith morphometric variables recorded, based on the right otolith observations, were the following: radius (*RA*, mm); otolith length (*OL*, mm); otolith width (*OW*, mm); otolith area (*OA*, mm^2); perimeter (*PE*, mm) (Figure 2); roundness (*RD*) which is the ratio between the actual area and the area of a circle of the same diameter, factor larger if and when the shape of otolith is more circular (Ponton, 2006) taking a minimum value of 1 (Pothin *et al*., 2006) and circularity (*CI*) which provides information on the complexity of the otolith contour (Tuset *et al*., 2003) taking a minimum value of 4π (Pothin *et al*., 2006). Additionally, the following shape factors were calculated:

Form factor $(FF) = ([4 \times OA/PE^2])$, which is a dimensionless value that indicates the similarity of the otolith contour to a circle, taking values from 0 to 1, with a value of 1 corresponding to a perfect circle;

Rectangularity $(RC) = (OA/[OL \times OW])$, which gives information about the approximation to a rectangular or square shape, indicating a perfect rectangle or square if it has a value of 1;

Ellipticity $(EL) = (OL - OW/OL + OW)$, which reflects the similarity to an ellipse, with values close to 0 indicating a tendency towards circularity (Tuset *et al*., 2003).

Data analysis

Growth

The total length (*TL*) frequency distribution of the samples in each study area was based on classes of 1 cm interval. The *WLR* relationship was estimated by applying the equation $TW = \alpha TL^b$, where *TW* is the total weight in g, *TL* the total length in cm, α the intercept and *b* the slope of the regression. The null hypothesis for isometric growth (H_0: $b = 3$) was tested by using Student's

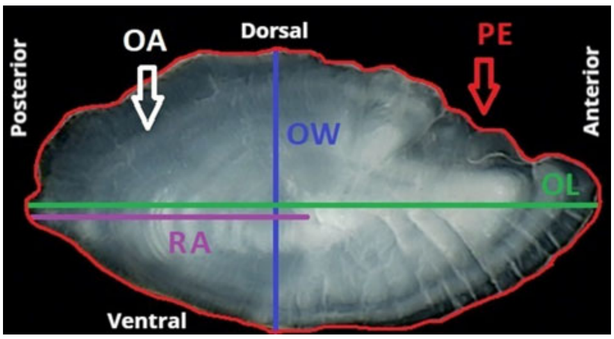

Figure 2. Right otolith of *Serranus hepatus*, illustrating the measurements analysed. RA, radius (mm); OL, otolith length (mm); OW, otolith width (mm); OA, otolith area (mm^2); PE, perimeter (mm).

t-test in each study area. Analysis of covariance (ANCOVA) was used to compare the intercepts and slopes between the two areas. Differences were considered at the significant level $a = 0.05$.

For the age study, age–length keys were constructed by area. The growth parameters were calculated through the Von Bertalanffy equation: $L_t = L\infty\ (1 - e^{-k(t-t0)})$ where, L_t is the predicted length at age *t* in cm, $L\infty$ is the mean theoretical asymptotic length in cm, *k* is a growth rate parameter in $year^{-1}$ and t_0 the theoretical age at zero length in years (von Bertalanffy, 1938). Differences in the growth parameters between the two study areas were tested using Student's *t*-test. In addition, the growth performance index Φ′ ($\Phi' = \log k + 2\log L_\infty$; Pauly and Munro, 1984) was applied to discuss the growth rate in the two study areas and that of the existing published literature.

Otolith morphometrics

The values of the mean ± standard error, and minimum and maximum of each otolith morphometric variable were presented by area. Since the examination of the length frequency distribution between the two study areas revealed statistically significant difference in the sizes of the samples (Kolmogorov–Smirnov test, $P < 0.01$), to minimize the effect of the size differences on the otolith variables between the two study areas, only individuals included in the length classes 70–109 mm were used in the following analyses (E. Ionian: $N = 98$ and SW Aegean: $N = 52$). These length classes were selected because no difference was identified in the length frequency of this size range (Kolmogorov–Smirnov test, $P = 0.07$). Differences were considered at the significant level $a = 0.05$.

