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Life-history traits of large-scaled gurnard, *Lepidotrigla cavillone* (Teleostei: Triglidae), from the Balearic Islands (Western Mediterranean)

Maria Valls [1], Marina Bibiloni-Socias [1], Beatriz Guijarro [1], Rosario Domínguez-Petit [2], Francesc Ordines [1]

[1] Centro Oceanográfico de Baleares (COB-IEO), CSIC. Moll de Ponent s/n, 07015-Palma (Balearic Islands), Spain.
(MV) (Corresponding author) E-mail: maria.valls@ieo.csic.es ORCID iD: https://orcid.org/0000-0001-9070-8181
(MB-S) E-mail: marinabibilonisocias@gmail.com ORCID iD: https://orcid.org/0009-0003-4963-0660
(BG) E-mail: beatriz.guijarro@ieo.csic.es ORCID iD: https://orcid.org/0000-0002-2083-4681
(FO) E-mail: xisco.ordinas@ieo.csic.es ORCID iD: https://orcid.org/0000-0002-2456-2214
[2] Centro Oceanográfico de Vigo (COV-IEO), CSIC. Subida a Radio Faro, 50-52 36390 Vigo (Galicia), Spain.
(RD-P) E-mail: rosario.dominguez@ieo.csic.es ORCID iD: https://orcid.org/0000-0003-1731-6848

Summary: The large-scaled gurnard, *Lepidotrigla cavillone*, is one of the most abundant Triglidae fish in the Mediterranean Sea. We studied its main life-history traits in the Balearic Islands. Samples were obtained monthly from the bottom trawl fleet and from oceanographic surveys delivered in spring-summer. Overall, 833 specimens were sampled, ranging from 4.3 to 15.3 cm total length, and a female-male ratio of 1:0.81. Length-weight relationships showed no differences between sexes and a positive allometric growth, using both total and eviscerated weight. The estimated age of the individuals ranged from 0 to 4 years. Females mature at a smaller length (L_{50}=9.1 cm) than males (L_{50}=10.2 cm). The spawning season runs from April to August, with annual realized fecundity of 16000-47000 oocytes per female. The seasonal variation of condition indices showed that food intake supported liver reserves during vitellogenesis, whereas muscle reserves were depleted during spawning, indicating a mixed income-capital breeder strategy. Diet analysis indicated generalist feeding habits, based on epi- and suprabenthic small-sized crustaceans, resulting in a trophic level of 3.35. In the Balearic Islands, the large-scaled gurnard inhabits up to 250 m depth, showing its highest abundances on sandy-muddy bottoms between 120 and 180 m.

Keywords: growth; spawning; fecundity; condition; diet; habitat.

Caracteríticas del ciclo biológico de *Lepidotrigla cavillone* (Teleostei: Triglidae) de las Islas Baleares (Mediterráneo Occidental)

Resumen: *Lepidotrigla cavillone* es uno de los triglidos más abundantes del Mediterráneo. En este trabajo se estudiaron sus principales características vitales en las Islas Baleares. Las muestras se obtuvieron mensualmente de la flota de arrastre de fondo y de las campañas oceanográficas realizadas en primavera-verano. En total, se muestrearon 833 ejemplares, con una longitud total que osciló entre 4.3 y 15.3 cm, y una proporción hembra-macho de 1:0.81. Las relaciones longitud-peso, calculadas tanto con el peso total como con el peso eviscerado, no mostraron diferencias entre sexos y señalaron un crecimiento alométrico positivo. La edad estimada de los individuos osciló entre 0 y 4 años. Las hembras maduran a una longitud menor (L_{50}=9.1 cm) que los machos (L_{50}=10.2 cm). La época de desove tiene lugar entre abril y agosto, con una fecundidad anual de 16000-47000 ovocitos por hembra. La variación estacional en los índices de condición mostró que la ingesta de alimentos mantuvo las reservas hepáticas durante la vitelogénesis, mientras que las reservas musculares se agotaban durante el desove, lo que indica una estrategia reproductiva mixta tipo income-capital. El análisis de la dieta indicó hábitos alimentarios basados en crustáceos epi- y suprabentónicos de pequeño tamaño, resultando en un nivel trófico de 3.35. En las Islas Baleares, *L. cavillone* habita hasta los 250 m de profundidad, mostrando sus mayores abundancias en fondos arenosos-fangosos entre los 120-180 m.

Palabras clave: crecimiento; puesta; condición; dieta; hábitat.

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INTRODUCTION

The large-scaled gurnard *Lepidotrigla cavillone* (Lacepède, 1801) is a demersal species belonging to the Triglidae family which, in the Mediterranean Sea, is represented by eight species (*Chelidonichthys cuculus, Chelidonichthys lastoviza, Chelidonichthys lucerna, Chelidonichthys obscurus, Eutrigla gurnardus, L. cavillone, Lepidotrigla dieuzeidei* and *Trigla lyra*). It is distributed in the Eastern Atlantic from the coast of Portugal to Mauritania, including the Mediterranean Sea (Fischer et al. 1987), where it is one of the most common gurnard species inhabiting muddy and sandy bottoms of the continental shelf and upper slope (Colloca et al. 1997). The species is mainly landed as a bycatch of the bottom trawl fisheries (Ordines et al. 2006, Ilkyaz et al. 2010). The commercial importance of *L. cavillone* varies between areas, e.g. it is commercially appreciated in Italy (Colloca et al. 1997) but has low commercial value in Turkey (Ilkyaz et al. 2010) and in the Balearic Islands, where it is frequently sold together with other species in a mixed fish category known as *morralla* (Ordines et al. 2006). The recent trends of the species show that its relative biomass has generally decreased in the Western and Eastern Mediterranean but increased in some areas, such as Corsica and Sicily (Colloca et al. 2019). *L. cavillone* biomass in the Balearic Islands is among the highest recorded in the Mediterranean Sea, with values ranging between 8 and 21.8 kg km^{-2} (Colloca et al. 2019).

Most of the previous studies on life-history parameters of *L. cavillone* are from the Central and Eastern Mediterranean. Age estimation, conducted in the Thyrrenian and Aegean Sea, ranged from 1 to 4 years for both males and females (Colloca et al. 1994, Uçkun 2005), although individuals up to 6 years have also been reported (Ilkyaz et al. 2010). This species is known to reach its maturity around 9 to 10 cm (Ilkyaz et al. 2010, Dobroslavić et al. 2015) and the spawning season is generally long, occurring between February and September, with some geographical variation (Colloca et al. 1997, Togulga et al. 2000, Ilkyaz et al. 2010, Dobroslavić et al. 2015). Feeding studies indicate that the large-scaled gurnard feeds basically on crustaceans and that mysids, decapods and amphipods are its most important food resources (Caragitsou and Papacostantinou 1990, Labropoulou and Machias 1998, Togulga et al. 2000). Furthermore, no seasonal or fish size effect was found in its diet composition (Labropoulou and Machias 1998). *L. cavillone* is mostly distributed along the continental shelf, although the species seems to conduct inshore-offshore migration along its depth range related to gonadal development and spawning (Papacostantinou 1982, Colloca et al. 1997), and more studies are needed to analyse bathymetric distribution changes and life-history events (Labropoulou and Machias 1998).

In the Western Mediterranean, there is no information on the life-history traits of this species except its feeding habits in the Catalan Sea (Kartas 1973, Moreno and Matallanas 1983), its growth parameters (Campillo 1992) and a recent study addressing the abundance and distribution of gurnards across the Mediterranean (Colloca et al. 2019). In the current context of a progressive change from a single-species to an ecosystem approach in the assessment and management of fisheries (e.g. Browman and Stergiou, 2004), increasing the biological knowledge of bycatch species is a key step. The objective of the present study is to provide new and updated biological information of the large-scaled gurnard in the Western Mediterranean. To this end, population structure, growth, reproduction, diet and distribution of this species were studied in the Balearic Islands.

