

Research Article

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Reproductive traits of the round sardinella in the Canary Islands (Spain, NW Africa)

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Abstract

The present study aims to investigate the reproductive biology of the small pelagic *Sardinella aurita* Valenciennes, 1847 in the Canary Islands, to enable its reliable assessment and advise on appropriate management measures for a fishing resource showing a declining trend in landings. Reproductive biology and sexual patterns of round sardinella were examined from monthly random samples of commercial catches landed by the artisanal purse-seine fleet. The landings' length frequencies, ranging between 9–32 cm (based on the total lengths, TL), were recorded from 2013–2019. The overall mean value of TL was 20.9 cm, with annual mean values between 20–22 cm, except in 2016 (TL = 19 cm). The overall sex ratio M:F was 1:0.92, with males significantly predominant. Sex ratios fluctuated as a function of size and month: females were more abundant in the larger length classes, as well as before and after spawning, whereas males were more abundant in the smaller length classes and during spawning. Based on gonad maturity stages and gonadosomatic index, round sardinella spawns during almost all the year, with a peak in January–February and a resting period during October–November. The length at first maturity was estimated at TL of 18.2 cm, notably smaller than the value obtained for the NW African coastal waters where the demographic structure in round sardinellas' landings is totally different.

Introduction

The round sardinella, *Sardinella aurita* Valenciennes, 1847, is a coastal small pelagic fish widely distributed in the Atlantic Ocean, including the eastern coastal waters from the Gulf of Biscay to South Africa, with higher abundances in the three West African upwelling areas (the highest, off Mauritania), the Mediterranean and Black Seas. In the western Atlantic Ocean, it occurs from Cape Cod in the USA to Argentina (Froese & Pauly, 2021). Round sardinella is a schooling, strongly migratory and warm-water species, with preferred temperatures between 18–25°C (Bianchi *et al.*, 1999). Its resilience and plasticity to adapt itself to new environments (Baldé *et al.*, 2019) is leading the expansion of *S. aurita*, driven by global warming (Sabatés *et al.*, 2006; Tsikliras, 2008; Zeeberg *et al.*, 2008).

There are noticeable differences in the commercial relevance of round sardinella among countries, being highly targeted by some fisheries (such as in Mauritanian waters, where round sardinella also constitutes a primary source for the fishmeal industry (Corten *et al.*, 2017)), retained bycatch, or even discarded in others (FAO, *in press*).

The Canary Islands (located in the central-eastern Atlantic Ocean between 27–29°N and 13–18°W, Figure 1) is a Macaronesian archipelago characterized by abrupt bathymetry, with profiles that rise sharply from depths of over 2000 m to narrow island shelves. There are deep inter-island channels and the islands act as obstacles to the south-westwards flow of the Canary Current and the trade winds (Barton *et al.*, 1998; Aristegui *et al.*, 2006). In contrast to the nearby NW African coast, one of the richest fishery regions worldwide, the Canary Islands are characterized by oligotrophic waters, leading to low rates of primary production and limited fishing resources (Braun, 1980). Among others, these characteristics make the region rather low productive, where pelagic species produce the main fishery yields in biomass. In this context, after tuna, small pelagic species are the main fishing resource in the archipelago, round sardinella being one of the four species targeted by the artisanal purse-seine fleet (Jurado-Ruzafa *et al.*, 2019). The monitoring of this fishery and the assessment of the targeted species have been included in the framework of the Fishery Committee for the Eastern Central Atlantic (CECAF) since 2015 (FAO, 2016). For statistical purposes, *S. aurita* is grouped with *S. maderensis* (Lowe, 1838) as *Sardinella* spp. due to known taxonomic misidentification in the official reporting process (FAO, 2020). Based on the short time series (considered reliable from 2013 onwards), the importance of *Sardinella* spp. in landings has strongly decreased in the region since 2018 (from 400 mean tons/year during 2013–2017 to 94 mean tons/year during 2018–2020). A similar trend is shown by the European sardine, *Sardina pilchardus* (Walbaum, 1792) (FAO, *in press*), which has almost disappeared in the Canary Islands waters since 2019. These two species constitute one of the species groups (clupeids) defined in the region, with

