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Age and Growth of European Sardine (*Sardina pilchardus*) in the Central Mediterranean Sea: Implication for Stock Assessment

Gualtiero Basilone [1,*], Rosalia Ferreri [1,*], Angelo Bonanno [1], Simona Genovese [1], Marco Barra [2] and Salvatore Aronica [1]

1 Consiglio Nazionale delle Ricerche (CNR)—Istituto per lo Studio Degli Impatti Antropici e Sostenibilità in Ambiente Marino (IAS) S.S. di Capo Granitola—Campobello di Mazara (TP), 91021 Campobello di Mazara, Italy
2 Consiglio Nazionale delle Ricerche (CNR)—Istituto di Scienze Marine (ISMAR) S.S. di Napoli, 80133 Napoli, Italy
* Correspondence: gualtiero.basilone@cnr.it (G.B.); rosalia.ferreri@cnr.it (R.F.)

Abstract: Understanding the drivers of fish growth is essential for predicting productivity, stability, and resilience of exploited populations. For the European sardine (*Sardina pilchardus*) in the Strait of Sicily (Central Mediterranean Sea, GSA16), growth parameters or length at age estimates have never been published before. To fill this data gap, the length and age as well as the von Bertalanffy parameters (the most widely used growth model) were estimated. Data from landing samples during the period 2009–2019 were collected by two methods (purse seine and mid-water pelagic trawl). Temporal trends in average length at age, as well as an overall age-length key were obtained and compared with other areas across the geographical distribution range of sardine in the Mediterranean Sea. The observed age range was 0–3 years with most of the individuals belonging to Age 1 (52%) and Age 2 (43%). The mean length at age, for the entire study period, was 11.7 (±0.08) cm for Age 0; 13.4 (±0.09) cm for Age 1; 15 (±0.1) cm for Age 2; and 16.6 (±0.11) cm for Age 3. Furthermore, during the considered period, a reduction in the length at age was observed in the older classes (Age 2 and Age 3). The estimated parameters of the von Bertalanffy growth model were L_{inf} = 18 (±1.15) cm, K = 0.459 (±0.018), and t_0 = −1.99 (±0.008) and, accordingly, the mortality vector was obtained according to Gislason's model, for each age class, these values were 0.99 (0.98–1.02) C at Age 0; 0.71 (0.7–0.73) y^{-1} at Age 1; 0.6 (0.59–0.62) y^{-1} at Age 2; 0.54 (0.53–0.56) y^{-1} at Age 3; and 0.51 (0.49–0.53) y^{-1} at Age 4. Results appeared in agreement with literature from other areas of the Mediterranean Sea and suggested a poor condition status of the sardine stock in the GSA16.

Keywords: length at age; Bayesian von Bertalanffy model; fish mortality; overexploited fish stock

Key Contribution: The main warnings from this study for the sardine stock status in the Strait of Sicily are the decrease in length at age along the period 2009–2019; as well as the contraction in the population structure based only on Age 1 and Age 2 groups. These results strongly suggest both a suffering population and new efforts for finding a compromise between the sampling program of commercial and scientific surveys to obtain representative information on the stock.

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1. Introduction

Small pelagic fishes (SPF) account for about 25% of global fish catches and, due to their abundance and position in the trophic web, constitute an important link between the lower and the upper trophic levels, thus representing both an economically and ecologically important group [1,2]. Among the SPF species, the European sardine (*Sardina pilchardus*, Walbaum 1792) plays a key role in maintaining ecological processes in marine systems, occupying an essential intermediate trophic level in pelagic ecosystems [3]. The European sardine, belonging to the Clupeidae family, lives from the North Sea to Senegal in the eastern Atlantic waters, as well as in the Mediterranean Sea [4]. It is a schooling fish, usually resident on the continental shelf [5,6], with a significant commercial value as it represents the second species (after anchovy, *Engraulis encrasicolus*) most important for fish landings, contributing to 14% of total catches including crustaceans and molluscs in the Mediterranean Sea (GFCM area of application) [7]. In terms of species contribution, it is worth nothing the strong reduction of landing quantities from 2018 (190,248 tons) to 2020 (139,576 tons).

