

Research Article

Cite this article: Jurado-Ruzafa A, Sotillo de Olano B, Santana Arocha Z, García Mañé B, Estil-las García C, Hernández E, Jiménez S, González-Lorenzo G, Perales-Raya C (2022). Reproductive traits of the round sardinella in the Canary Islands (Spain, NW Africa). *Journal of the Marine Biological Association of the United Kingdom* 1–7. <https://doi.org/10.1017/S0025315422000583>

Received: 21 March 2022

Revised: 14 May 2022

Accepted: 1 July 2022


Key words:

Artisanal fisheries; CE Atlantic; NW Africa; *Sardinella aurita*; small pelagic fish

Author for correspondence:

Alba Jurado-Ruzafa,
E-mail: alba.jurado@ieo.csic.es

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

Alba Jurado-Ruzafa , Begoña Sotillo de Olano, Zoraida Santana Arocha, Bertín García Mañé, Clara Estil-las García, Eva Hernández, Sebastián Jiménez, Gustavo González-Lorenzo and Catalina Perales-Raya

Centro Oceanográfico de Canarias, Instituto Español de Oceanografía (IEO-CSIC), C. Farola de Mar n. 22 (38180), Santa Cruz de Tenerife, Spain

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; Arístegui *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

© The Author(s), 2022. Published by Cambridge University Press on behalf of Marine Biological Association of the United Kingdom. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.



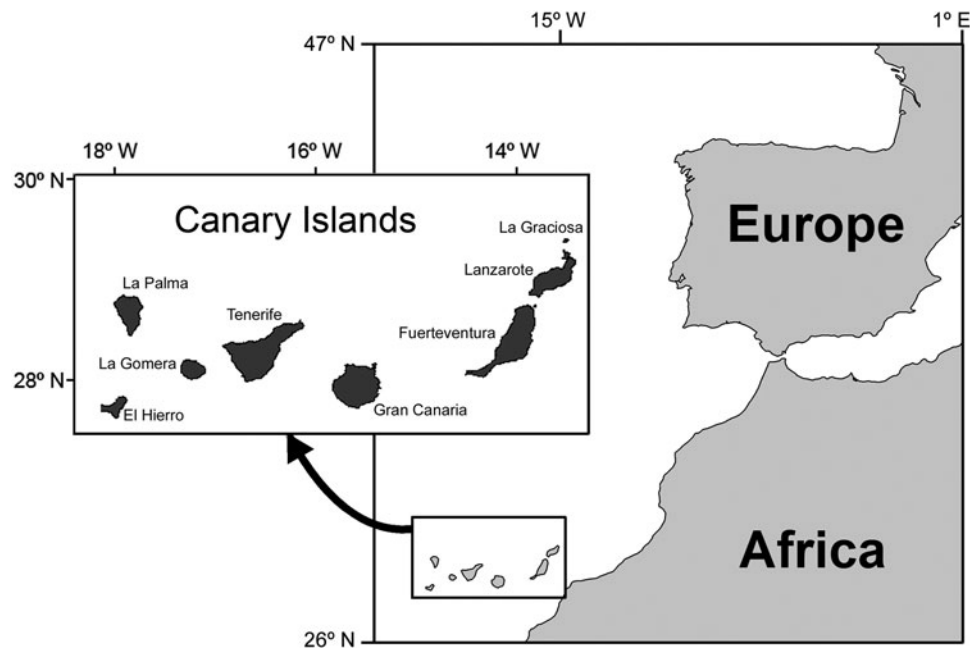


Fig. 1. Study area allocation and name of the eight islands which constitute the Canary Islands archipelago.