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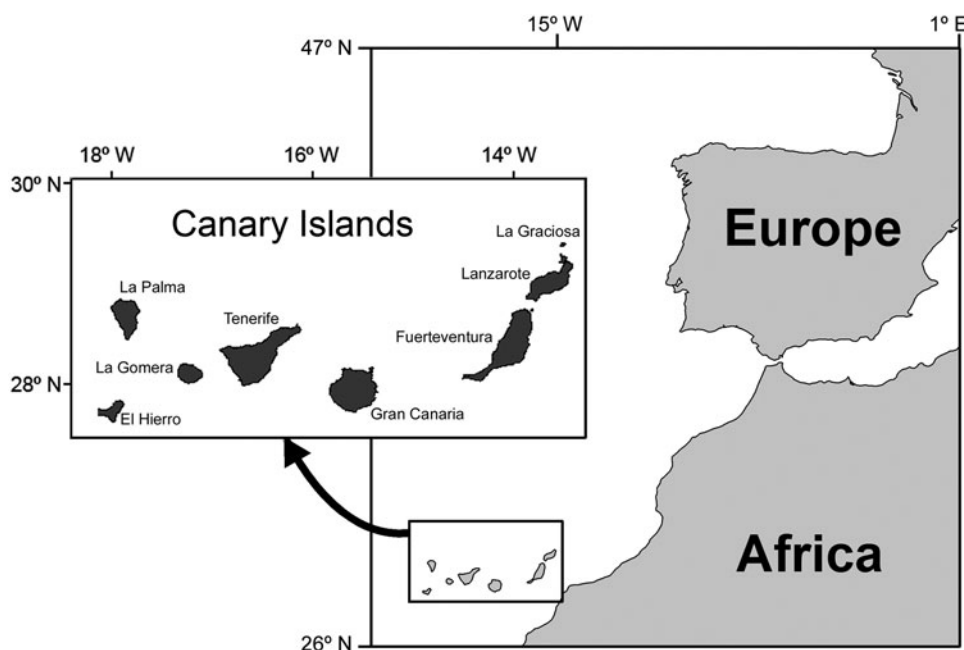


Fig. 1. Study area allocation and name of the eight islands which constitute the Canary Islands archipelago.

higher landings during the warmer season; whereas the other group, conformed by medium-sized pelagic species (i.e. *Scomber colias* Gmelin, 1789 and *Trachurus* spp.) shows higher landings during the cooler season (Jurado-Ruzafa *et al.*, 2019).

Despite the importance of the species for the local market, little is known about the life history traits of the species inhabiting Canary Islands waters. In addition, aside from the technical regulations imposed on the fleet, any specific consideration is applied to *S. aurita* at the national level, not even a size limitation. The short time series available and the limited knowledge of the biology of the species in the area make it a typical data-poor stock whose assessment has not been feasible so far (Quinzán & Jurado-Ruzafa, *in press*).

Based on the high variability in the reproductive traits of this strongly adaptable species (Whitehead, 1984, 1985), the aim of the present study was to describe the main reproductive traits of the round sardinella inhabiting the Canary Islands waters, in order to provide updated information and useful knowledge for the assessors and managers of a critically decreasing species.

Materials and methods

In January 2013, a long-term monitoring system was launched for the artisanal purse-seine fleet in the Canary Islands, through the European Data Collection Framework (EU, 2017). When