The relationship of each otolith morphometric variable with *TL* was also described for each area by the exponential regression: $y = ax^b$, where *y* is the otolith morphometric variable in mm, *x* the total length in mm, *a* is the intercept and *b* the slope of the regression. The significance of these relationships was based on the *P*-value. ANCOVA was used to test the between-area differences by comparing the slopes of the regressions, which indicated significant correlation between otolith variable and *TL*. Differences were considered at the significant level $a = 0.05$.

The identification of the effect of the study area on the otolith variables was examined using the following approach:

As proposed by Agüera and Brophy (2011), the otolith variables which do not present a consistent *b* in the two study areas should be excluded from further analyses. Otolith variables that were significantly correlated with *TL* were used for the comparison of the two study areas, based on their standardized values calculated using a common within-group slope (*b*). The following equation, reported by Elliott *et al*. (1995), was used for these standardizations to remove the size effect: $M_s = M_o(TL_s/TL_o)^b$ where, M_s = standardized otolith variable, M_o = measured otolith variable, TL_s = overall (arithmetic) mean length for all fish from all samples in each analysis, TL_o = length of the specimen and *b* the common within-group slope for each measured otolith variable, estimated from the combined data of both study areas by the equation $M_o = aTL_o^b$. The estimated common within-group slope (*b*) is presented in Supplementary Table S1. The relationship of *TL* with each standardized otolith morphometric variable was re-examined to cross-validate that the size effect has been removed successfully from the data.

For a more comprehensive picture, multivariate general linear models (multivariate GLM) were used to identify the effect of the factor area on the otolith variables. The standardized values of the otolith variables were used as dependent variables and the study area was used as independent variable. When needed, square root transformation was performed as more appropriate on the parameters to achieve normality. The partial eta squared was

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applied to evaluate the relative importance of each variable in differentiating the two study areas.

The standardized values of the otolith variables were also used to explore the relationships between them using principal component analysis (PCA).

Results

Growth

Length distribution

A total of 239 individuals were examined for the present study: 150 from the E. Ionian Sea and 89 from the SW Aegean Sea. The total length *TL* of the samples from the E. Ionian Sea ranged from 6.6 to 10.0 cm, while those from the SW Aegean Sea ranged from 5.7 to 10.0 cm (Figure 3). The *TL* distribution showed that the length class of 8.0 cm was predominant in both areas.

Total weight–total length relationship

The values of the total weight *TW* ranged between 3.67–13.66 g and 3.06–14.50 g in the E. Ionian and the SW Aegean, respectively. For each study area, the *WLR* was as follows:

$TW = 0.016382526 \times TL^{2.93331}$ ($R^2 = 91\%$) for the E. Ionian Sea;

$TW = 0.009369 \times TL^{3.18154}$ ($R^2 = 89\%$) for the SW Aegean.

The *WLR* revealed that the value of *b* did not differ significantly than 3 in both areas, which indicated isometric growth (E. Ionian Sea: *t*-test = −0.83, $P = 0.41$; SW Aegean Sea: *t*-test = 1.45, $P = 0.15$). The comparison of *b* in the *WLR* of the two study areas did not show statistically significant differences (ANCOVA, for *b*: $P = 0.08$).

Age and growth

Age readings of the three readers were quite similar (PA = 95.99%, CV = 4.70% and APE = 3.60%). For those otoliths with age disagreement, re-reading or exclusion of them resulted in a common data set with PA = 100%. Three age groups (from 1 to 3) in the E. Ionian and four age groups (from 0 to 3) in the SW Aegean were identified from the otolith readings of *S. hepatus*. One

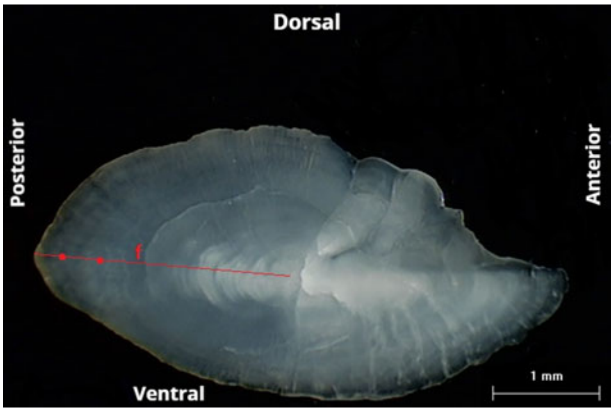

Figure 4. Otolith of *Serranus hepatus* with two annual rings (red dots) and the false ring (f); date of capture October.

false ring was always observed before the first annual growth ring. The first annulus was identified at a distance from the core (posterior area) ranging from 1.5 to 2.0 mm (Figure 4). The relevant age–length keys of *S. hepatus* for the two study areas are presented in Table 1. Most of the sampled individuals belonged to the age group one, followed by the age group two.