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 métier 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 sardinellas 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 & Sinovic, 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

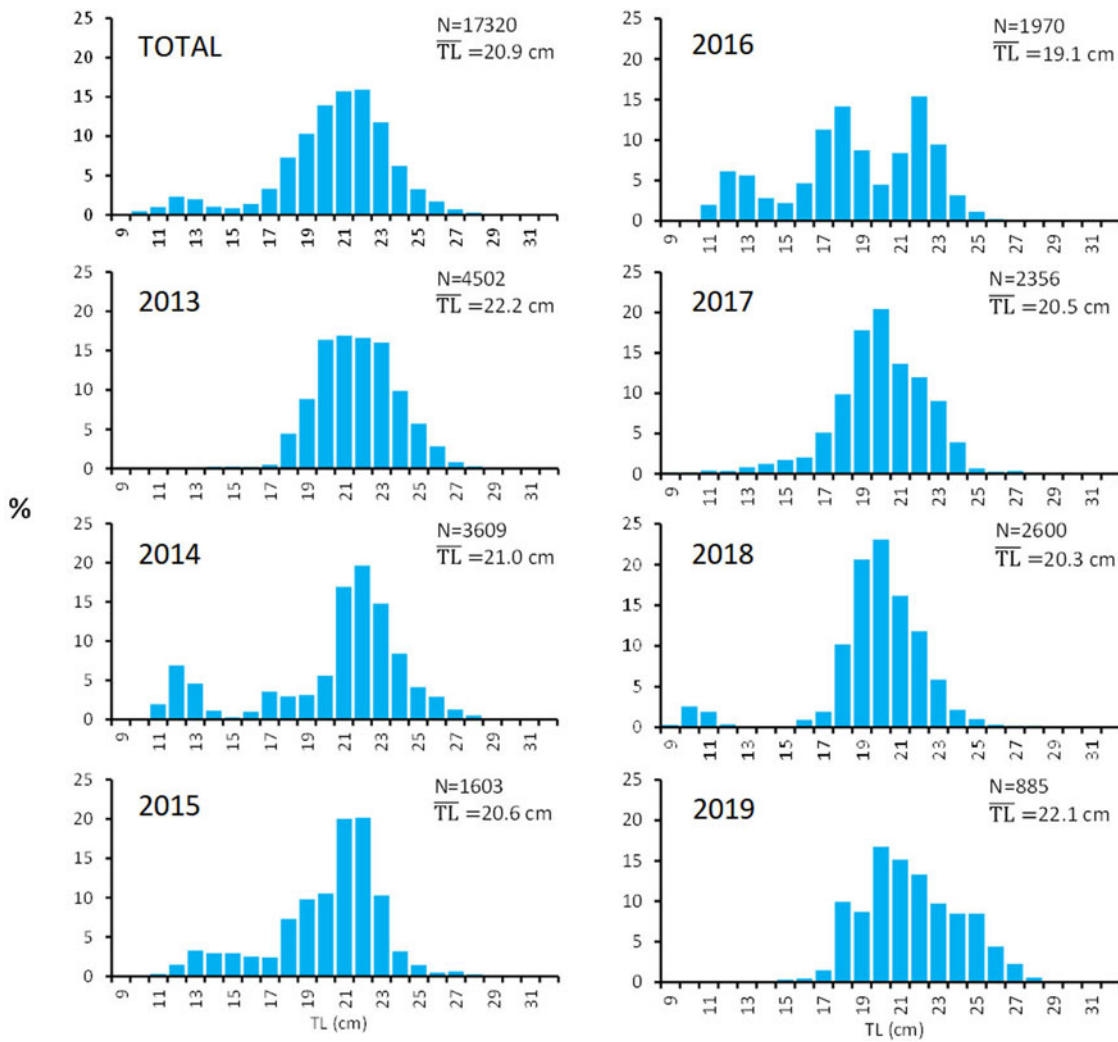


Fig. 2. Total and annual length frequencies (%) of the *S. aurita* landings analysed in the Canary Islands. N, number of fish measured; \bar{TL} , average total length.

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 & Santamaria, 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

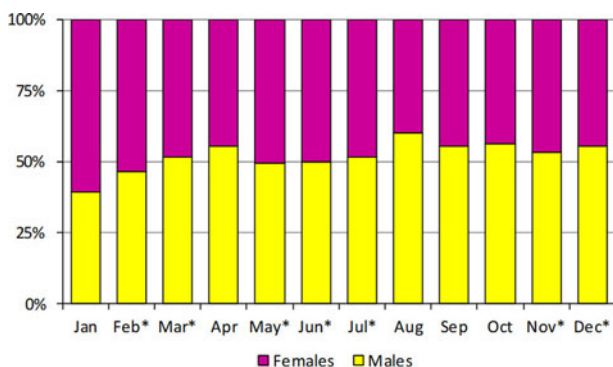


Fig. 3. Monthly sex ratios of the *S. aurita* landings analysed in the Canary Islands (time period: 2013–2019). (*) indicates χ^2 values with $P > 0.05$, meaning balanced sex ratios.