MATERIAL AND METHODS

Sampling

Biological samples were mainly obtained monthly from landings of the bottom trawl fleet operating in Mallorca (Balearic Islands), between May 2021 and May 2022 (Fig. 1) and from the International bottom trawl survey in the Mediterranean (MEDITS) carried out annually in spring-summer around the Balearic Islands (GSA5) (Table 1). Samples obtained from commercial catches were obtained monthly by buying a commercial category known as *morralla*, in which dozens of small fish species are gathered and sold together, including *L. cavillone*. The goal of the MEDITS scientific survey is to assess the state of demersal fishing resources and ecosystems along the continental shelf and slope of the Mediterranean coast down to 800 m depth (Bertrand et al. 2002, Spedicato et al. 2019). During the survey, the hauls were conducted during daylight, and their duration varied from 20 to 60 minutes, depending on depth, at a standard velocity of 3 knots. The depth at which the net arrived at and departed from the bottom and the horizontal and vertical openings (usually ranging from 16 to 22 m and 2.5 to 3.2 m, respectively) were measured using acoustic monitoring systems. Once the samples were on board, the species were sorted and identified. Then, individuals were counted, weighed and measured. The abundance and biomass of catches were standardized to 1 km^2 (GOC 73), using the area swept by the net over the bottom, which was calculated using the distance covered by the net over the bottom and its horizontal opening.

We carried out a biological sampling of *L. cavillone* individuals from both commercial landings and surveys, recording the individual total length (TL; to the lowest mm) and weight (TW), eviscerated weight (EW), gonad weight (GW), digestive tract weight (DW) and liver weight (LW) (all weights with a ±0.01 g precision). The sex and maturity of individuals was also determined by macroscopic inspection of gonads. Females were classified as immature, developing, spawning-capable or regenerating according to the description of maturity stages in Brown-Peterson et al. (2011), whereas males were categorized as active or inactive. Female gonads were fixed in

a 4% solution of buffered formaldehyde for histological and fecundity analysis. Finally, the sagittal otoliths were removed, cleaned and stored dry in envelopes for age determination.

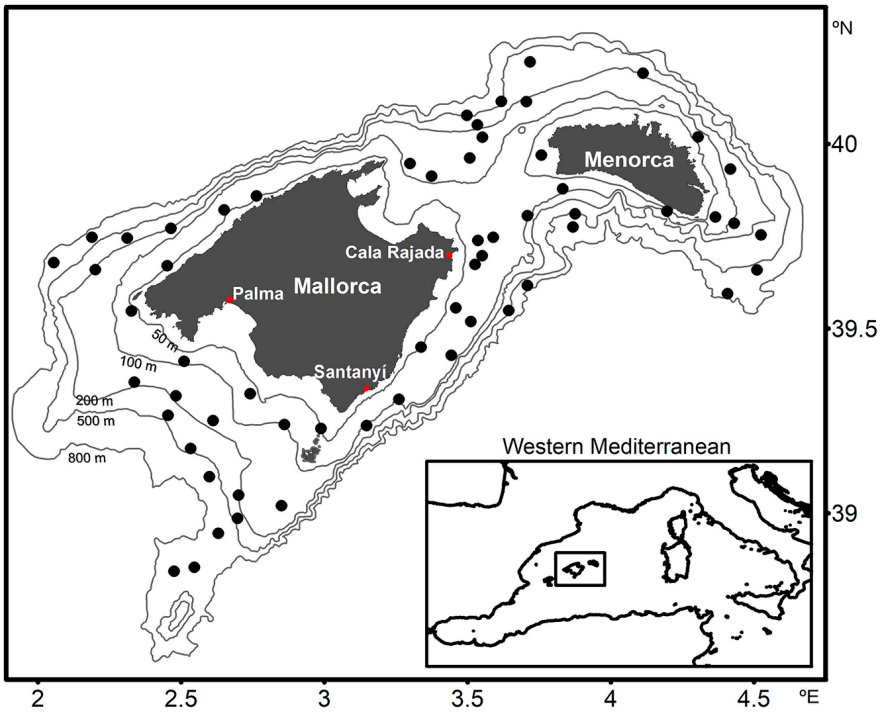

Fig. 1. – Map of the study area in the Balearic Islands showing the stations sampled during MEDITS (black dots). Fishing ports (Palma, Santanyi and Cala Ratjada) where commercial samples were obtained are also shown (red dots).

Table 1. – Number of individuals sampled, their length ranges and respective data sources according to the biological traits analysed in this study.

Sampling	N	Length range (cm)	Source
Population structure, reproduction and condition	833	4.3–15.3	MEDITS and landings (2021-2022)
Length-weigth and age-length	336	4.3–14.6	MEDITS and landings (2021-2022)
Maturity	496	4.3–14.6	MEDITS and landings (2021-2022)
Fecundity	25	9.2–14.6	MEDITS and landings (2021-2022)
Diet	636	8.0–14.6	MEDITS (2007-2022)

Population structure

We calculated length-frequency distributions by sex of all the sampled individuals (Table 1). We compared length-frequency distributions between sexes by applying a Kolmogorov-Smirnov two-sample test. The sex ratio (female-male proportion) was calculated and the chi-square test was used to detect bias from the 1:1 proportion for the whole sampled population, by season and by length class.

Growth

Length-weight relationships (LWR) were established using a power regression function, $W=aTL^b$, where W is weight data (TW or EW), *a* is the intercept and *b* is the allometric growth factor. Differences in LWR between males and females were tested by applying analysis of covariance (ANCOVA) after log-transforming W and TL for linearization. Before the ANCOVA, the assumption of homogeneity of regression slopes was assessed by testing the significance of the interaction between the covariate (TL) and the dependent variable (W). If the ANCOVA detected no difference between sexes, an LWR was calculated for the whole population. The 95% confidence interval (CI) of the allometric coefficient was used to assess the growth allometry; allometry was considered negative or positive if the CI was below or above 3, respectively, whereas CI including 3 was considered isometric growth. LWR analyses and comparisons were performed using the Microsoft Excel and Past (Hammer et al. 2001) software packages.

Age determination from otolith reading was performed using a stereoscopic microscope under reflected light against a black background, following standard techniques (Morales-Nin et al. 1998). Opaque and transparent bands were counted. Once the annual periodicity of rings was validated, each specimen was assigned to a year class, taking

into account the date of capture, the number of rings, their formation period and the spawning season in the area. The INBIO R package was used to fit the von Bertalanffy growth function: $L_t = L_\infty * (1 - e^{(-k(t - t0))})$, where L_t is the TL at age t, L_∞ is the asymptotic length [fixed in the model according to the formulae of Taylor (1958), where $L_\infty = L_{max}/0.95$], k is the instantaneous growth coefficient, and t_0 is the hypothetical age at which length is equal to zero.

Reproduction

To prepare histological sections for microscopic maturity staging, fixed gonads were dehydrated in increasingly concentrated ethanol (70, 80, 95-100%), followed by tissue clearing. Then, the tissue was embedded in paraffin, sectioned on a microtome (4 µm sections) and stained with haematoxylin and eosin. A total of 180 histological sections were studied. Female ovarian follicles were classified according to the size and development of oocytes as primary growth, cortical alveoli, vitellogenesis (Vtg1, Vtg2, and Vtg3), germinal vesicle migration, hydration and post-ovulatory follicles according to Brown-Peterson et al. (2011).

The spawning season was assessed based on i) the monthly variability of the gonadosomatic index (GSI), calculated as GSI=GW/EW×100, considering that spawning activity takes place when monthly average of GSI was above 4; and ii) the monthly prevalence of spawning females (ovaries in spawning-capable and actively spawning stage) based on histological maturity staging, considering as the spawning period those months when the prevalence of spawning females was higher than 60%.

Once the spawning season was established, individuals sampled during that period were used to calculate the maturity ogive to reduce the likelihood of errors in the maturity assignment between immature and mature recovering individuals. Maturity ogive was calculated by fitting the logistic curve $PL = e^{(a+b\times L)}/(1+e^{(a+b\times L)})$, where PL is the proportion of mature individuals for a given size class L, and *a* and *b* the logistic parameters to be estimated. The length at first maturity (L_{50}, length at which 50% of the individuals are mature) was estimated as $L_{50} = -a/b$ for females, males and sex combined.