Table 2 and Supplementary Figure S1 present the von Bertalanffy parameters and curves, respectively, per area. The von Bertalanffy growth parameters did not present statistically significant differences between the two areas (L_{∞}: $P = 0.99$; *k*: $P = 0.94$; t_0: $P = 0.80$). The growth performance index Φ′ is also shown in Table 2.

Otolith morphometrics

The mean (± standard error) and the minimum and maximum values of *RA* (radius); *OL* (otolith length); *OW* (otolith width); *OA* (otolith area); *PE* (perimeter); *RD* (roundness); *CI* (circularity); *FF* (form factor); *RC* (rectangularity) and *EL* (ellipticity) of the right otolith are presented in Table 3 per area. Their

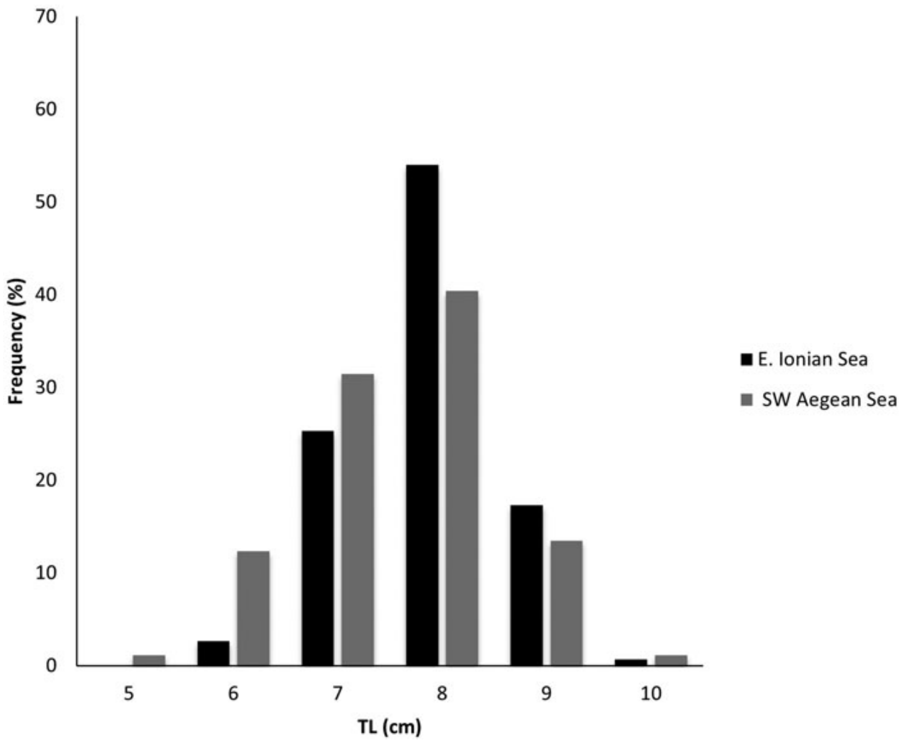

Figure 3. Length frequency distribution (TL, cm) of *Serranus hepatus* in the E. Ionian and SW Aegean Seas.

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Table 1. Age–length key of *Serranus hepatus* from the E. Ionian and SW Aegean Sea

	E. Ionian Sea				SW Aegean Sea				
	Age classes								
Length classes (*TL*, cm)	1	2	3	*N*	0	1	2	3	*N*
5.0–5.9					1				1
6.0–6.9	4			4	2	8			10
7.0–7.9	38			38		27			27
8.0–8.9	72	8		80		26	7		33
9.0–9.9	1	22	3	26		2	6	4	12
10.0–10.9			1	1				1	1
N	115	30	4	149	3	63	13	5	84
(*N*%)	(77.18)	(20.14)	(2.68)	(100)	(3.57)	(75)	(15.48)	(5.95)	(100)

TL, total length (cm); *N*, total number of individuals; *N*%, percentage to the total number of individuals.