available, 100 randomly selected individuals were measured on a monthly basis for their total length (TL, precision 0.1 cm) and weighed (TW, precision 0.1 g). Sex and maturity are assigned macroscopically, based on a general 5-stages key (Holden & Raitt, 1975). Virgins and recovering individuals were considered immature, and the maturing, spawning and post-spawning individuals were considered mature. Finally, gonad weight (GW, precision 0.1 g) was recorded. In addition to the biological analyses, length samplings of commercial landings of the metier are performed in both fish markets and onboard. During these samplings, length classes (L_i , to the lower cm) and weight of the total fish sampled were registered. Based on all the length data (including biological analyses, length samplings in fish markets and onboard), the total and annual length frequencies were obtained. Length and biological samplings of round sardinella commercial landings are carried out in Tenerife, where more than 70% of the total landings of small pelagic species in the archipelago are performed (FAO, 2020). During 2020, commercial catches of *S. aurita* were not available for sampling due to several reasons (including the pandemic situation). As a consequence, a total of 17,320 individuals caught between 2013 and 2019 and covering length classes from 9–32 cm were measured from commercial landings in the Canary Islands.

Length-weight relationships (LWR) were calculated using the log-transformation of the power formula $TW = a \times TL^b$ (where

Table 1. Descriptive statistics of the round sardinella biologically analysed in the Canary Islands from commercial landings (time period 2013–2019) and LWR estimated for the total and by sex

Group	N	TL (cm)		TW (g)		LWR			
		mean \pm SD	Min–Max	mean \pm SD	Min–Max	a	b	R^2	GP
Total	7363	20.9 \pm 3.1	9.6–30.7	77.5 \pm 30.0	6.3–242.7	0.007	3.036	0.98	I
Female	3311	21.6 \pm 2.5	11.6–30.7	84.7 \pm 29.3	13.6–242.7	0.007	3.044	0.97	A+ (*)
Male	3587	21.2 \pm 2.1	12.0–28.9	78.6 \pm 23.3	13.8–207.6	0.009	2.962	0.96	A– (*)
Undetermined	465	13.0 \pm 1.7	9.6–17.9	18.0 \pm 7.8	6.3–47.5	0.006	3.129	0.98	I

N, number of individuals; TL, total length; TW, total weight; Min–Max, minimum–maximum; SD, standard deviation. For the length-weight relationships (LWR): a and b are the estimated parameters of the power function, R^2 the correlation factor, GP is the growth pattern (* $P < 0.05$, based on the Student t -test modified by Pauly (1984)), being isometric growth (I) when $b = 3$, or allometric positive or negative (A+ or A–, respectively) if $b \neq 3$.

a is the condition factor and b is the allometry coefficient). A Student t -test was applied to compare LWRs between sexes. Growth pattern (allometry) was tested using the Student's t -test modified by Pauly (1984).

Sex ratio was studied for the whole sample, by quarters and by L_i . The χ^2 test was applied to detect significant differences in the hypothesized 1:1 relationship (Zar, 1996). Spawning behaviour was followed based on the seasonal changes in gonad development, including both sexes, by correlating two approaches: quantitative (the quarterly evolution of the mean gonadosomatic index ($GSI = GW \times 1000/TW$)) and qualitative (the monthly variation of the percentage of mature stages vs the immature ones) (Jennings et al., 2001; King, 2007).

The length at first maturity (LFM, length at which 50% of individuals are in sexually mature stage) was estimated from the curves of maturity by length class (L_i). Proportions of mature specimens (p_i ; mature sexuality was considered for individuals in stage III, IV and V) were estimated for each L_i including the whole year, as spawning individuals are found all the year round. Maturity ogives were then estimated using the non-linear regression of the Gompertz model (Pope et al., 1983). The equation for the model is: $p_i = \exp[-\beta \times \exp(\beta_1 \times L_i)]$, p_i being the proportion of mature individuals for each L_i (p' for moving average was used = $(p_{i-1} + p_i + p_{i+1})/3$), and β and β_1 were the function parameters.

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 15.0 and Microsoft Office Excel 2019.

Results

A summary of descriptive statistics for the 7363 round sardinellas sampled in the laboratory is presented in Table 1, jointly to the LWR estimations. In all the cases, the power formula fitted well to the observed data ($R^2 > 0.96$) and no statistically significant differences were found between sexes (Student's $t = 1.056$; $P > 0.05$). Growth pattern should be taken with caution. No differences are evident between sexes, therefore the growth pattern assumed by the authors is the isometric model obtained for the whole sample of round sardinellas analysed, which includes the widest length range.