As *L. cavillone* is a species with indeterminate fecundity (Bibiloni-Socias et al. 2022), potential fecundity could not be estimated (Domínguez-Petit 2017). Instead, batch fecundity (BF) was estimated by applying the gravimetric method (Hunter and Goldberg 1980, Hunter et al. 1989). From all the females analysed histologically, only 25 specimens were eligible for BF estimation (those with hydrated oocytes and without early-stage post-ovulatory follicles). Samples of 0.25–0.5 g of ovarian tissue were taken, avoiding the ovarian wall and ensuring a sufficient number of oocytes (100–150 eggs). The hydrated oocytes were separated with a 600 µm sieve and counted using a computer-aided image analysis system, the Image J software with the ObjectJ plugin (https://sils.fnwi.uva.nl/bcb/objectj/). The relationship between batch fecundity and fish body size was analysed by linear regression. Differences in batch fecundity between seasons were examined by the Kruskal-Wallis test. Annual realized fecundity (RF) was estimated from number of batches (NB) and BF, RF=BF×NB. The NB was calculated as individual spawning season duration (in days)/spawning frequency; for this purpose, we assumed that a single female spawns for a maximum of two months (61 days). The spawning frequency was calculated as the inverse of spawning fraction (as the % of females actively spawning from the total of mature females) (Murua and Saborido-Rey 2003).

Condition indices

The reproductive bioenergetic strategy was determined by analysing the trend of different condition indices throughout the year: 1) The hepatosomatic (HSI) and 2) digestivosomatic (DSI) indices, calculated following the equations HSI=(LW/EW)×100 and DSI=(DW/EW)×100, respectively and 3) The relative condition index (K_n; Le Cren 1951), calculated from $K_n = (EW/EWt)\times 100$, where EWt is the predicted eviscerated weight of the individual estimated from the LWR. To test for significant differences of these indices between seasons and maturity stages, we used the Kruskal-Wallis test due to a lack of normality of the data. When significant differences were found, the Mann-Whitney test was applied for pairwise post-hoc comparisons.

Diet

The study of feeding habits of *L. cavillone* was based on the analysis of stomach contents collected and sampled in the MEDITS surveys during a longer time series, from 2007 to 2022, than the period in which biological samples were collected (Table 1). Whenever possible, a minimum of ten individuals per haul were analysed and their TL (in mm) and sex were noted. For stomachs containing food, prey items were identified to the lowest possible taxonomic level. All prey items were counted and their percentage contribution to the total stomach content in volume (in mL) was measured with a calibrated device (see Olaso et al. 1998 for details).

The diet of *L. cavillone* was described using the following indices: 1) frequency of occurrence (%F), calculated as the percentage of stomachs with a specific prey item referred to the total number of stomachs containing food; 2) numerical (%N) and volumetric (%V) composition, calculated as the percentage contribution of each prey relative to the whole content, in number and volume, respectively; and 3) the index of relative importance (IRI=%F(%N+%V)), which integrates each of the above indices, standardized as $\%IRI = (IRI/\sum IRI)\times 100$ (Cortes 1997) to facilitate comparisons between food types and with other studies.

To test whether sufficient stomachs had been sampled to precisely characterize the diet of *L. cavillone,* the mean (Sobs) and standard deviation (sd) of the cumulative number of total prey items was calculated (after 999 permutations) using PRIMER6 (Anderson et al. 2008). Then, Sobs±sd was plotted against the cumulative number of non-empty stomachs (Ferry and Cailliet 1996). The slope (b) of the linear regression, obtained from the last four randomly sampled stomachs, was used to determine sample-size sufficiency: b≤0.05 determined that the curve had reached an acceptable asymptote (Bizzarro et al. 2007).

Niche breadth was calculated from the number of the lowest possible taxonomical level using Levin's standardized index (Krebs 1989), $B=(1/n-1)*(1/\sum_j p^2_{ij}-1)$, where p_{ij} is the proportion of diet of predator *i* that is made up of prey *j*, and *n* is the number of prey categories. This index ranges from 0 to 1, low and high values indicating specialist and generalist diets, respectively.

Finally, the trophic level of *L. cavillone* was calculated using the formula $TROPH_i=1+\sum^n_{j=1} DC_{ij} \times TROPH_j$ where $TROPH_j$ is the fractional trophic level of prey *j*, DC_{ij} is the volume of *j* in the diet of *i*, and *n* is the total number of prey species. TROPH value was calculated using TrophLab (Pauly et al. 2000).

Habitat modelling

To determine the habitat where the studied species is found, we used general additive models (Wood 2006) from the *mgcv* package for the R software (R Core Team 2024). To do so, we modelled the standardized density (ind. km^{-2}) of *L. cavillone* considering as explanatory variables (smoothers) the depth and location (latitude and longitude) and the year of each sampling station. For this analysis we used a longer time series from MEDITS surveys, from 2007 to 2022, than the period in which biological samples were collected, including up to 527 sampling stations between 50 and 210 m depth. Previously to the modelling, density was log-transformed in order to use the Gaussian distribution as the identity link function. The model was used to predict density in the entire study area. To do so, the study area was divided into a 0.01×0.01° grid, and predictions were made in each grid node. Finally, we averaged predicted densities in each node throughout the time series and mapped them using the Surfer software. We used the standardized abundance (ind. km^{-2}) at each MEDITS station to model the bathymetric and spatial distribution of the species using a general additive model.

RESULTS

Population structure

The length-frequency distribution of the 833 specimens sampled ranged from 4.3 to 15.3 cm TL, with a mode at 11 cm TL (Fig. 2). The indeterminate sex specimens ranged from 4.3 to 9.9 cm (mean TL=8.2±1.6 cm), with a mode at 9 cm. Length ranged from 7.6 to 14.5 cm (mean TL=11.2±1.2 cm) for males and from 8.0 to 15.3 cm (mean TL=11.1±1.3 cm) for females. Both males and females displayed a mode at 11 cm. Below 7.5 cm sex could not be determined macroscopically. The Kolmogorov-Smirnov test showed no significant differences in the length-frequency distribution between sexes ($D_{443, 359}=5.01$, p=0.08).

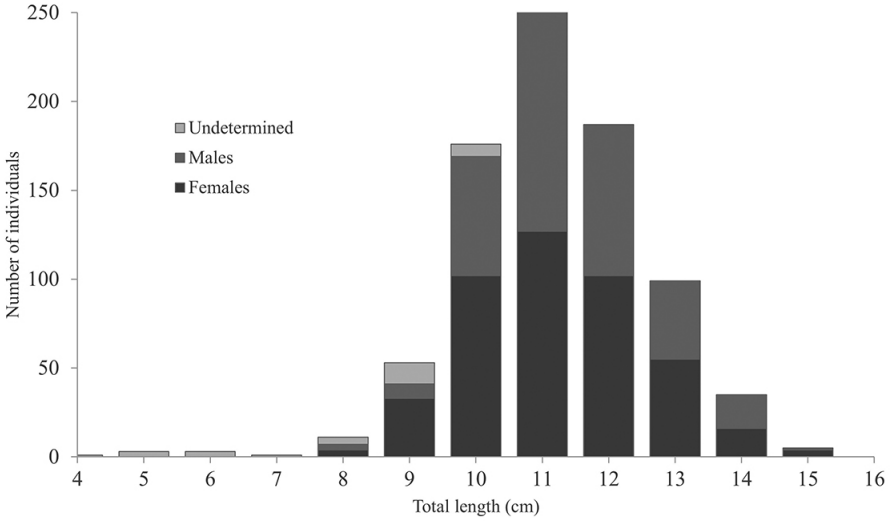

Fig. 2. – Length-frequency distribution of *L. cavillone* by sex (females, males and undetermined) sampled from the Balearic Islands.

Females represented 53.18% of the studied population, whereas males and indeterminate specimens represented 43.10% and 3.72%, respectively. The female-male ratio of the sampled population was 1:0.81, and the proportion of females was significantly higher than that of males (χ^2=8.79, p<0.01). By season, females showed a significantly higher proportion than males in spring (61%) and autumn (58%) (χ^2=13.24, p<0.001 and χ^2=6.82, p<0.01, respectively), whereas sex ratio showed no significant deviations from 1:1 in summer and winter. Along the size range, females predominated in the 9 and 10 cm TL classes (χ^2=12.24, p<0.01 and χ^2=7.25, p<0.01, respectively). For the rest of the size classes, the sex ratio showed no significant deviations from 1:1.