Table 2. Von Bertalanffy growth parameters of *Serranus hepatus* in the E. Ionian and the SW Aegean Sea

Area	*N*	L_∞ ± SE (cm)	*k* ± SE (year^{-1})	t_0 ± SE (year)	Φ′
E. Ionian Sea	149	12.94 ± 5.47	0.22 ± 0.27	−3.52 ± 2.67	1.56
SW Aegean Sea	84	12.90 ± 5.11	0.25 ± 0.30	−2.65 ± 2.08	1.62

N, total number of individuals; *L*∞, the mean theoretical asymptotic length in cm; *k*, a growth rate parameter in year^{-1}; t_0, the theoretical age at zero length in years; SE, standard error; Φ′, the growth performance index.

Table 3. Mean ± standard error (minimum–maximum) of the otolith morphometric variables

Morphometric variable	E. Ionian (all data)	SW Aegean (all data)	E. Ionian (70–109 mm)	SW Aegean (70–109 mm)
RA (mm)	2.22 ± 0.02 (1.75–2.67)	2.09 ± 0.03 (1.52–2.70)	2.19 ± 0.01 (1.90–2.46)	2.14 ± 0.02 (1.75–2.45)
OL (mm)	4.39 ± 0.41 (3.46–4.95)	4.09 ± 0.06 (2.88–4.95)	4.29 ± 0.27 (3.75–5.28)	4.23 ± 0.41 (3.24–4.65)
OW (mm)	2.23 ± 0.02 (1.75–2.74)	2.06 ± 0.03 (1.45–2.66)	2.20 ± 0.01 (1.86–2.61)	2.10 ± 0.02 (1.70–2.39)
OA (mm^2)	7.10 ± 0.12 (4.39–10.07)	6.23 ± 0.19 (3.38–10.08)	6.85 ± 0.90 (5.47–9.65)	6.43 ± 0.12 (4.44–8.10)
PE (mm)	10.67 ± 0.09 (8.33–13.31)	10.06 ± 0.15 (7.44–12.67)	10.52 ± 0.66 (9.29–12.73)	10.26 ± 0.09 (8.88–11.45)
RD	1.29 ± 0.00 (1.20–1.42)	1.31 ± 0.05 (1.22–1.58)	–	–
CI	16.16 ± 0.05 (15.07–17.90)	16.43 ± 0.62 (15.30–19.79)	–	–
FF	0.79 ± 0.00 (0.70–0.83)	0.76 ± 0.03 (0.63–0.82)	–	–
RC	0.73 ± 0.00 (0.68–0.78)	0.73 ± 0.03 (0.69–0.80)	–	–
EL	0.32 ± 0.00 (0.26–0.38)	0.33 ± 0.00 (0.24–0.39)	0.32 ± 0.00 (0.27–0.38)	0.33 ± 0.03 (0.23–0.39)

RA, radius (mm); *OL*, otolith length (mm); *OW*, otolith width (mm); *OA*, otolith area (mm^2); *PE*, perimeter (mm); *RD*, roundness; *CI*, circularity; *FF*, form factor; *RC*, rectangularity; *EL*, ellipticity of *Serranus hepatus* for the E. Ionian and SW Aegean Seas.
The standardized otolith morphometric variables for the length classes 70–109 mm are also shown.

standardized values for the length classes 70–109 mm are also shown in Table 3.

TL was found to be statistically significantly correlated ($P <$ 0.05) with all examined otolith variables in the E. Ionian Sea (Table 4, Supplementary Figure S2). In the SW Aegean Sea, all morphometric variables were statistically significantly correlated with *TL* ($P < 0.05$); however, the otolith shape variables (*RD*, *CI*, *FF*, *RC*, except *EL*) showed a low no significant correlation with size (Table 4, Supplementary Figure S3). For the otolith variables that were significantly correlated with *TL* in both the E. Ionian and SW Aegean Seas (*RA*, *OL*, *OW*, *OA*, *PE* and *EL*), no significant differences (ANCOVA, $P > 0.05$) were detected for the slope *b* between these areas (Table 4). As a result, only these otolith variables were used for the estimation of the common within-group slope (see Supplementary Table S1) for the estimation of their standardized values and for the identification of differences between the two study areas.