The analysis of the whole sample (Figure 2) resulted in a bi-modal length structure, with the main mode representing adult individuals of 20–23 cm (accounting for more than 50% of the fish measured) and the smaller mode accounting for the 4% of individuals of 12–13 cm, probably juveniles. Although the sampling design has been maintained throughout the study period, when observing the annual length frequencies, no clear pattern was observed. One main mode is clear around 20 cm, but with a noticeable exception in 2016 when a tri-modal distribution was obtained with an averaged TL lower than for the other years of the period. The low number of individuals measured in 2019 was mainly due to the obvious decrease in landings which made the availability of the species difficult.

Considering the overall analyses, males significantly outnumbered females in a proportion 1:0.92 ($\chi^2 = 11.043$, $P = 0.001$). On a monthly basis, different sex ratios were found with balanced proportions or a major presence of males, with the exception of January, when females outnumbered males when the whole study period was considered (Figure 3). However, a noticeable variability was found in the sex ratio among length classes (L_i), mainly among the largest sizes of the range (>19 cm), with males being predominant in the length classes 19–21, a balanced sex ratio occurred in $L_i = 22$ –23 cm, and females being predominant from 24 cm onwards (Figure 4).

The quarterly evolution of the GSI did not allow identification of clear seasonal spawning peaks, but the lowest mean GSIs

occurred in the fourth quarter (Figure 5). Most of the spawning activity happened during the first and/or second quarters except in 2015, when the highest GSI occurred during the third quarter. On the other hand, no clear recruitment seasons were observed in the time period studied, based on the quarterly averaged TL of the landings analysed. Nevertheless, the monthly proportion of mature/immature individuals found in landings (Figure 6) seems to indicate a noticeable spawning peak from January to February, when more than 90% of the analysed individuals were sexually mature. Additionally, a short time period with high proportion of immatures between October and November indicates a period of recovery process.

Results of the maturity ogive fitting the Gompertz model are presented in Figure 7 ($\beta = -678.5$ SE = 0.325; $\beta_1 = -0.379$ SE = 0.015), and the LFM estimated for $p_i = 0.5$ was 18.2 cm.

Discussion

The annual landings series show a drastic decrease in the landings of clupeids in the Canary Islands waters since 2019 (FAO, 2020). Santamaría et al. (2008) suggested a replacement of the European sardine by round sardinella in the archipelago. However, Jurado-Ruzafa et al. (2019) detected significant seasonal patterns in landings related to the environmental variations, grouping clupeids (*Sardinella* spp. and *S. pilchardus*) on one hand, and medium pelagic on the other. Both sardinellas and European sardines are experiencing a decreasing trend in the latest years. In this context, the almost collapse of *S. pilchardus* in Atlantic Iberian waters observed until 2019 (when a total ban was imposed in Portuguese waters), as well as the stopping of the purse-seiners activity in Spanish Iberian waters during 2019 and 2020 (ICES, 2021) should have alerted managers in the Canary region to avoid the probable consequences in the archipelago, where these species represent residual landings by the artisanal purse-seiners since 2019.

The annual length frequencies of round sardinella landings in the Canary Islands between 2013 and 2019 did not show any clear pattern. However, length frequencies clearly differed from the demographic structures found in NW African countries, including noticeably larger individuals (up to ~40 cm sized individuals, with modes in ~20–22 cm, ~26 and ~30 cm) (Baldé et al., 2019; Jurado-Ruzafa et al., 2020). The growth pattern observed in the present study should be considered as an informative punctual-trait, to be updated ad hoc if necessary in future studies, because (a) statistically significant differences between sexes were rejected, and (b) previous works in the area showed different results as well as significant seasonal variations (Jurado-Ruzafa et al., 2016).