Sardine populations show high variability in terms of recruitment, biomass, and spatial distribution, which mainly depend on environmental and climatic conditions [8–10]. As with other life history traits, growth and age depend on the interaction between genetic characteristics and environmental influences, such as geographic and/or reproductive isolation, temperature, and food availability [11,12]. In particular, growth represents an important piece of information for assessing population productivity and resilience [13,14]; nonetheless, despite their relevance, the life history of most SPF is poorly understood in several areas of the Mediterranean Sea [15,16], and only few studies have focused on the growth of sardines in this area [12,17]. Furthermore, as life history traits are adaptive and may change in response to changing environmental conditions [18–22], it is advisable that such parameters are updated on annual basis, in order to feed stock assessment models with the most recent estimates. Recently, the sardine stock in GSA 16 displayed low biomass levels and it was considered overexploited, thus the advice to reduce fishing mortality [23].

In this study, an 11-year time series of age and growth data from catch sampling of sardine in the Strait of Sicily was analysed to provide robust estimates of the growth parameters and fishing mortality during the study period. Warnings about the stock status are provided, based on the obtained results.

2. Material and Methods

For 11 years (2009–2019), samples of European sardine were collected from purse seiner (PS) and mid-water pelagic trawl (PTM) vessels in the most important harbours along the south Sicilian coast [GSA 16 [24]; Figure 1]. The sampling design was based on monthly sampling, or at least one sample for each quarter in a year, collected by each type of gear (i.e., PS and PTM) in the study area [25]. At the laboratory, individuals were dissected, sexed, and measured for total body length (TL; to nearest 1 mm), total body weight (TW; to nearest 0.1 g), and gonadic weight (GW; to nearest 0.01 g). Otoliths (sagittae) were removed from a sub-sample of a maximum five individuals per length class (0.5 cm length intervals). Then otoliths were cleaned, dried, and stored in black-plastic labelled moulds.

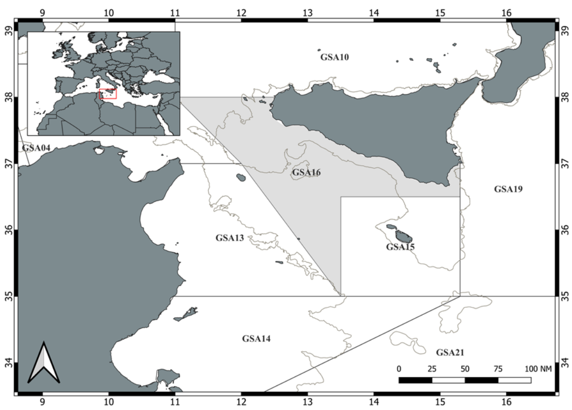

Figure 1. Strait of Sicily (GSA 16) map with the study area (shadowed). The grey line represents the 250 m isobath.

2.1. Age Estimation

Otolith readings were revised according to latest protocols and guidelines, agreed within international expert working groups [26–28]. The whole otolith was immersed in a 30% alcohol solution, with the distal surface turned up, and analysed under a dissecting microscope with reflected light against a black background at 25× magnification. The annulus was identified by the brightest contrast between the preceding translucent and the subsequent opaque zone deposited in the following year. To reduce misidentification of false and true annual rings, the measurements of subsequent annual growth zone widths were also carried out by a micrometre fitted in the eyepiece of the microscope. Only agreed readings between two experienced readers were used for the analysis, considering the high percentage of agreement between these readers in the Strait of Sicily (96%) and the relatively low coefficient of variation [29]. Finally, age assignment was made according to the conventional birthday (set at 1st of January for this species) and the date of capture, following the interpretation of the growth development of the annual zones over the course of a year [30].

The edge marginal analysis was used for corroborating the periodicity of growth increment formation, based on complete randomization of samples and age specificity [31]. The edge was classified as opaque (O) or hyaline (H), according to the criteria described in literature ([26] and references therein). Since the start of opaque growth on the margin may vary among age groups, the method was applied for the Age 1 group, as the most representative of the population.

Plots of edge state analysis for the Age 1 class by month were obtained, fitting the proportion by means of generalized additive models (GAM). The error distribution and link function used in the model were from the family of binomial distributions with logit linkage.