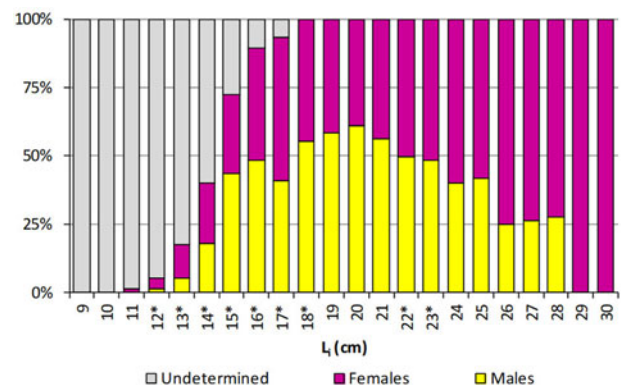


Fig. 4. Sex ratios by length class of the *S. aurita* landings analysed in the Canary Islands (time period: 2013–2019). (*) indicates χ^2 values with $P > 0.05$, meaning balanced sex ratios.

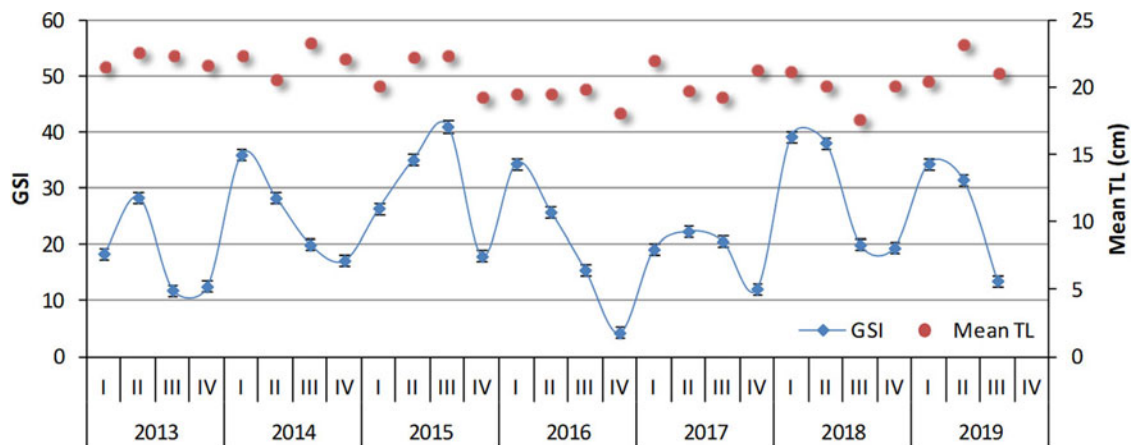


Fig. 5. Quarterly evolution of the mean values of the gonadosomatic index (GSI) and the total length (TL) of the round sardinellas landed in the Canary Islands.

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 LFM’s 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,

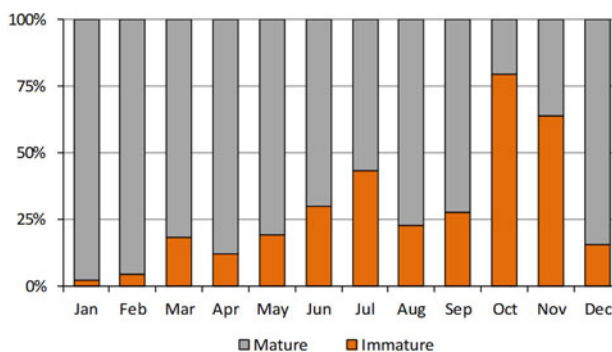


Fig. 6. Monthly proportions of mature and immature sexual stages of the round sardinellas landed in the Canary Islands (time period: 2013–2019).