The overall sex ratio obtained for the round sardinella in the Canary Islands resulted in a significant unbalance towards males, in contrast with NW African waters where balanced sex ratios have been observed off Mauritania (Wagué & M'Bodj, 2002; Chesheva, 2006), or where females predominated in landings off South Morocco (Baali et al., 2017), Mauritania (Jurado-Ruzafa et al., 2020) and Senegal (Boëly, 1982; Ndiaye et al., 2018; Baldé et al., 2019). Unbalance to females is also reported in the Mediterranean Sea (Tsikliras & Antonopoulou, 2006; Mustac & Sinovcic, 2012). Regarding the sex ratio variation by length range, the predominance of females in the largest sizes, as well as a balance for the middle length classes, had been observed for both the Atlantic (Wagué & M'Bodj, 2002; Baali et al., 2017; Amenzoui & Baali, 2018; Jurado-Ruzafa et al., 2020) and the Mediterranean round sardinellas (Tsikliras & Antonopoulou, 2006).

Sardinella aurita spawns year-round in NW Africa with a maximum period from June to September–December (depending on the area included) (Boëly et al., 1982; Chesheva, 2006; Ndiaye

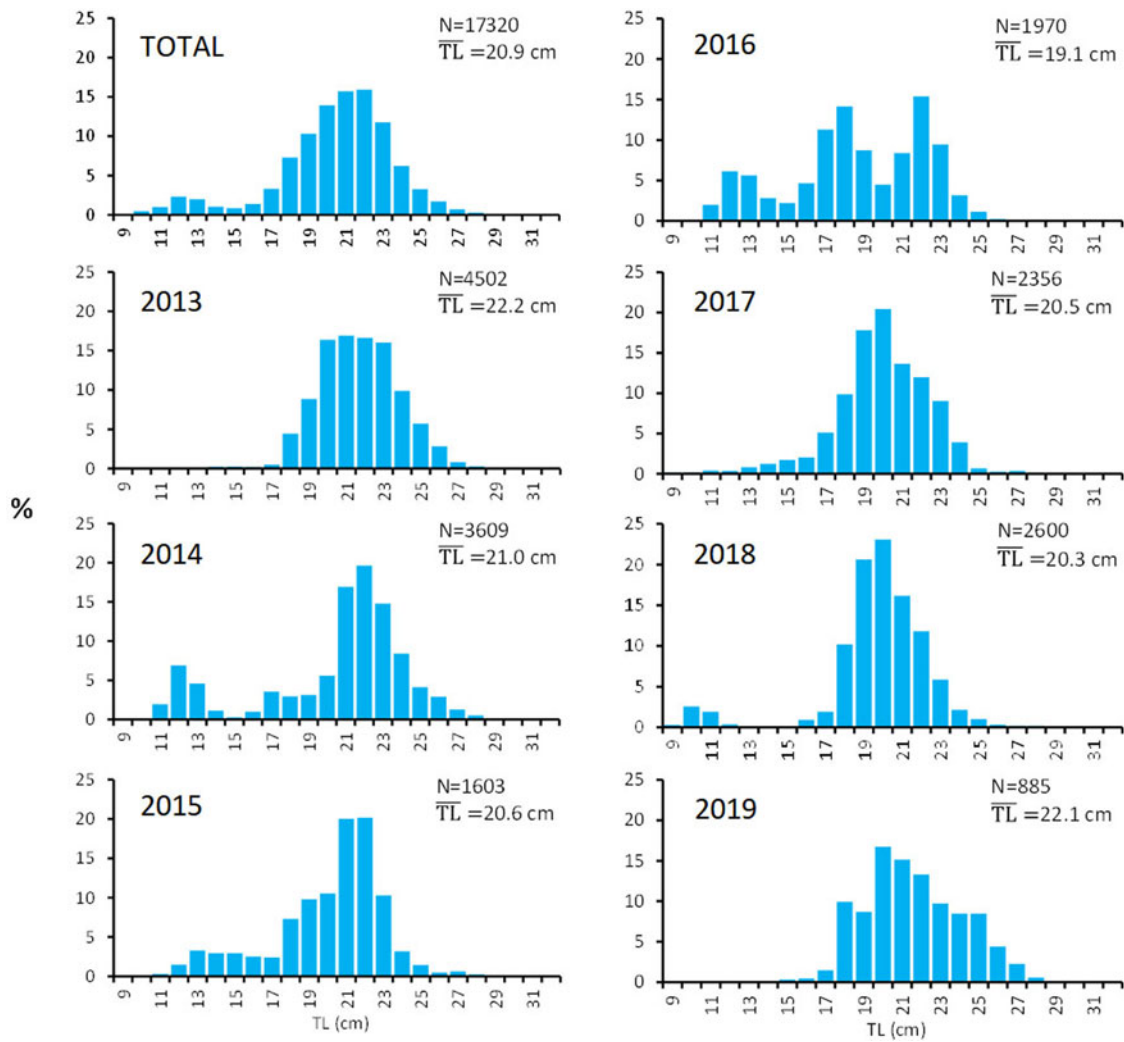


Fig. 2. Total and annual length frequencies (%) of the *S. aurita* landings analysed in the Canary Islands. N, number of fish measured; \bar{TL} , average total length.