2.2. Growth and Mortality

Due to the lack of a marked sexual dimorphism in this species, the assessment as well as management measures were taken on both sexes. Therefore, to avoid gaps in the length range on yearly basis, growth models, age-length keys (ALK), and mortality parameters were estimated on combined sexes.

The traditional von Bertalanffy growth (VBG) model was preferred to other models mainly for its diffusion in literature, allowing direct comparisons with other areas. To estimate the von Bertalanffy growth curve, the Bayesian approach was used [32]. More details on this approach are available at the website https://fishecology.shinyapps.io/B-VBGM/_w_f961b92d/#tab-8771--2 (accessed on 28 March 2023). This approach assumes that all individuals come hierarchically from the same population with a common normal distribution and also considers the Bayesian confidence intervals (2.5–97.5%) of the posterior distribution of each parameter, while the priors for the growth parameter estimation were: $t0 = -2.2$; $k = 0.1$ and $Linf = 15.20$ cm.

The estimated parameters on a yearly basis were obtained together with a diagnostic statistic, which provided an objective tool to highlight those years with higher uncertainty. The upper and lower quartiles of the Bayesian confidence intervals (2.5–97.5%) to the mean estimate ratio, expressed in percentage (*itv*), were used to select the acceptable annual estimates of growth parameters, by setting a threshold of 20%. Such a threshold was mainly based on the assumption that an estimate with mean uncertainty of 20% is reasonable to accept a fitting estimation. Accordingly, all those years with mean *itv* higher than 20% were considered uncertain.

Natural mortality by age (M) was calculated for sardine in GSA 16 using the VBG parameters, obtained by the Bayesian approach and based on Gislason's Second Estimator [33]. The Bayesian confidence intervals (2.5–97.5%) of the posterior distribution of each parameter were used to set the confidence intervals for both growing and growth-propagated information on the estimates of the natural mortality vector. Gislason's equation was used also to obtain lower and upper mortality estimations by means of the higher and lower lengths at age predicted by the VBG-estimated final model.

All computations were performed in R environment [34].

3. Results

During the study period (2009–2019), a total amount of 4700 sardines was analysed to provide the age and growth information (Table 1). The monthly sampling was poorly represented in 2013, 2017, 2018, and 2019, when a lower number of fish was available for age assignment purposes (Table 1).

Table 1. Number of fish sampled per month for age reading purposes along the study period.

Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
January			44					198				242
February	50			45		58	49		49			251
March	37	79	32	66	27	58	77	64	56		39	535
April	44	35	31	27				53	52		30	272
May		37		52		31	112	64	107		30	433
June	35	41	28	18		49	61	62			30	324
July				44		31	53	119				247
August				85	68		63	64				280
September	90	43	96	34	76	76	60	65			30	570
October	53			40	44	35	163				40	375
November	45	64	33	43	46	89	82		234	70		706
December		40				98	77		76	135	39	465
Total	354	339	264	454	261	525	797	689	574	205	238	4700

The data obtained by quarter and gear showed relevant gaps in some years; in particular from 2016 up to 2018, when very few samples per gear and quarter were available (Table 2).

Table 2. Distribution and availability of biological samples collected from landings per quarter (1 to 4), gear (PS: purse seine; PTM: mid-water pelagic trawl) and year (2009 to 2019).

Quarter	Gear	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
I	PS	2	2	3	2		2	2	2			1
II		2	2	3	1		1	3		2		2
III		2		5	2	3	1	1				1
IV		4	1	2	3	3	5	3			3	1
I	PTM	1	1		1	1	2	2	1	2		
II		4	4		3			3	3	2		1
III		4	5		3	4	4	3	4			
IV			3				1	6				1

Moreover, in 2011 and 2018, only the purse seine fleet was sampled, therefore the sampling resulted in an imbalance of length frequencies, since the PS fleet targets a different length range (bigger fishes) than PTM (Figure 2).

The analysis of the otolith edge morphology on 1-year-old individuals showed a clear yearly cycle (Figure 3). The shape of the relation of hyaline margin occurrence displayed one clear minimum in June/July, and higher values between November and February, corroborating the validation of the first annulus formation ([26] and references therein).