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

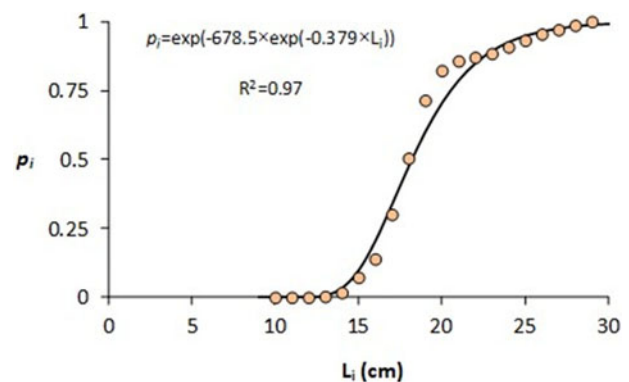


Fig. 7. Maturity ogive obtained for the round sardinellas landed in the Canary Islands (time period: 2013–2019). The p_i is the mature proportion by length class (L_i , cm). R^2 is the coefficient of determination when fitting the p_i observed by L_i to the Gompertz model (resulting formula presented 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, Bertin Garcia Mañé, Clara Estil-las Garcia, Eva Hernández: contributed to samples' acquisition, biological sampling and data collation. All authors discussed the results and commented to the final manuscript.

Financial support. This project was partially funded by the EU through the European Maritime and Fisheries Fund (EMFF) within the Spanish National Programme of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy.

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.