Growth

Fitting of LWR was similar using both TW and EW independently of the sex, males (R^2=0.85) and females (R^2=0.86) (Table 2) increasing considerably (R^2=0.94) when all individuals were pooled together (males, females and immatures). There were no significant differences between the LWR of females and males ($F_{1,798}$=1.65, p=0.2). The confidence intervals of the allometric coefficient indicated an isometric growth for both sexes when considered separately, whereas a positive allometric growth (b> 3) was obtained when males, females and immature individuals were pooled together.

The otoliths of *L. cavillone* showed an opaque nucleus surrounded by an alternation of translucent and opaque bands (Fig. 3A). The prevalence of otoliths with an opaque edge showed a seasonal trend, with the opaque deposition mainly occurring in spring and summer (Fig. 3B). The estimated ages of *L. cavillone* ranged from 0 to 4 years for both sexes (Table S1), and the predominant age classes were 2 and 3 (53% and 35% for males and 49% and 38% for females, respectively). The only individual with age 0 was indeterminate. The estimation of L∞ applying the formulae by Taylor (1958) to the maximum TL found for both sexes was 15.8 cm. The Von Bertalanffy growth function (Table 3) suggests a faster growth rate for males (k=0.35) than for females (k=0.28) (Fig. 4).

Table 2. – Estimated parameters of the length-weight relationships for males, females and sex combined (inmature individuals included). TL, total length (cm); TW, total weight (g); EW, eviscerated weight (g); a, intercept; b, slope; 95% CI (b), confidence limits of b; R^2, coefficient of determination.

	N	TL range	*a*	*b*	95% CI (*b*)	R^2
Males (TL-TW)	13	8.5–14.0	0.1747	2.8226	2.6076, 3.0381	0.8539
Males (TL-EW)	3		0.1492	2.9446	2.7223, 3.1756	0.8521
Females (TL-TW)	16	7.5–14.6	0.1472	3.0016	2.8297, 3.1746	0.8651
Females (TL-EW)	4		0.1415	2.9788	2.8061, 3.1644	0.8657
All (TL-TW)	33	4.3–14.6	0.1267	3.1369	3.0657, 3.2299	0.9457
All (TL-EW)	0		0.1179	3.1613	3.0875, 3.2556	0.9459

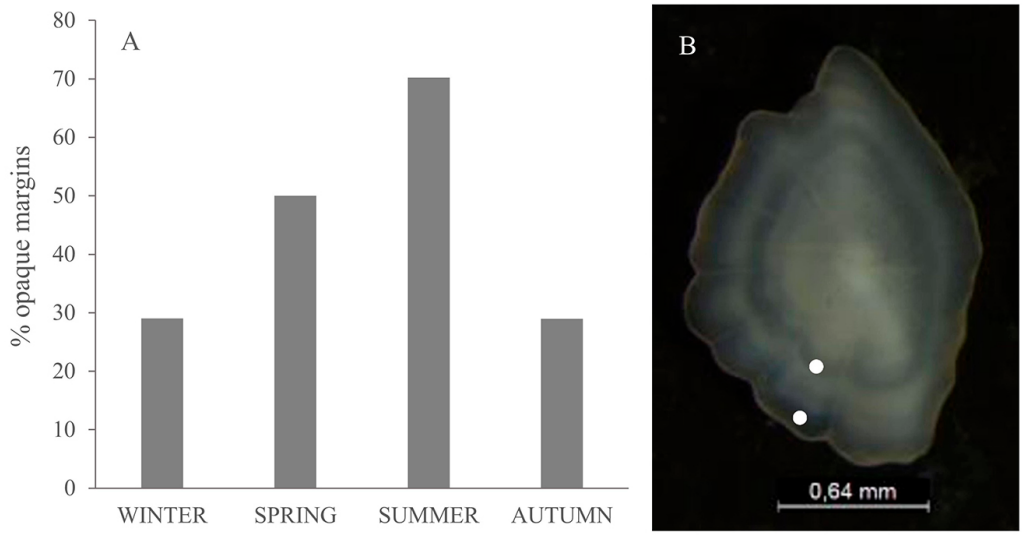

Fig. 3. – A, seasonal percentage of opaque rings at the edge of the otholits of *L. cavillone*. B, Photo of an otolith of a 2 years old female of 10.2 cm total length. The white dots indicate the hyaline rings detected.

Table 3. – Estimated *L. cavillone* maturity parameters (L_{50}: length at which 50% of the individuals are mature in cm, B_0 and B_1: logistic function parameters) and von Bertalanffy growth parameters (K, growth coefficient in year–1; t_0, hypothetical age at which length is equal to zero in years; L∞, asymptotic length fixed as 15.79 cm for both sexes). The associated coefficient of variation of all parameters is shown in brackets.

		Maturity			Von Bertalanffy	
	N	L_{50} (cm)	Bo	B_1	K (yr^{-1})	t_0 (yr)
All	496	9.41 (0.02)	–7.45 (0.16)	0.79 (0.14)	0.35 (0.07)	–0.48 (0.63)
Males	236	10.25 (0.01)	–11.92 (0.18)	1.16 (0.17)	0.35 (0.1)	–0.62 (0.65)
Females	285	9.18 (0.03)	–7.08 (0.22)	0.77 (0.20)	0.28 (0.14)	–1.20 (0.5)

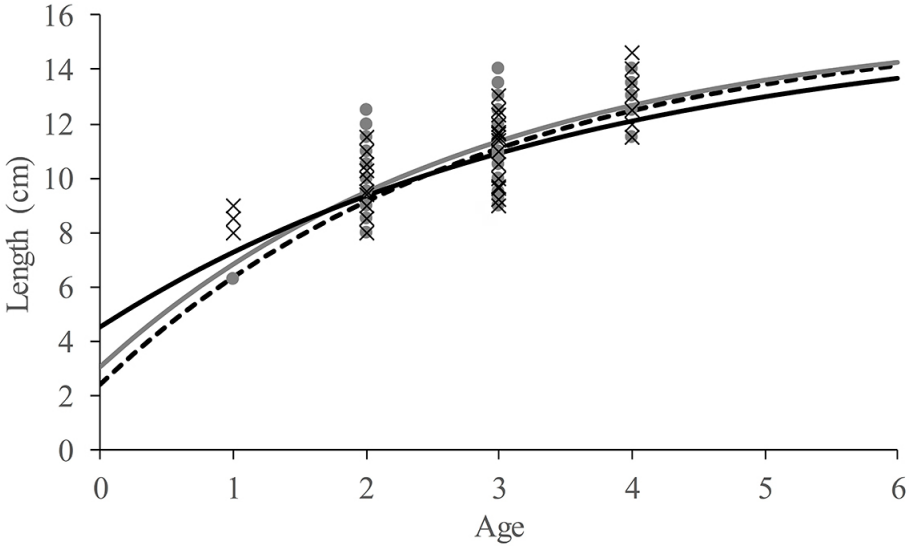

Fig. 4. – Growth curves for males (grey line) and females (black line) of *L. cavillone* and for both sexes combined (dashed black line). The individual data are represented by grey dots for males and black crosses for females.

Reproduction

The GSI showed significant monthly differences (Kruskal-Wallis test, H_{11}=117.18, $p<0.05$) (Fig. 5). Maximum GSI values were recorded in April (7.02) and July (7.17). From April to August, GSI values remained above 4 and more than 60% of females were actively spawning (Fig. 6). L_{50} was higher for males (10.2 cm TL) than for females (9.1 cm TL), with a value of 9.4 cm TL for both sexes combined (Table 3). The maturity ogive by length and sex (females, males and sex combined) is shown in Figure 7.