Significant trends in length along the time series by age class were also evaluated (Figure 4; Table 3). In particular, the Age 0 class showed a significant positive trend; however, excluding the year 2019, no trend was recorded for Age 0 or for Age 1 (with or without 2019; results not shown). Otherwise, in the older age classes (Age 2 and Age 3) the decreasing trend is stronger and significant.

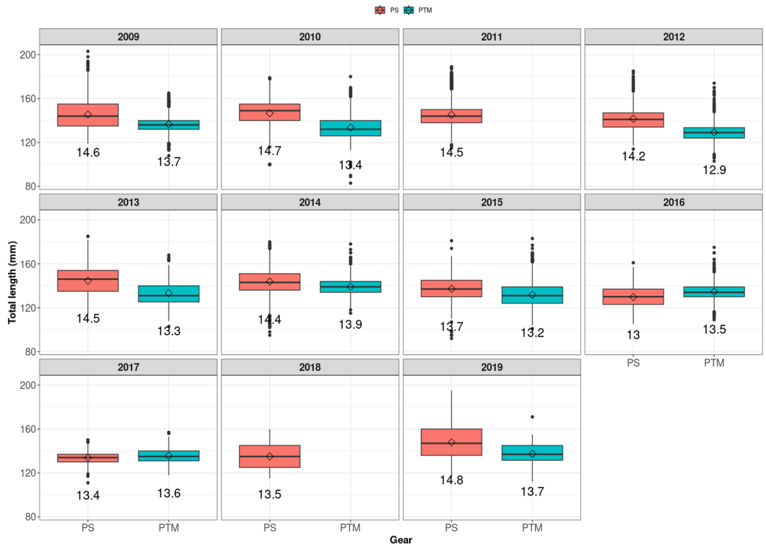

Figure 2. Boxplot of sardine total length categorized by gear (PS: purse seine; PTM: pelagic pair trawl). The average total length (cm) is reported for each year and gear.

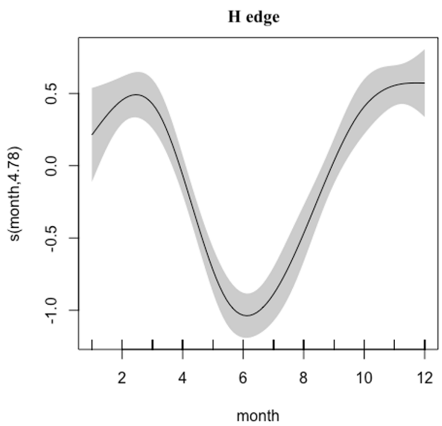

Figure 3. Plot of the proportion of hyaline (H) edges for the Age 1 class by month.

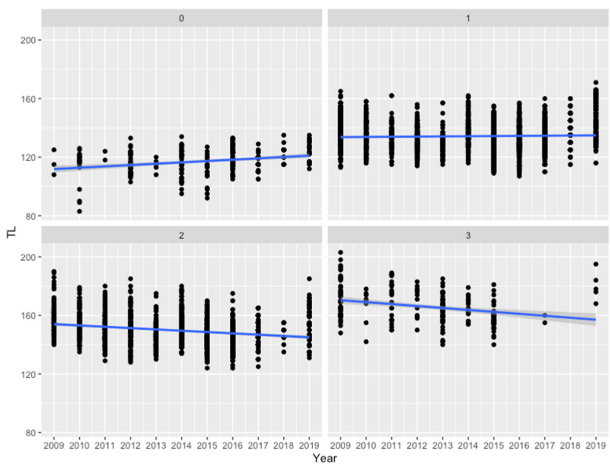

Figure 4. Temporal trend in the average length (Total length, TL in mm) per age class during the study period.

Table 3. Linear regression carried out to detect TL trends among years by Age. Estimated coefficients for each linear regression model were provided together with the F statistics for each age class.