References

- Amenzoui K and Baali A (2018) Biological parameters of *Sardinella aurita* (Valenciennes, 1847) exploited in the Dakhla zone (South Atlantic Morocco). *International Journal of Scientific & Engineering Research* **9**, 85–90.
- Aristegui J, Álvarez-Salgado XA, Barton ED, Figueiras FG, Hernández-León S, Roy C and Santos AMP (2006) Oceanography and fisheries of the Canary currents/Iberian region of the eastern North Atlantic. In Robinson R and Brink KH (eds), *The Sea. Volume 14B: The Global Coastal Ocean. Interdisciplinary Regional Studies and Syntheses*. Cambridge, MA: Harvard University Press, pp. 878–931.
- Ba A, Schmidt J, Dème M, Lancker K, Chaboud C, Cury P, Thiao D, Diouf M and Brehmer P (2017) Profitability and economic drivers of small pelagic fisheries in West Africa: a twenty year perspective. *Marine Policy* **76**, 152–158.
- Baali A, Bourassi H, Falah S, Abderrazik W, Manchih K, Amenzoui K and Yahyaoui A (2017) Reproductive biology of *Sardinella* sp. (*Sardinella aurita* and *Sardinella maderensis*) in the South of Morocco. *Pakistan Journal of Biological Sciences* **20**, 165–178.
- Baali A, Yahyaoui A, Amenzoui K, Manchih K and Abderrazik W (2015) A preliminary study of reproduction, age and growth of *Sardinella aurita* (Valenciennes, 1847) in the southern of Atlantic Moroccan area. *AAFL Bioflux* **8**, 960–974.
- Bacha M, Jeyid AM, Jaafour S, Yahyaoui A, Diop M and Amara R (2016) Insights on stock structure of round sardinella *Sardinella aurita* off north-West Africa based on otolith shape analysis. *Journal of Fish Biology* **89**, 2153–2166.
- Baldé B, Sow F, Ba K, Ekau W, Brehmer P, Kantoussan J, Fall M and Diouf M (2019) Variability of key biological parameters of round sardinella *Sardinella aurita* and the effects of environmental changes. *Journal of Fish Biology* **94**, 391–401.
- Barton ED, Aristegui J, Tett P, Cantón M, García-Braun J, Hernández-León S, Nykjaer L, Almeida C, Almunia J, Ballesteros S, Basterretxea G, Escánez J, García-Weill L, Hernández-Guerra A, López-Laatzén F, Molina R, Montero MF, Navarro-Pérez E, Rodríguez JM, van Lenning K, Véléz H and Wild K (1998) The transition zone of the Canary Current upwelling region. *Progress in Oceanography* **41**, 455–504.
- Baudron A, Brunel T, Blanchet M-A, Hidalgo M, Chust G, Brown E, Kleisner K, Millar C, Mackenzie B, Nikolioudakis N, Fernandes J and Fernandes P (2020) Changing fish distributions challenge the effective management of European fisheries. *Ecography* **42**, 1–12.
- Bianchi G, Carpenter KE, Roux J-P, Molloy FJ, Boyer D and Boyer HJ (1999) *FAO Species Identification Guide for Fishery Purposes. Field Guide to the Living Marine Resources of Namibia*. Rome: FAO, 265 pp.
- Boëly T (1982) Étude du cycle sexuel de la sardinelle ronde (*Sardinella aurita* Val. 1847) au Sénégal. *Océanographie Tropicale* **17**(1), 3–13.
- Boëly T, Fréon P and Stequert B (1982) La croissance de *Sardinella aurita* (Val. 1847) au Sénégal. *Océanographie Tropicale* **17**, 103–119.
- Braun JG (1980) Estudios de producción en aguas de las Islas Canarias I. Hidrografía, nutrientes y producción primaria. *Boletín del Instituto Español de Oceanografía* **285**(5), 149–154.
- Chesheva Z (2006) On the biology of gilt sardine *Sardinella aurita* (Clupeidae) of the central Eastern Atlantic. *Journal of Ichthyology* **46**, 759–767.
- Chesheva ZA and Zimin AV (2004) The use of otolith measurement for the elucidation of the population structure of round sardinella *Sardinella aurita* (Clupeidae) from the Central Eastern Atlantic. *Journal of Ichthyology* **4**, 624–628.