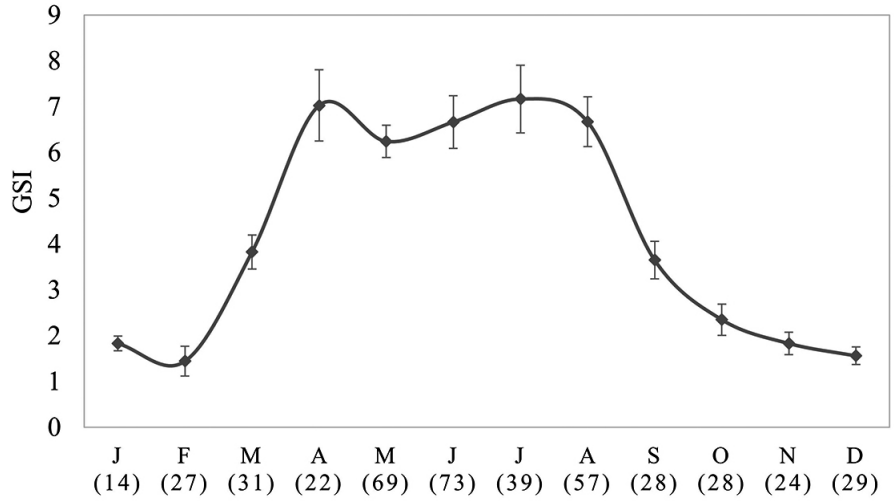

Fig. 5. – Monthly GSI mean values (±se) of *L. cavillone* females throughout the year 2021. The number of individuals sampled is shown below each month.

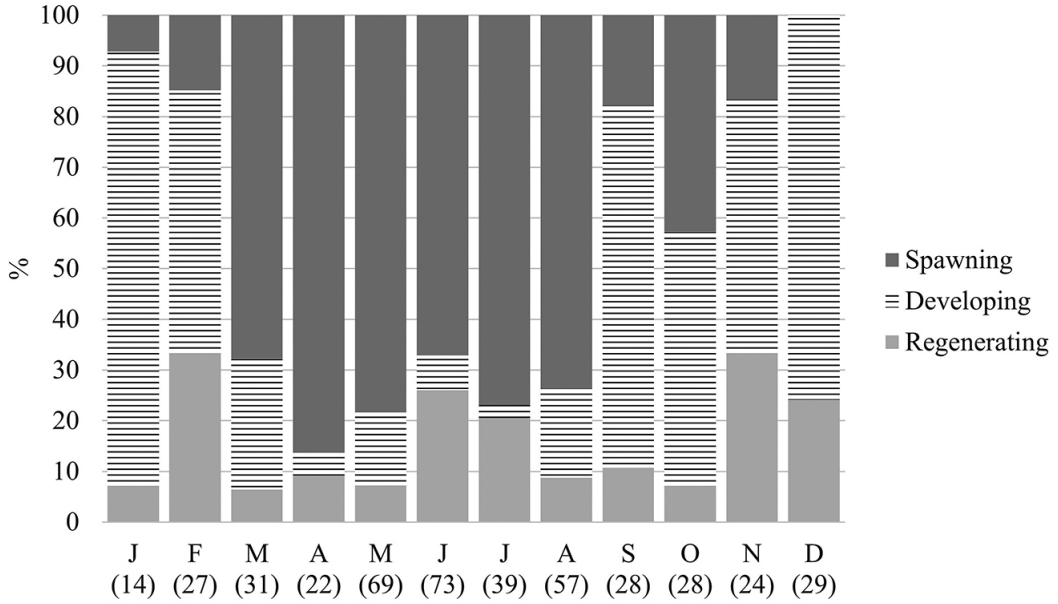

Fig. 6. – Monthly variation (%) of female gonad maturity stages of *L. cavillone* (regenerating, light grey; developing, grey lines; actively spawning, dark grey). The number of individuals sampled is shown below each month.

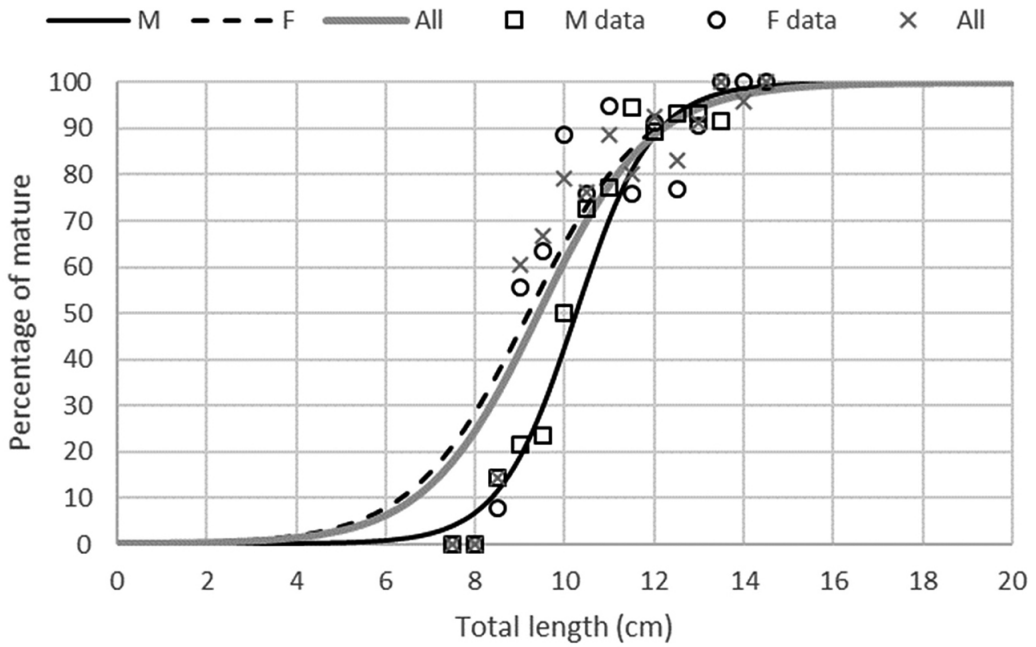

Fig. 7. – Percentage of mature individuals of *L. cavillone* by total length (in cm). Males, white squares (data) and black solid line; females, white circles (data) and black discontinuous line; all individuals, grey cross (data) and grey line.

The histological analysis of the ovaries showed that all stages of oocyte development were present simultaneously in the gonad (Fig. 8), indicating an asynchronous oocyte development typical of batch spawners species with indeterminate fecundity. The diameter of oocytes, based on histological sections, in the cortical alveoli stage ranged from 101.2 to 240 µm. The primary/secondary vitellogenic oocytes ranged from 168.2 to 370.5 µm, while the tertiary vitellogenic oocytes ranged from 188.1 to 552.6 µm.

Batch fecundity ranged between 101 and 2249 hydrated oocytes per female (mean: 926±104 eggs/batch). Batch fecundity increased with body size (R^2=0.24; F=7.467, $p<0.05$), but no significant differences were found among seasons (Kruskal-Wallis test, H_3=3.142, p=0.3702). According to our estimations, large-scale gurnard effectively spawn from 15816 to 47071 eggs per year and female.