Age Class	Coefficient	Estimate	Std. Error	t Value	Pr (>|t|)	F Value	d.f	*p*-Value
0	(Intercept)	−1729.61	370.56	−4.67	5×10^{-6}	24.84	1, 288	1.1×10^{-6}
	Year	0.92	0.18	4.98	1×10^{-6}			
1	(Intercept)	−106.31	134.32	−0.79	4×10^{-1}	3.21	1, 2770	0.07331
	Year	0.12	0.07	1.79	7×10^{-2}			
2	(Intercept)	1957.48	209.91	9.33	$<2 \times 10^{-16}$	74.16	1, 1410	$<2 \times 10^{-16}$
	Year	−0.90	0.10	−8.61	$<2 \times 10^{-16}$			
3	(Intercept)	2842.05	627.15	4.53	9×10^{-6}	18.21	1, 226	2.91×10^{-5}
	Year	−1.33	0.31	−4.27	3×10^{-5}			

The trend of decreasing length observed at Age 3 from the beginning of the study period is evident until the latest year (Figure 4). In 2019, higher lengths appear linked to the higher number of samples retrieved from PS gear that year (Table 2), when landings had a higher mean length compared to the PTM (Figure 2).

The age-length key was built on an annual basis (Figure 5). The visual inspections of the ALK highlighted the effects of sample gaps on the representativeness of the collected data relative to the population, by reducing the length range and number of age classes available, as was observed in 2011, 2017, and 2018 (Figure 5).

The ALKs obtained by year displayed ages from 0 to 3 years old with a higher proportion of individuals of Age 1 and Age 2 (respectively, 59% and 30%), while Age 0 and Age 3 were poorly represented in the landed catches with 6% and 5%, respectively (Table 4). However, the low proportion of Age 0 in the ALKs must be interpreted in the light of the minimum landing length, which is set to 11 cm for this species in the study areas, as also shown by landing length range in Figure 2.

The mean lengths at age over the whole study period were 11.7 cm for Age 0; 13.4 cm for Age 1; 15 cm for Age 2; and 16.6 cm for Age 3. These values of length at age plotted together with similar estimates from several studies showed wide agreement with the literature (Figure 6).

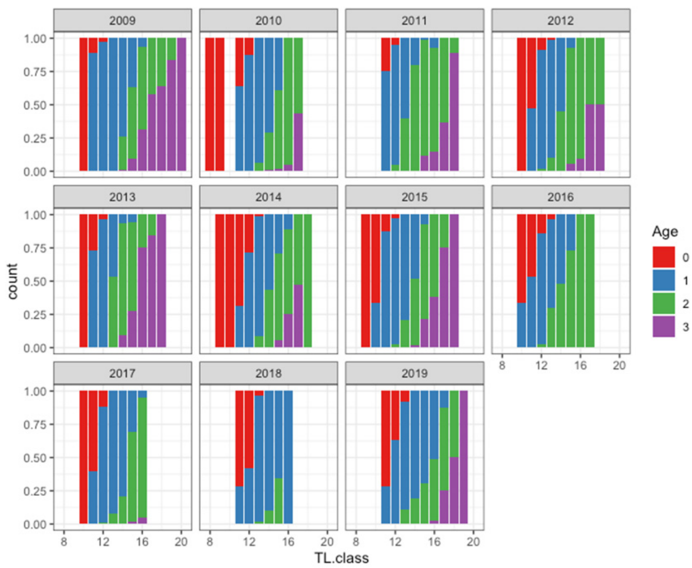

Figure 5. The age-length key (ALK) for sardine estimated during the study period (11 years: 2009–2019). Total length (TL) is in cm.

Table 4. Proportions (%) of individuals by age per sampling year (2009–2019) and average over the whole study period.

	Age			
Year	**0**	**1**	**2**	**3**
2009	1	57	29	13
2010	6	65	26	3
2011	1	27	63	9
2012	9	60	29	3
2013	2	27	49	22
2014	8	52	34	5
2015	3	63	30	5
2016	9	60	31	0
2017	7	75	17	0
2018	18	74	8	0
2019	7	68	23	2
Average	6	59	30	5