- Chikhi L, Bonhomme F and Agnès J-F (1998) Low genetic variability in a widely distributed and abundant clupeid species, *Sardinella aurita*: new empirical results and interpretations. *Journal of Fish Biology* **52**, 861–878.
- Corten A, Braham C-B and Sadegh AS (2017) The development of a fishmeal industry in Mauritania and its impact on the regional stocks of sardinella and other small pelagics in NorthWest Africa. *Fisheries Research* **186**, 328–336.
- Cury P, Bakun A, Crawford RJM, Jarre A, Quiñones RA, Shannon LJ and Verheye HM (2000) Small pelagics in upwelling systems: patterns of interaction and structural changes in “wasp-waist” ecosystems. *ICES Journal of Marine Science* **57**, 603–618.
- De Donato M, Mimbela de Loroño I, Ramírez I and Marín B (2005) Baja diferenciación genética entre poblaciones de sardina, *Sardinella aurita*, del oriente venezolano. *Ciencias marinas* **31**, 529–535.
- De León AR and Braun JG (1973) Annual cycle of primary production and its relation to nutrients in the Canary Islands waters. *Boletín del Instituto Español de Oceanografía* **167**, 1–24.
- EU (2017) Report of the Regional Co-ordination Meeting for the Long Distance Fisheries (RCM LDF) 2017. Hamburg, Germany, 06–08 June 2017. 47 pp.
- FAO (2016) Fishery Committee for the Eastern Central Atlantic, Report of the seventh session of the Scientific Sub-Committee, Tenerife, Spain, 14–16 October 2015. FAO Fisheries and Aquaculture Report, 1128. 96 pp.
- FAO (2020) Report of the Working Group on the Assessment of Small Pelagic Fish of Northwest Africa. Casablanca, Morocco, 8–13 July 2019. FAO Fisheries and Aquaculture Report, 1309. 320 pp.
- FAO (2022) “Shared sardinella” project: promoting regional collaboration for sustainable management of the transboundary fishery in Northwest Africa. Available at <https://www.fao.org/in-action/eaf-nansen/news-events/detail-events/en/c/1269478/> (Accessed 21 March 2022).
- FAO (in press) Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. On-line meeting 21–25 June 2021. FAO Fisheries and Aquaculture Report (tbc).
- Froese R and Pauly D (eds) (2021) *FishBase*. World Wide Web electronic publication. Available at www.fishbase.org, version (08/2021) (Accessed 21 March 2022).
- Holden MJ and Raitt DFS (1975) *Manual of Fisheries Science. Part 2 – Methods of Resource Investigation and their Application*. FAO Fisheries Technical Papers, 115. 211 pp.
- ICES (2021) Working Group on Southern Horse Mackerel Anchovy and Sardine (WGHANSA). *ICES Scientific Reports* **3**, 55, 455 pp.
- Jennings S, Kaiser MJ and Reynolds JD (2001) *Marine Fisheries Ecology*. Oxford: Blackwell Science, 417 pp.
- Jurado-Ruzafa A, Bartolomé A, Carrasco N and Duque-Nogal V (2016) Length–weight relationships of the most caught small pelagic fish from the Canary Islands (NE Atlantic, Spain). *Vieraea* **44**, 107–116.
- Jurado-Ruzafa A, González-Lorenzo G, Jiménez S, Sotillo B, Acosta C and Santamaría MTG (2019) Seasonal evolution of small pelagic fish landings index in relation to oceanographic variables in the Canary Islands (Spain). *Deep Sea Research II* **159**, 84–91.
- Jurado-Ruzafa A, Hernández E, Duque-Nogal V, Pascual-Alayón PJ, Carrasco MN, Sancho A and Santamaría MTG (2020) Life history parameters of the round sardinella *Sardinella aurita* in the Central East Atlantic off north-West Africa. *Journal of the Marine Biological Association of the United Kingdom* **100**, 997–1009.