The standardized values of *RA*, *OL*, *OW*, *OA*, *PE* and *EL* (square root of *OL* and *RA*) of the length classes 70–109 mm were analysed by multivariate GLM to identify the effect of the area factor on these variables and the relative importance of each one in differentiating the two areas. Since the variable *EL* was not found to be statistically significant, the model was rerun excluding this variable. The final model was found to be statistically significant ($P = 0.012$, Supplementary Table S2). The variables contributing to the separation of the two study areas

Table 4. Parameters of the exponential regression of the total length (*TL*) of *Serranus hepatus* with the otolith morphometric variables

Variables	Area	*a*	*b*	R^2	*r*	Regression *P*-value	ANCOVA *P*-value for *b*
TL/RA	E. Ionian	0.08	0.76	0.58	0.76	< 0.01*	0.56
	SW Aegean	0.10	0.70	0.59	0.77	< 0.01*	
TL/OL	E. Ionian	0.16	0.74	0.71	0.84	< 0.01*	0.49
	SW Aegean	0.20	0.69	0.68	0.83	< 0.01*	
TL/OW	E. Ionian	0.04	0.89	0.65	0.80	< 0.01*	0.58
	SW Aegean	0.03	0.95	0.76	0.88	< 0.01*	
TL/OA	E. Ionian	0.00	1.74	0.75	0.87	< 0.01*	0.65
	SW Aegean	0.00	1.67	0.72	0.85	< 0.01*	
TL/PE	E. Ionian	0.27	0.83	0.77	0.88	< 0.01*	0.77
	SW Aegean	0.29	0.81	0.74	0.86	< 0.01*	
TL/RD	E. Ionian	1.89	−0.09	0.06	−0.25	0.01*	–
	SW Aegean	1.59	−0.04	0.02	−0.13	0.34	
TL/CI	E. Ionian	23.49	−0.09	0.06	−0.25	0.01*	–
	SW Aegean	20.00	−0.04	0.02	−0.13	0.34	
TL/FF	E. Ionian	0.52	0.09	0.05	0.23	0.02*	–
	SW Aegean	0.63	0.04	0.02	0.13	0.33	
TL/RC	E. Ionian	0.47	0.10	0.10	0.31	< 0.01*	–
	SW Aegean	0.72	0.00	0.00	0.01	0.93	
TL/EL	E. Ionian	1.11	−0.28	0.09	−0.30	< 0.01*	0.58
	SW Aegean	0.82	−0.21	0.09	−0.30	0.02*	

RA, radius (mm); *OL*, otolith length (mm); *OW*, otolith width (mm); *OA*, otolith area (mm^2); *PE*, perimeter (mm); *RD*, roundness; *CI*, circularity; *FF*, form factor; *RC*, rectangularity; *EL*, ellipticity in the E. Ionian and SW Aegean Seas.
R^2, coefficient of determination; *r*, correlation coefficient. The *P*-value of the regressions and the *P*-value of the comparison of the slope *b* of the regression lines between the two areas (ANCOVA) are also shown.
*Significance level $a = 0.05$

Table 5. Results of the multivariate GLM analysis showing the relative importance of each otolith variable (based on the partial eta squared η^2) in differentiating the two study areas

Variable	Type III SS	df	MS	*F*	*P*-value	Partial η^2
SQR *OL*	0.03	1	0.03	13.36	0.000*	0.083
OW	0.28	1	0.28	13.23	0.000*	0.082
OA	7.58	1	7.58	12.51	0.001*	0.078
PE	2.83	1	2.83	8.09	0.005*	0.052
SQR *RA*	0.01	1	0.01	6.26	0.013*	0.041

SQR *OL*, square root of otolith length; *OW*, otolith width; *OA*, otolith area; *PE*, perimeter; SQR *RA*, square root of radius; SS, sum of squares; df, degrees of freedom; MS, mean square.
*Significance level $a = 0.05$.

ordered by their relative importance, based on the partial eta squared, were *OL*, *OW*, *OA*, *PE* and *RA* (Table 5).

The PCA showed two principal components explaining the 93.7% of the variability of the otolith variables. The most important variables of the first principal component were (*OA*, *OL* and *OW*) expressing 72.9% while the second one included only *EL* which expressed 20.8% (Table 6).

Table 6. Component matrix of PCA results of the total variance explained and the weight of each initial variable at each principal component

	Component		Cumulative variance %
	1	2	
% of Variance	72.937%	20.785%	93.722%
Otolith variable			
OA	0.970	0.157	
SQR *OL*	0.965	−0.231	
OW	0.964	−0.235	
PE	0.907	0.348	
SQR *RA*	0.777	0.425	
EL	−0.387	0.901	

OA, otolith area; SQR *OL*, square root of otolith length; *OW*, otolith width; *PE*, perimeter; SQR *RA*, square root of radius; *EL*, ellipticity.