et al., 2018; Baldé et al., 2019; Jurado-Ruzafa et al., 2020). Conversely the spawning peak observed in the Canary Islands occurs in winter, matching with the breeding periods found in the other small pelagic species caught by the same fleet, i.e. *S. colias* (Lorenzo & Pajuelo, 1996), *Trachurus picturatus* (Bowdich, 1825) (Jurado-Ruzafa & Santamaría, 2013) and *S. pilchardus* (Méndez-Villamil et al., 1997). The coldest period (i.e. winter) also matches with the main annual upwelling event in the archipelago (De León & Braun, 1973; Barton et al., 1998;

Moyano & Hernández-León, 2009; Valdés & Déniz-González, 2015). The coincidence of the spawning peaks with upwelling processes is in line with previous observations on breeding of round sardinellas. It seems synchronized with the major upwelling events in the nearby areas off South Morocco (Amenzoui & Baali, 2018), Mauritania (Jurado-Ruzafa et al., 2020), or with the period when the sea surface temperature reaches the annual minimum values (Baldé et al., 2019). Furthermore, the coincidence of the spawning peaks in the main target species of the

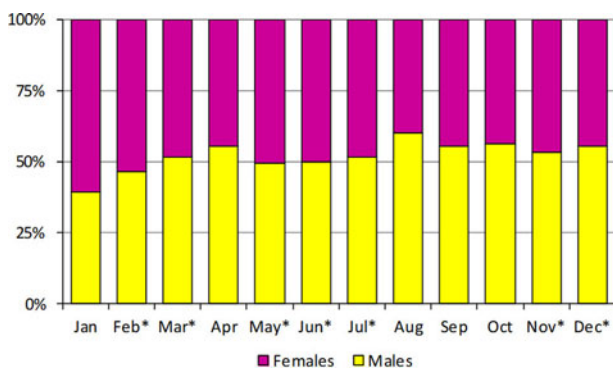


Fig. 3. Monthly sex ratios of the *S. aurita* landings analysed in the Canary Islands (time period: 2013–2019). (*) indicates χ^2 values with $P > 0.05$, meaning balanced sex ratios.

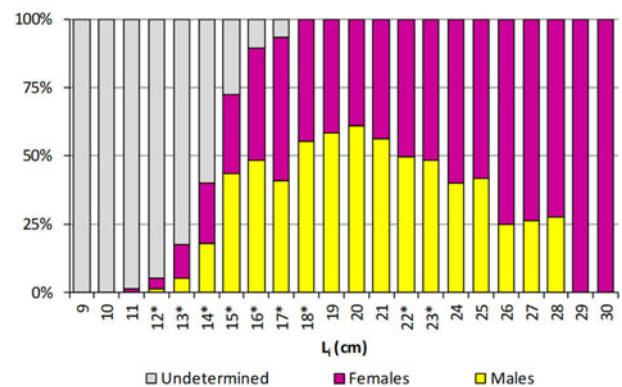


Fig. 4. Sex ratios by length class of the *S. aurita* landings analysed in the Canary Islands (time period: 2013–2019). (*) indicates χ^2 values with $P > 0.05$, meaning balanced sex ratios.