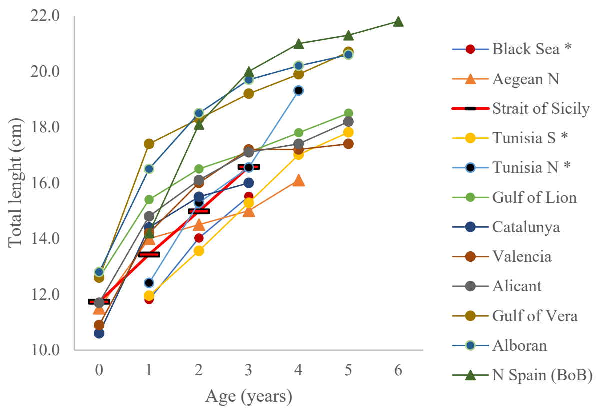

Figure 6. Length-age comparison plot of areas along an east-west longitudinal gradient from the otolith-based literature selection and current study results: Black Sea [35]; North Aegean Sea [36]; North and South Tunisia [37]; South of Sicily males and females (present study); Gulf of Lyon, Catalunya, Valencia, Alicante, Gulf of Vera Alboran Sea [36]; Bay of Biscay Eastern Atlantic [38]. * The values from Black Sea and Tunisian waters were converted from fork to total length (TL) for comparison purposes, using the total vs. fork length linear relationship obtained by present study data (TL = 1.1502 × fork length + 3.3413; $r^2 = 0.98$).

The years with higher *itv* and higher sampling gaps (2011, 2018 and 2019) were excluded from the overall fitting of the Bayesian growth model (Table 5), as well as those years (2016 and 2017) characterized by a reduced age range (i.e., no Age 3; Table 4).

Table 5. VBG Bayesian approach parameter estimates by year. The upper quartile of the Bayesian credibility intervals (2.5%; 97.5%) to the mean estimate ratio, expressed in percentage (*itv*%).

Year	Linf (mm)	t_0 (Years)	K (Years^{-1})	Linf *itv*	t_0 *itv*	k *itv*	Mean itv
2009	197 (188; 205)	−1.81 (−1.99; −1.49)	0.43 (0.38; 0.53)	8.63	27.62	34.18	23.48
2010	185 (176; 196)	−1.9 (−2; −1.71)	0.46 (0.39; 0.54)	10.81	15.26	31.44	19.17
2011	188 (176; 199)	−1.89 (−2; −1.61)	0.43 (0.36; 0.54)	12.23	20.63	41.26	24.71
2012	180 (172; 186)	−1.96 (−2; −1.85)	0.46 (0.42; 0.52)	8.33	7.65	22.29	12.76
2013	185 (176; 193)	−1.9 (−2; −1.68)	0.42 (0.37; 0.48)	9.19	16.84	26.82	17.62
2014	173 (168; 178)	−1.93 (−2; −1.8)	0.56 (0.51; 0.62)	5.78	10.36	19.78	11.97
2015	173 (168; 180)	−1.94 (−2; −1.79)	0.48 (0.43; 0.54)	6.94	10.82	22.89	13.55
2016	151 (150; 154)	−1.96 (−2; −1.85)	0.73 (0.69; 0.78)	2.65	7.65	12.3	7.53
2017	162 (158; 168)	−1.94 (−2; −1.81)	0.6 (0.53; 0.67)	6.17	9.79	22.98	12.98
2018	154 (150; 180)	−1.88 (−2; −1.63)	0.81 (0.49; 0.96)	19.48	19.68	57.46	32.21
2019	169 (161; 175)	−1.87 (−1.98; −1.59)	0.68 (0.56; 0.83)	10.65	20.86	44.74	25.42

The values obtained from the model fitted over the selected years (2009–2015 excluding 2011) were Linf = 18 cm, k = 0.459 y^{-1} and t_0 = −1.99 y (Table 6).

Table 6. Bayesian VBG fitting of the selected years (2009–2015 excluding 2011), model parameter estimates with their standard error (sd), lower (LCI), and upper (UCI) confidence intervals.

Parameter	Mean	sd	LCI (2.5%)	UCI (97.5%)
Linf cm	18	1.15	17.8	18.2
t_0 *year*	−1.99	0.018	−2	−1.95
K $year^{-1}$	0.459	0.008	0.448	0.474

Natural mortality (M) was obtained according to Gislason's model, with relative lower and upper confidence intervals for each age class, particularly 0.99 (0.98 −1.02) y^{-1} at Age 0; 0.71 (0.7–0.73) y^{-1} at Age 1; 0.6 (0.59–0.62) y^{-1} at Age 2; 0.54 (0.53–0.56) y^{-1} at Age 3; and 0.51 (0.49–0.53) y^{-1} at Age 4. These estimates were calculated taking into account the Bayesian VBGM parameters and the average length at age for each age class during the selected years (2009–2015 excluding 2011) (Figure 7).