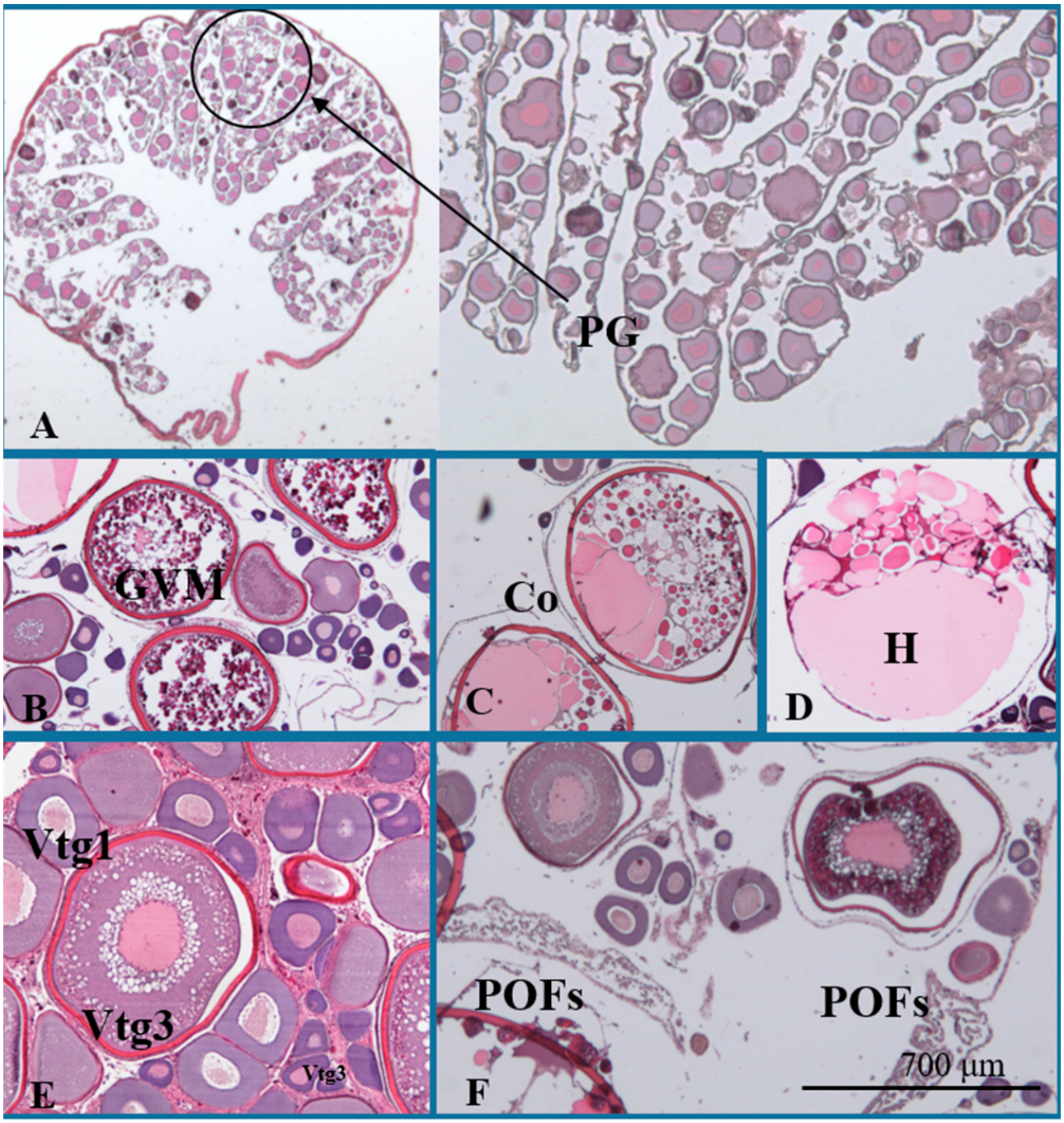

Fig. 8. – Photomicrographs of female oocyte development stages in *L. cavillone*. A. PG, primary growth; B. GVM, germinal vesicle migration; C. Co, Coalescence; D. H, hydrated; E. Vtg1, primary vitellogenic oocyte; Vtg3, tertiary vitellogenic oocyte; F. POFs, post-ovullatory follicles.

Condition indices

Significant seasonal differences were found for all the indices in both females and males (Table 4; Fig. 9). In both sexes, the highest HSI values were observed in summer (HSI♀=2.49±0.11, HSI♂=1.78±0.08), decreasing progressively until spring in the case of males (HSI=1.04±0.06), while in females, the lowest values (HSI=1.99±0.11) were observed in winter (Fig. 9). DSI pattern was also similar between males and females, showing the lowest values in autumn and winter (DSI♀=1.17±0.05, DSI♂=0.83±0.03) and the highest values in spring and summer (DSI♀=1.93±0.08, DSI♂=1.24±0.04). Finally, both female and male K_n decreased from winter to spring, when the lowest values were recorded (K_n♀=0.88±0.00, K_n♂=0.93±0.01), increasing progressively until their highest values in autumn (K_n♀=0.97±0.00, K_n♂=1.01±0.01).

Table 4. – Kruskal-Wallis tests on hepatosomatic (HSI), digestivosomatic (DSI) and condition (Kn) index differences between seasons by sex of *L. cavillone*. P-values of pairwise tests between seasons for females and males are shown in lower and upper triangular matrix, respectively.

HSI: ♀ H_3=10.73, p<0.05; ♂ H_3=54.76, p<0.001				
	Autum	Spring	Summer	Winter
Autum		<0.001	1	<0.05
Spring	0.8917		<0.001	<0.05
Summer	1	<0.05		<0.01
Winter	1	1	0.0825	
DSI: ♀ H_3=60.61, p<0.001; ♂ H_3=53.98, p<0.001				
	Autum	Spring	Summer	Winter
Autum		<0.001	<0.001	1
Spring	<0.001		1	<0.001
Summer	<0.001	0.9004		<0.001
Winter	1	<0.001	<0.001	
Kn: ♀ H_3=45.42, p<0.001; ♂ H_3=24.16, p<0.001				
	Autum	Spring	Summer	Winter
Autum		<0.001	<0.001	<0.05
Spring	<0.001		0.1639	<0.01
Summer	<0.001	<0.01		0.0742
Winter	<0.01	<0.01	0.4734	

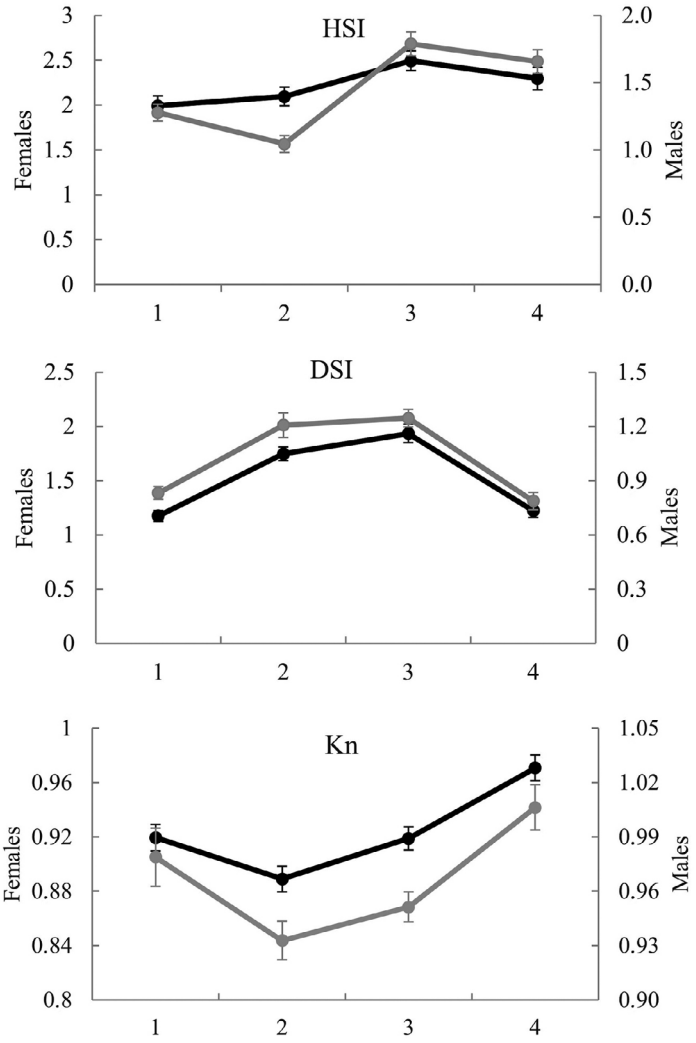

Fig. 9. – Seasonal mean values (se) (winter, 1; spring, 2; summer, 3; autum, 4) by sex of the hepatosomatic index (HSI), digestivosomatic index (DSI) and Le Cren's relative condition factor (Kn) for *L. cavillone* in the Balearic Sea. Black dots and line, females; grey dots and line, males.

The values of the condition indices varied across the maturity stages in females, with all the indices showing significant differences (Table 5; Fig. 10). HSI values exhibited a significant increase from the immature (1.29±0.11) to the developing (2.29±0.11) stage, remaining relatively constant in spawning females (2.41±0.08) and decreasing in regenerating females (1.49±0.12) to values similar to those recorded in immature individuals (Table 5). On the other hand, the K_n and DSI pattern by maturity stage exhibited opposing trends. The former showed the highest values during the developing (0.95±0.01) and regenerating (0.93±0.01) stages, which corresponded to the lowest values for DSI (1.22±0.10), while the highest values of DSI were observed in immature (1.93±0.15) and spawning females (1.83±0.06) (Table 5).