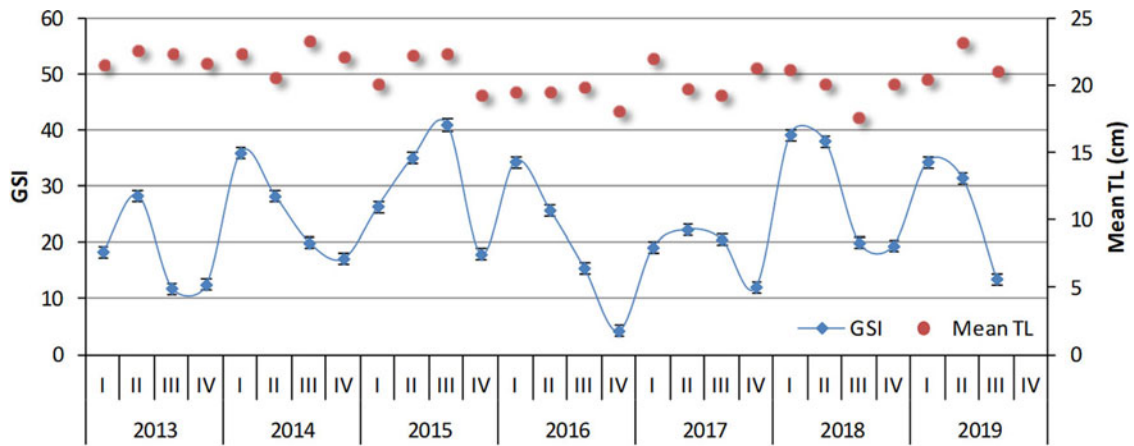


Fig. 5. Quarterly evolution of the mean values of the gonadosomatic index (GSI) and the total length (TL) of the round sardinellas landed in the Canary Islands.

fleet (artisanal purse-seines) should be considered as an advantage by the fishery managers who face the huge challenge of managing mixed fisheries (Penas Lado, 2019), as the one addressed in the present study, and even more for a species in expansion in the current climate change scenario (Baudron et al., 2020). In fact, expansion of species leads to transboundary geographic distributions, which in the case of *S. aurita* is promoting several projects whose aim is to facilitate collaboration between countries involved to share stocks to achieve the coordinated management programmes in NW Africa, such as the ‘Shared sardinella’ project (FAO, 2022).

The length at first maturity estimated for *S. aurita* inhabiting the Canary Islands waters (18 cm) is notably smaller than the LFMs estimated in NW African waters (ter Hofstede et al., 2007; Baali et al., 2015, 2017; Amenzoui & Baali, 2018; Ndiaye et al., 2018; Jurado-Ruzafa et al., 2020, among others). This is a common result in other small pelagic species, probably due to the more favourable oceanographic conditions in the continental NW African coasts, characterized by the influence of one of the four major upwelling systems of the world (Barton et al., 1998; Cury et al., 2020). Going deeper into the landings’ length frequencies, we can observe the presence of high proportions of juveniles (<18 cm, as in 2016), which could be explained by the absence of legal size limitations for this species, which makes it a perfect bycatch when other more valued and size-limited small pelagics are not found.

Several studies suggest a potential African larvae inflow into Canary Islands waters based on the presence of clupeid larvae in cooler filaments reaching the archipelago and originating in African upwelling areas (Rodríguez et al., 1999; Moyano, 2009; Moyano & Hernández-León, 2009). In the CECAF region,