- Jurado-Ruzafa A and Santamaría MTG** (2013) Reproductive biology of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), off the Canary Islands. *Journal of Applied Ichthyology* **29**, 526–531.
- King M** (2007) Stock structure and abundance. In *Fisheries Biology: Assessment and Management*. Oxford: Blackwell Publishing, pp. 172–238.
- Kinsey ST, Orsoy T, Bert TM and Mahmoudi B** (1994) Population structure of the Spanish sardine *Sardinella aurita*: natural morphological variation in a genetically homogeneous population. *Marine Biology* **118**, 309–317.
- Lorenzo JM and Pajuelo JG** (1996) Growth and reproductive biology of chub mackerel *Scomber japonicus* off the Canary Islands. *South African Journal of Marine Science* **17**, 275–280.
- Méndez-Villamil M, Lorenzo JM, González JM and Soto R** (1997) Periodo reproductor y madurez sexual de la sardina *Sardina pilchardus* (Walbaum, 1792) en aguas de Gran Canaria (Islas Canarias). *Boletín del Instituto Español de Oceanografía* **13**, 47–55.
- Moyano M** (2009) *Temporal and spatial distribution of the ichthyoplankton in the Canary Islands*. Doctoral Thesis, Universidad de Las Palmas de Gran Canaria. 287 pp.
- Moyano M and Hernández-León S** (2009) Temporal and along-shelf distribution of the larval fish assemblage at Gran Canaria, Canary Islands. In Clemmesen C, Malzahn AM, Peck MA and Schnack D (eds), *Advances in Early Life History Study of Fish*. Barcelona: Scientia Marina, pp. 85–96.
- Mustac B and Sinovcic G** (2012) Inshore vs offshore length distribution of round sardinella (*Sardinella aurita*) in the middle eastern Adriatic Sea. *Acta Adriatic* **53**, 341–350.
- Navarro FP** (1932) Nuevos estudios sobre la alacha (*Sardinella aurita* C. & V.) de Baleares y de Canarias. Instituto Español de Oceanografía. *Notas y Resúmenes. Serie II* **60**, 1–35.
- Ndiaye I, Sarr A, Faye A, Thiaw M, Diouf M, Ba K, Ndiaye W, Lazar N and Thiaw OT** (2018) Reproductive biology of round sardinella (*Sardinella aurita*) (Valenciennes, 1847) in Senegalese coastal waters. *Journal of Biology and Life Science* **9**, 31–45.
- Pauly D** (1984) *Fish Population Dynamics in Tropical Waters: A Manual for Use with Programmable Calculators*. Manila: ICLARM, 325 pp.
- Penas Lado E** (2019) The challenge of mixed fisheries. In Penas Lado E (ed.), *Quo Vadis Common Fisheries Policy?*. Brussels: Wiley Blackwell, pp. 71–90. <https://doi.org/10.1002/9781119576907.ch4>.
- Pope JA, Margetts AR, Hamley JM and Akyüz EF** (1983) *Manual of Methods for Fish Stock Assessment. Part 3 – Selectivity of Fishing Gear*. FAO Fisheries Technical Papers, 41. 56 pp.
- Quinzán M and Jurado-Ruzafa A** (in press) Exploratory assessment of small pelagic stocks in the Canary Islands using data-poor methods. In FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Online meeting, 21–25 June 2021. FAO Fisheries and Aquaculture Report (tbc).
- Riveiro I, Guisande C, Iglesias P, Basilone G, Cuttitta A, Giráldez A, Patti B, Mazzola S, Bonanno A, Vergara A-R and Maneiro I** (2011) Identification of subpopulations in pelagic marine fish species using amino acid composition. *Hydrobiologia* **670**, 189–199.
- Rodríguez JM, Hernández-León S and Barton ED** (1999) Mesoscale distribution of fish larvae in relation to an upwelling filament off NorthWest Africa. *Deep Sea Research Part I* **46**, 1969–1984.
- Sabatés A, Martín P, Lloret J and Raya V** (2006) Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. *Global Change Biology* **12**, 2209–2219.
- Santamaría MTG, González JF, Barrera A, López Abellán LJ, Quintero ME and Balguerías E** (2008) Substitution of sardine (*Sardina pilchardus*) for round sardinella (*Sardinella aurita*) in the Canary Islands waters. In Fréon P, Barange M and Aristegui J (eds), *Eastern Boundary Upwelling Ecosystems: Integrative and Comparative Approaches. Book of Abstracts*. Las Palmas de Gran Canaria, p. 213.
- Takvi E** (2019) Population genetic structure of *Sardinella aurita* and *Sardinella maderensis* in the eastern central Atlantic region (CECAF) in West Africa. Master's Thesis, University of Rhode Island. 54 pp.
- ter Hofstede R, Dickey-Collas M, Mantingh IT and Wague A** (2007) The link between migration, the reproductive cycle and condition of *Sardinella aurita* off Mauritania, north-West Africa. *Journal of Fish Biology* **71**, 1293–1302.
- Tsikliras AC** (2008) Climate-related geographic shift and sudden population increase of a small pelagic fish (*Sardinella aurita*) in the eastern Mediterranean Sea. *Marine Biology Research* **4**, 477–481.
- Tsikliras AC and Antonopoulou E** (2006) Reproductive biology of round sardinella (*Sardinella aurita*) in the north-eastern Mediterranean. *Scientia Marina* **70**, 281–290.
- Valdés L and Déniz-González I** (eds) (2015) *Oceanographic and Biological Features in the Canary Current Large Marine Ecosystem*. Paris: IOC-UNESCO. IOC Technical Series, 115. 383 pp.
- Wagué A and M'Bodj OB** (2002) Étude de quelques aspects de la reproduction chez la sardinelle ronde *Sardinella aurita* (Valenciennes, 1847) pêchée le long des côtes mauritaniennes. *Bulletin Scientifique de l'Institut Mauritanien de Recherches Océanographiques et des Pêches* **29**, 13–18.
- Whitehead PJP** (1984) Clupeidae (incl. Dussumieridae). In Whitehead PJP, Bauchot M-L, Hureau J-C, Nielsen J and Tortonese E (eds), *Fishes of the North-Eastern Atlantic and the Mediterranean*, vol. 1. Paris: UNESCO, pp. 268–281.
- Whitehead PJP** (1985) *FAO Species Catalogue. Vol. 7. Clupeoid Fishes of the World (suborder Clupeoidei). An Annotated and Illustrated Catalogue of the Herrings, Sardines, Pilchards, Sprats, Shads, Anchovies and Wolf-herrings*. FAO Fisheries Synopsis, 125(7/1): 303 pp.
- Zar JH** (1996) *Biostatistical Analysis*. Hoboken, NJ: Prentice-Hall, 718 pp.
- Zeeberg J, Corten A, Tjoe-Awie P, Coca J and Hamady B** (2008) Climate modulates the effects of *Sardinella aurita* fisheries off NorthWest Africa. *Fisheries Research* **89**, 65–75.