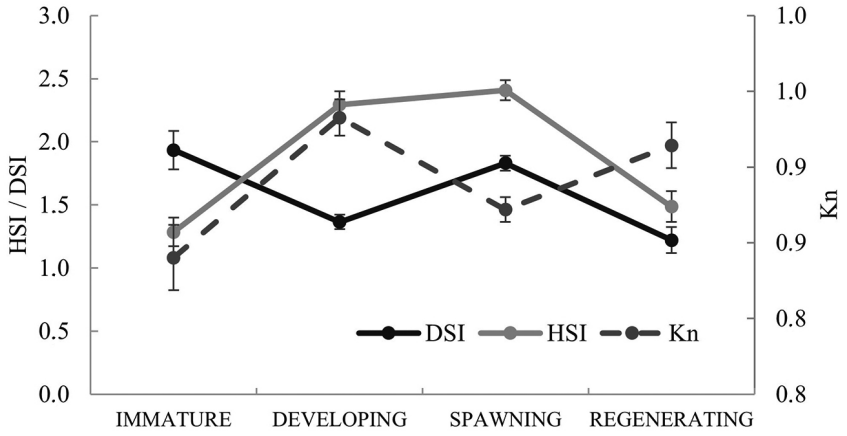

Fig. 10. – Mean values (±se) of hepatosomatic index (HSI), digestivosomatic index (DSI) and Le Cren's relative condition factor (Kn) through the different maturity stages (immature, developing, spawning and regenerating) for female specimens of *L. cavillone* in the Balearic Sea.

Table 5. – Kruskal-Wallis tests (H) on hepatosomatic (HSI), digestivosomatic (DSI) and condition (Kn) index differences between maturity stages of female *L. cavillone*. P-values of pairwise test between maturity stages.

HSI: H_3=60.42, p<0.001				
	Regenerating	Developing	Spawning	Immature
Regenerating				
Developing	<0.001			
Spawning	<0.001	1		
Immature	1	<0.001	<0.001	
DSI: H_3=55.97, p<0.001				
	Regenerating	Developing	Spawning	Immature
Regenerating				
Developing	0.1031			
Spawning	<0.001	<0.001		
Immature	<0.001	<0.01	1	
Kn: H_3=33.34, p<0.001				
	Regenerating	Developing	Spawning	Immature
Regenerating				
Developing	0.7396			
Spawning	<0.001	<0.001		
Immature	<0.01	<0.001	0.1223	

Diet

The size composition of the individuals sampled for stomach contents ranged from 35 to 506 mm. Only 274 (43%) out of the 636 stomachs analysed contained prey items. The cumulative prey curve (Fig. S1) and the slope of the linear regression (b=0.0437) indicated a sufficient sample size to precisely describe the diet of *L. cavillone*.

Overall, 39 different prey items representing five phyla (Annelida, Crustacea, Mollusca, Pisces and Cnidaria) were identified (Table 6). Crustaceans were by far the most important prey taxa in terms of %IRI (99.94), as well as in number (%N=95.13), volume (%V=96.54) and frequency of occurrence (%F=98.91). Within crustaceans, 10 order-family groups were identified (Amphipoda, Cumacea, Isopoda, Lophogastridae, Mysidacea, Anomura, Brachyura, Natantia, Euphausiacea and Ostracoda) (Table 6). *L. cavillone* feed mostly on peracarids crustaceans (i.e. Mysidacea, Amphipoda and Lophogastridae) (%IRI=85.02), while decapod crustaceans (Anomura, Brachyura and Natantia) were less important (%IRI=7.12) and abundant (%N=12.70) in the diet. At species level, *Lophogaster typicus* (44.46%) was by far the most important identified prey in terms of volume. *L. cavillone* showed a wide niche breadth (B=0.83), indicating a generalist foraging strategy. The estimated trophic level from stomach contents was 3.35±0.44.

Table 6. – Percentage contribution by number (%N), volume (%V), frequency of occurrence (%F) and relative importance index (%IRI) of prey in the diet of *L. cavillone* from the Balearic Islands

Taxon/prey item	%N	%V	%F	%IRI
Crustacea	95.13	96.54	98.91	99.94
Anomura	2.87	0.94	6.20	0.45
Galathea spp.	0.78	0.29	2.19	0.05
Galatheidae	0.44	0.05	1.46	0.02
Munida spp.	0.52	0.09	0.73	0.01
Paguroidea	1.13	0.51	1.82	0.06
Brachyura	0.52	1.08	2.19	0.07
Brachyura unid.	0.26	0.13	1.09	0.01
Inachus dorsettensis	0.09	0.23	0.36	<0.01
Liocarcinus spp.	0.09	0.46	0.36	<0.01
Pisa armata	0.09	0.27	0.36	<0.01
Natantia	7.22	11.92	17.88	6.52
Crangonidae	0.09	0.76	0.36	0.01
Natantia unid.	1.04	3.84	3.65	0.38
Pandalidae	0.17	0.27	0.73	0.01
Philocheras bispinosus	0.09	0.09	0.36	0.00
Philocheras sculptus	3.66	4.67	7.30	1.31
Philocheras spp.	2.09	2.22	5.11	0.47
Processa spp.	0.09	0.08	0.36	<0.01
Decapoda (other)	2.09	0.61	1.46	0.08
Decapoda unid.	2.00	0.61	1.46	0.08
Decapod larvae (Phyllosoma)	0.09	<0.01	0.36	<0.01
Euphausiacea	1.04	0.34	0.73	0.02
Euphausiacea unid.	1.04	0.34	0.73	0.02
Amphipoda	23.76	9.60	37.23	23.66
Ampeliscidae	0.09	0.27	0.36	<0.01
Gammaridae	19.15	8.39	34.67	20.58
Leucothoe sp.	0.09	0.06	0.36	<0.01
Phtisica marina	4.44	0.89	5.84	0.67
Cumacea	1.04	0.57	3.28	0.10
Cumacea unid.	1.04	0.57	3.28	0.11
Isopoda	3.13	2.69	9.49	1.05

Eurydice spp.	0.87	0.68	3.28	0.11
Isopoda unid.	2.18	1.95	5.84	0.52
Paragnathia formica	0.09	0.06	0.36	<0.01
Lophogastridae	12.71	44.46	33.94	36.97
Lophogaster typicus	12.71	44.46	33.94	41.83
Mysidacea	29.24	11.54	31.39	24.39
Gastrosaccus spp.	0.35	0.26	1.09	0.01
Mysidacea unid.	28.89	11.28	30.29	26.24
Ostracoda	3.22	0.75	5.11	0.39
Skogsbergia mediterranea	2.87	0.67	4.38	0.33
Ostracoda unid.	0.35	0.08	0.73	0.01
Crustacea	8.27	11.37	16.42	6.14
Crustacea unid.	8.27	11.37	16.42	6.95
Mollusca	0.44	2.61	1.82	0.03
Bivalvia	0.17	0.05	0.73	<0.01
Bivalvia unid.	0.17	0.05	0.73	<0.01
Cephalopoda	0.17	3.00	0.73	0.04
Cephalopoda unid.	0.17	3.00	0.73	0.05
Gastropoda	0.09	0.06	0.36	<0.01
Gastropoda unid.	0.09	0.06	0.36	<0.01
Pisces	0.17	0.32	0.73	<0.01
Pisces unid.	0.17	0.38	0.73	0.01
Cnidaria	3.57	0.14	0.73	0.01
Siphonophorae	3.57	0.17	0.73	0.06
Annelida	0.70	0.39	2.19	0.01
Polychaeta unid.	0.70	0.47	2.19	0.06

Habitat modelling

The general additive model indicated a significant effect of all three variables considered, depth, location and year ($p<0.001$), which explained 82.9% of the deviance. The species appeared in the depth range between 56 and 176 m, with the highest abundances at around 125 m depth (Fig. 11). Samples taken at the predicted depth of maximum abundance (115–135 m) exhibited densities ranging from 373 to 13167 ind. km^{-2}, with an average of 3967±730 ind. km^{-2}. The highest mean annual densities were found on the bottoms of the shallow and deep continental shelf off the south and southwest coast of Mallorca (Fig. 11).