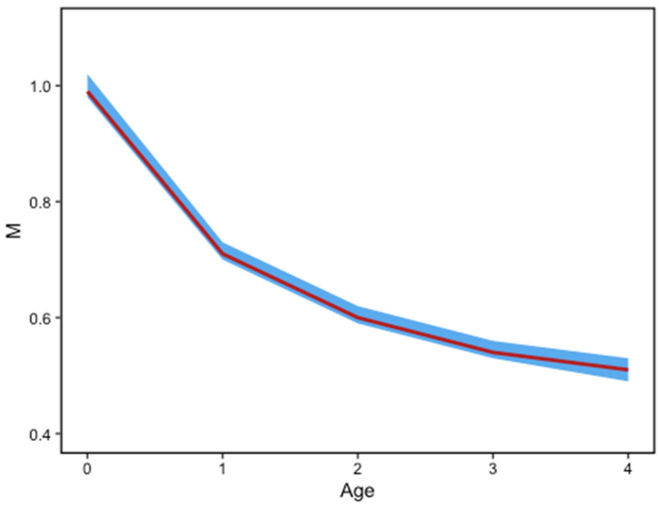

Figure 7. Sardine natural mortality (M) in GSA 16 based on Bayesian VBG parameters of selected years (2009–2015 excluding 2011): mean values, and lower and upper confidence intervals when uncertainty about the estimates of VBGP is propagated in the estimation of natural mortality using Gislason's Second Estimator.

4. Discussion

Age validation studies on sardine are still a matter of concern for many stocks and areas [39], while in the case of European anchovy the verification of increment periodicity for most populations and the corroboration of the first growth ring have been carried out, providing a valid support for the accuracy of age data [26,39]. Nevertheless, the adoption of an internationally agreed age-reading protocol allows a better comparison with age data from different areas and laboratories [39]. In the present study, the edge morphology analysis further corroborated the first annulus formation.

The age range during the whole study period showed sardines not older than 3 years, although in the Mediterranean Sea age ranges have displayed higher ages, in some studies even up 8 years old ([40] and references therein). Since these previous observations mainly rely on age reading of scales instead of otoliths, this evidence may invalidate a tight comparison of results with otolith-based studies [36,41]. Otolith-based studies recorded a maximum age of 5 years old among individuals in the western Mediterranean [36], while in the eastern part of the basin the age ranges were closer to the present study with fish not older than 4 years [42]. Although sardines have been observed to reach ages of up to

13 years in oceanic waters, they have also shown greater lengths than in the Mediterranean, with total lengths of 24–27 cm [38]. However, more recently, a contraction of the age classes was observed with individuals not older than 4 years in sardine stocks across the Mediterranean Sea, together with a decline in landings and overexploitation of this important resource [7]. A reduction in the age of landings was also observed in the present results, due to the reduction in the number of older individuals (i.e., Age 3) in recent years (2016 onwards). Although the sampling gaps of the last few years may also be responsible for the under-sampling of the older age classes, the structure of the population in the study area appeared mainly based on two classes (i.e., Age 1 + Age 2 = 90%), suggesting a population decline. Furthermore, a warning on the stock status is also indicated by the reduction in the average length at age along the time series analysed.

Significant trends were detected for the oldest age classes; such behaviour suggests a poorer condition in these age classes along the time series, most likely due to the higher fishing mortality on older/bigger individuals, especially those targeted by the PS fleet. However, it is not possible to exclude the concurrent effects of the environmental drivers, which appeared to worsen the body conditions of older age classes and increase their natural mortality [39,42]. Over the past two decades, European sardines have shown a decrease in average length in the Mediterranean Sea for each age class and this was linked to higher fishing pressure [43–45]. Moreover, as observed in the present study, this decrease in length at age is concomitant with a disappearance of older individuals [46].