Discussion

Serranus hepatus is a species of widespread occurrence; however, information on its biology and ecology is rather scarce, particularly in the E. Ionian and SW Aegean Seas. Although some published information on age, growth and *WLR* from other localities of the Greek seas exists from the past (Wagué, 1997; Wagué and Papaconstantinou, 1997; Labropoulou *et al.*, 1998; Lamprakis *et al.*, 2003), the results of the present study provided updated

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Table 7. Weight–length relationship and growth parameters of *Serranus hepatus* from different study areas

Reference	Area	*N*	*TL* range (cm)	α	*b*	L_{∞} (cm)	*k* (year^{-1})	t_0 (year)	Φ′	Ageing method
Merella *et al.* (1997)	Balearic Islands	61	4.7–11.1	0.0091	3.24	–	–	–	–	
Wagué (1997)	Thermaikos Gulf	1290	5–12.7	0.1770	1.89	–	–	–	–	
Wagué and Papaconstantinou (1997)	Thermaikos Gulf	3350	5–13.1	–	–	14.66	0.23	−2.56	1.69	O and LF
Labropoulou *et al.* (1998)	Cretan Sea	1024	3.1–14	–	–	15.20	0.36	−0.57	1.92	S
Abdallah (2002)	Alexandria, Egypt	153	3.1–12.5	0.025	2.84	–	–	–	–	
Lamprakis *et al.* (2003)	N. Aegean Sea	2318	2.9–12.1	0.0121	3.122	–	–	–	–	
Valle *et al.* (2003)	Spain	87	3.4–7.9	0.01117	3.123	–	–	–	–	
Çiçek *et al.* (2006)	Babadillimani Bight	584	2.4–10.5	0.0161	3.029	–	–	–	–	
Dulčić and Glamuzina (2006)	Adriatic	87	5.4–18.9	0.0112	3.123	–	–	–	–	
Dulčić *et al.* (2007)	Adriatic	1218	5.8–13	0.010	3.187	14.82	0.22	−1.67	1.68	S
Sangün *et al.* (2007)	Coast of Turkey	573	4.8–13	0.0143	3.044	–	–	–	–	
Bilecenoğlu (2009)	Izmir Bay	603	5.2–11.7	0.0157	2.998	11.90	0.56	−1.14	1.90	O
Yapici *et al.* (2012)	Izmir Bay	5222	6.5–11.7	0.0200	2.89	12.50	0.54	−1.08	1.93	O
Soykan *et al.* (2013)	Izmir Bay	2410	3.9–12.3	0.013	3.11	13.19	0.25	−0.63	1.64	O
Erdoğan and Torcu (2016)	Sea of Marmara	162	6.5–11.1	0.021	2.840	12.46	0.19	−4.32	1.48	O
Başusta *et al.* (2017)	Iskenderun Bay	202	5.7–9.5	0.0172	2.966	–	–	–	–	
This study	Eastern Ionian Sea	150	6.6–10	0.0164	2.933	12.94	0.22	−3.52	1.56	O
This study	Southwestern Aegean Sea	89	5.7–10	0.0094	3.182	12.90	0.25	−2.65	1.62	O

N, total number of individuals; *TL* range, minimum–maximum total length in cm; α, intercept; *b*, slope of the weight–length relationship; L_{∞}, mean theoretical asymptotic length in cm; *k*, growth rate in year^{-1}; t_0, theoretical age at zero length in years; Φ′, growth performance index; O, otoliths; LF, length-based analysis; S, scales.

information for the Aegean Sea and new information for the Ionian Sea, which is needed for fisheries stock assessment and management.