latitudinal differences in seasonal patterns of the demographic composition and reproductive traits in *S. aurita* have been related to different temperature regimes and food availability (Amenzoui & Baali, 2018). The present study supports the reproductive behaviour complexity of *S. aurita* described by Whitehead (1985), also showing longitudinal differences in the demographic composition and the reproductive biology of *S. aurita* when compared with the species caught in NW African coasts. In this context, there are several studies discussing the population structure of the species in the CE Atlantic (e.g. Chesheva & Zimin, 2004; Riveiro et al., 2011; Bacha et al., 2016), but the use of genetic markers indicates low genetic variability for the Atlantic *S. aurita* (Kinsey et al., 1994; Chikhi et al., 1998; De Donato et al., 2005; Takyi, 2019). Therefore, although the results obtained in the present study strengthen the consideration of the Canary *S. aurita* as a different management unit than the NW African stock assumed by the CECAF experts group (FAO, 2020), further efforts are needed to describe the actual population structure of the round sardinella, including the whole geographic distribution of the species in the west Atlantic Ocean.

The round sardinella is experiencing an expansion process through latitudes where temperatures are getting warmer due to global warming (Navarro, 1932; Zeeberg et al., 2008; Amenzoui & Baali, 2018). In the NW African context, where it is considered a valuable protein source (Ba et al., 2017), from a precautionary approach and based on the limited data available, the assumed one-stock is considered overexploited (FAO, 2020), which should alert the Spanish managers to pay more attention to the Canary

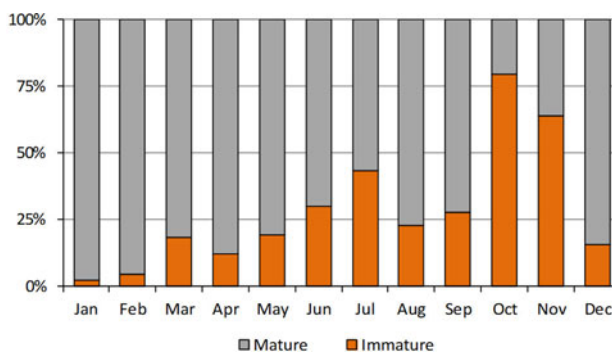


Fig. 6. Monthly proportions of mature and immature sexual stages of the round sardinellas landed in the Canary Islands (time period: 2013–2019).

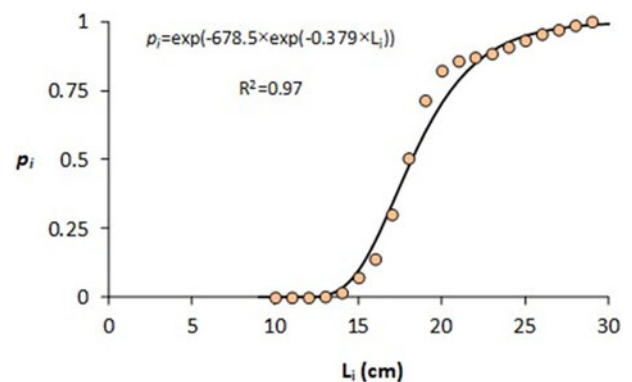


Fig. 7. Maturity ogive obtained for the round sardinellas landed in the Canary Islands (time period: 2013–2019). The p_i is the mature proportion by length class (L_i , cm). R^2 is the coefficient of determination when fitting the p_i observed by L_i to the Gompertz model (resulting formula presented in the graph).

sardinellas. The knowledge of the biology of species is crucial to achieving reliable assessment and sound management measures focused on the conservation of the natural resources along with sustainability of the fishing activity. In the critical scenario presented for *S. aurita*, the updated biological knowledge for this little-known species in the Canary Islands provides the base to address its status assessment and evaluate the management options.

Author contributions. Alba Jurado-Ruzafa: conceived and carried out the study, performed biological sampling and data collation, analysed the data, interpreted the findings and wrote the article. Begoña Sotillo de Olano, Zoraida Santana Arocha, Bertín García Mañé, Clara Estil-las García, Eva Hernández: contributed to samples' acquisition, biological sampling and data collation. All authors discussed the results and commented to the final manuscript.

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Conflict of interest. The authors declare no conflict of interests.

Ethical standards. The research did not involve animal experimentation or harm.

Data availability. Data available on request from the authors.

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