A comparison with the available literature data for this species in Mediterranean and Atlantic waters (Figure 6) highlighted the observed average length at age for GSA16 falls between the estimates of Tunisia, Aegean and Black Seas (lower values) and the other areas (Spain, France, and the Bay of Biscay [38]). In northern Tunisian waters (which are the area closest to the study area), similar lengths at age have been found for sardines [37]. However, spatial variability in length at age has been observed in literature, with a latitudinal decline along the eastern Atlantic coast. Moreover, a west-east oriented gradient was also observed in the Mediterranean basin, with greater length toward the west [38]. Differences in sardine growth have also been recorded between northern and southern Tunisian waters, due to the coexistence of two different populations [37].

Difficulties in fitting the growth models appear to be related to the very large number of gaps in the sampling of landings in the years 2011, 2018, and 2019, while in 2016 and 2017 a reduced age range did not permit an adequate sample for fitting. However, the growth model parameter estimates, with their confidence intervals, showed values within the range observed in the literature for European sardine in the Mediterranean Sea [47] and references therein, especially if the present results are compared with other growth studies based on the otolith examination [36,42]. However, the present study results clearly fall within an Atlantic to Mediterranean gradient, with larger body length and longer lifespans in western areas (NE Atlantic and western Mediterranean) decreasing toward the Greek waters [47].

Uncertainty in estimating natural mortality can have a strong impact on stock assessments, especially in the case of short-lived species, such as sardines [42,48]. A wide range of variations in natural mortality values has been found in the literature, depending on the method and data used [49]. With regard to the selection of the best estimation method for natural mortality (M), a review study showed that none of the existing methods can provide robust evaluation for every species and none appears to be accurate enough to be used in analytical stock assessments, while many models provide such poor results that they have no practical application [49]. However, the same author noted that Gislason's first and second estimators appear to be the most useful for a wide variety of finfishes to delimit the mean M of a population. Certainly, the M values reported in the literature for the European sardine in the Mediterranean Sea have shown a high variability even among different areas and ecosystems, but sometimes it is difficult to disentangle the portion of habitat variability from other factors [49]. The M estimates of several Mediterranean regions showed a consistent variability by area, that was related to the variability and uncertainty in the growth parameters used as the basic input of Gislason's M estimator [50]. Due to the relative paucity of up-to-date studies on sardine mortality, authors have sometimes referred to theoretical values between 0.8 and 1, but without substantial evidence for such a choice [51]. However, current mortality estimates appeared in agreement with the literature [42,52].

5. Conclusions

Growth and mortality of European sardine were evaluated for GSA16, providing useful information for the management of this important resource. The main warnings from this study for the stock status in the GSA16 are the decrease in length at age along the study period, as well as the contraction in the population structure based only on Age 1 and Age 2 groups. These results, accordingly to the latest GFCM-WGSASP Report [23], strongly suggest a suffering population that appears not capable (over the study period) of returning to safe limits for a healthy stock. Homogenously sampling throughout the year is a well-accepted prerequisite for obtaining a reliable estimate of the population age structure (e.g., also including fish below the legal minimum length). Therefore, new efforts would be devoted to finding a compromise between the sampling program of commercial and scientific surveys to obtain representative information on the stock. Well-balanced temporal and gear sampling, along with the presence of observers on board the fishing vessels to obtain also smaller length individuals, would provide a better picture of the stock structure, which could be reflected in more accurate stock evaluation and more precise control rules.

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Institutional Review Board Statement: No use of live animals has been required for this study and no specific permissions were needed for the sampling activities in all of the investigated areas, because the target species is commercially harvested (neither endangered nor protected) and it was caught in areas where fishing is allowed.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data analyzed in this study is subject to the following licenses/restrictions: Due to the data policy of the Research Project (Piano di lavoro Raccolta Dati Alieutici-REG. (UE) N. 508/2014 relativo al Fondo europeo per gli affari marittimi e la pesca (FEAMP) e REG. (EU) N. 2017/1004) the datasets analyzed in this article cannot be made publicly available. Requests to access these datasets should be directed to https://dcf-italia.cnr.it/web/#/request-data.

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