The study of the *WLR* in this work revealed an isometric growth for the species in both areas. No significant differences were detected between the two study areas. Isometric somatic growth was also reported by Çiçek *et al.* (2006), Sangün *et al.* (2007) and Başusta *et al.* (2017). However, positive allometry was mentioned by Merella *et al.* (1997), Lamprakis *et al.* (2003), Valle *et al.* (2003), Dulčić and Glamuzina (2006), Dulčić *et al.* (2007) and Soykan *et al.* (2013). In opposite, negative allometry was reported by Wagué (1997), Abdallah (2002), Bilecenoğlu (2009), Yapici *et al.* (2012) and Erdoğan and Torcu (2016) (Table 7). The differences in the parameters of *WLR* are usually attributed to factors such as genotype (Garvey *et al.*, 2003), habitat, differences in length composition, number of specimens examined, preservation techniques, health, stomach conditions, diet, sex, maturity stages (Tesch, 1971; Wootton, 1990), sampling season, growth rate and age (Shepherd and Grimes, 1983; Weatherly and Gill, 1987). The spawning period of the species extends from spring to autumn in both areas of the present study, which coincides with the sampling period of our samples. Therefore, the body morphometry of the examined individuals of both areas is expected to be similarly affected.

In the present work, four age groups (0–3 years old) were identified. More age groups have been reported in the published literature, which however, corresponded to a wider size range than the examined samples (Table 7). The von Bertalanffy parameters did not show statistically significant differences between the E. Ionian and SW Aegean, similarly, the growth performance index Φ'. The growth parameters and Φ' estimated in this work were included within the range of parameters found in the published literature (Table 7) and seem close to the values of some works from the Aegean and Adriatic Seas (but see Labropoulou *et al.* [1998] from the Cretan Sea). Differences in the growth parameters may be related to differences in the environmental conditions, life-history traits, methodological approaches and size range of the examined samples.

The study of the relationship of *TL* with the otolith morphometric variables revealed statistically significant correlation with the ten examined morphometric variables in the E. Ionian, while only with six (*RA*, *OL*, *OW*, *OA*, *PE* and *EL*) in the SW Aegean Sea. The low sample size in the latter area may be the reason of the low correlation of the other variables (*RD*, *CI*, *FF* and *RC*) with *TL* and the absence of statistically significant *P*-value in these cases. Our results are in accordance with the findings of Altin and Ayyildiz (2017) and Bilge *et al.* (2018), who also indicated a high correlation in the relationships between total length and otolith radius, length and width in *S. hepatus*. No published information was found for the other otolith variables examined in the present work in *S. hepatus* (*OA*, *PE*, *RD*, *CI*, *FF*, *RC* and *EL*). No significant differences (ANCOVA, $P > 0.05$) were detected for the slope *b* of the regression lines of *RA*, *OL*, *OW*, *OA*, *PE* and *EL* between the two study areas.

According to the results of the multivariate GLM, the variables *RA*, *OL*, *OW*, *OA* and *PE*, which are related more to the otolith morphology, were found to differ statistically significantly between the E. Ionian and SW Aegean Seas. It is noteworthy to mention that the otolith shape variable *EL* did not contribute to this difference. The *OL*, *OW* and *OA* were the variables with the greatest contribution in differentiating the two study areas. The PCA also showed that these three variables expressed a major part of the variability of the first principal component. However, although *OA* was the third variable in importance in differentiating the two study areas, it was the first in variability. This was expected since *OA* includes the variability of both *OL* and *OW*. The differences in otolith morphometric variables between the two study areas may indicate differences between the populations of *S. hepatus* in the broader area. However, similar growth patterns characterized the species in the two study areas. Variation in otolith morphology and shape is known to be related to genetic and/or environmental factors such as temperature, salinity, depth and food availability (Campana and Casselman, 1993; Lombarte and Lleonart, 1993; Capoccioni *et al.*, 2011; Bostanci *et al.*, 2016; Smolinski *et al.*, 2020; Nazir and Khan, 2021). In addition, Bose *et al.* (2020) suggest that the otolith width is highly influenced by selected environmental factors. Moreover, Friedland and Reddin (1994) and Libungan *et al.* (2015) mentioned that subpopulation differences in otolith shape increase with increasing geographical separation. Avigliano *et al.* (2014) mentioned that the differences in the water chemistry and salinity among regions may be responsible for variations in the otolith morphometrics of a fish species in two geographical locations. Velaoras *et al.* (2013) mentioned that the Aegean Sea exhibits greater values for both temperature and salinity than the Ionian Sea. Therefore, the variations in the otolith morphometrics found in the present work could be related to different environmental conditions of the two study areas. This needs to be proved by specific studies relating otolith morphometrics with the environmental conditions of the two areas. In addition, further genetic studies are also necessary to investigate the genotype of the species in the two regions.

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