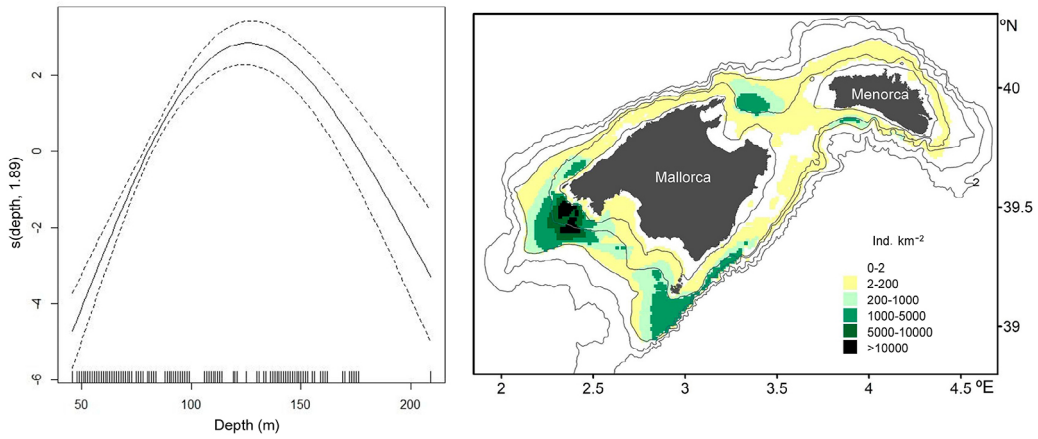

Fig. 11. – General additive model results. Left: bathymetric distribution model for *L. cavillone*. The y-axis is in the additive scale, and it measures the effect that depth (in m) has on density (log-transformed ind. km^{-2}). Right: Map showing the predicted mean annual density of *L. cavillone* in the Balearic Islands. Isobaths represent 50, 100, 200, 500 and 800 m depth.

DISCUSSION

This study provides information on most biological traits of the large-scaled gurnard (*Lepidotrigla cavillone*) in the Western Mediterranean, specifically in the Balearic Islands, one of the areas with the highest relative biomass for this species in the Mediterranean (Colloca et al. 2019). The use of different sources of data (oceanographic surveys and commercial catches) allowed us to sample a wide range of sizes. However, it should be noted that there were insufficient small-sized juvenile individuals in our samples. This result might be related to the fact that the nursery grounds are located on shallow bottoms (30–50 m; Papacostantinou 1982) and therefore out of our sampling depth range. The opposite situation occurs in the Tyrrhenian Sea (Colloca et al. 1997), where there is a lower abundance of large sizes (larger than 11 cm in length), which could be related to a higher level of exploitation in the area (Colloca et al. 2019) than in the Balearic Islands.

Our results also showed a greater presence of females than males, similar to previous reports for this species in the Mediterranean (Colloca et al. 1997, Ilkyaz et al. 2010, Dobroslavić et al. 2015), although sex ratio varied depending on the season. Indeed, females of 9–10 cm size classes, which coincides with the estimated L_{50} (9.1 cm), were more abundant than males in spring and autumn, probably related to spawning aggregations. This would suggest that females arrive at the spawning grounds before males and stay there longer.

Sexual dimorphic growth was not observed in *L. cavillone* from the Balearic Islands. Length-weight relationship indicated a positive allometric growth similar to that observed in other study areas in the Mediterranean (Voliani et al. 2000, Ilkyaz et al. 2010).

Regarding growth, the seasonal deposition pattern observed in the otoliths during this study confirmed that the combination of an opaque and a translucent band can be assigned to an annual increment (Panfili et al. 2002). The age of the individuals ranged from 1 to 4 years for both sexes, with most of the population belonging to age classes 2 and 3. These results coincide with most of the studies carried out in other Mediterranean areas, including the Tyrrhenian Sea (Colloca et al. 1997) and the Aegean Sea (Togulga et al. 2000, Uçkun 2005), although, in some areas individuals of ages 5 and 6 were reported (Papaconstantinou 1982, Ilkyaz et al. 2010). *Lepidotrigla cavillone* appears to exhibit a similar age structure across the Mediterranean, reflecting a short life-span. Some Triglidae species have been found to live longer in the Mediterranean; for example, *Lepidotrigla dieuzeidei* reach up to 11 years old in the northeastern Mediterranean (Başusta et al. 2017), and *Chelidonycthis lastoviza* up to 8 years old and *Trigla lucerna* up to 10 years old in Greek waters (Papaconstantinou 1984).

An extended spawning season was observed (April–August), with a slight decrease in the spawning activity during the months of May and June. Our results were similar to those observed in the Tyrrhenian Sea (April–September; Colloca et al. 1997). In the Adriatic Sea the spawning season was earlier and longer (February–September; Dobroslavić et al. 2015), whereas in the Aegean Sea, it was earlier and shorter (February–May; Ilkyaz et al. 2010). The discrepancies observed in comparison to the findings of Ilkyaz et al. (2010) may be attributed to the methodological approach used in the present study, which estimated the spawning season based on females that were spawning-capable and actively spawning. However, the differences found between Dobroslavić et al. (2015) and this study are probably due to environmental differences between the Western and Eastern Mediterranean. The higher temperatures found in the eastern than in the western basin (15.5°C and 13°C, respectively; Zavatarielli and Mellor 1995) could be the reason for an earlier spawning season in the former. It has been demonstrated that the duration of the spawning season may be influenced by increasing or decreasing latitude, which is highly related to environmental conditions, mainly temperature (Rogers and Dougherty 2019, Slesinger et al. 2021, Brulé et al. 2022). Aside from abiotic conditions, body size and female condition are important factors in spawning timing (Slotte et al. 2000, Rogers and Dougherty 2019). Despite some differences in the duration and period of the spawning season, the above studies agree that *L. cavillone* is a partial spawner that releases several batches of eggs during the spawning period (Colloca et al., 1997, Dobroslavić et al. 2015).

Females reach the length at first maturity during their second year of life (L_{50}=9.1 cm), confirming the length at maturation previously reported for *L. cavillone* in other Mediterranean areas (Colloca et al. 1997, Ilkyaz et al. 2010, Dobroslavić et al. 2015). Considering Beverton-Holt life-history invariants, the ratio between L_{50} and L_{∞} estimated in the present study is 0.57, i.e. it is within the expected range for teleost fish, but rather far from the extremes (Prince et al. 2015). Regarding batch fecundity, the range of hydrated oocytes per batch obtained in this study (101-2249) was higher than that estimated in Turkish waters (98–1245 eggs/batch; Ilkyaz et al. 2010). The differences could be caused by methodological approaches, since Ilkyaz et al. (2010) used the size-frequency distribution method, assuming as hydrated oocytes those having a diameter greater than 0.73 mm, while in this study we used the gravimetric method and measured all hyaline eggs detected by image analyser, regardless of their size. Although no studies on realized fecundity were available for this species, higher values have been reported in other species of the Triglidae family (Neves et al. 2021). Such a difference could be due to the varying size of the females analysed, as well as to specific variability in reproductive strategies. Though the number of eggs produced by females can vary among populations (Oren 1975, Abdulrasol et al. 2018), our results must be interpreted with caution because the number of fecundity samples analysed in the present study was low (N= 25).

Egg production depends on female size and feeding capacity (Kjesbu et al. 2007), but also on spawning timing, among other factors (Klibansky et al. 2013, Serrat et al. 2019). In this study, the correlation between batch

fecundity and female length was found to be significant but low. Given that the fecundity data come from only 25 individuals caught in different months of the year, it cannot be concluded that larger *L. cavillone* females have higher partial fecundity than smaller ones. It remains uncertain whether the observed differences are attributable to seasonal variability or a combination of both length and season. Though the batch fecundity of *L. cavillone* in Balearic Islands was not found to vary over the spawning season, female reproductive condition, lipid reserves and feeding activity reached the highest values in summer, which would favour egg production. The highest digestivosomatic index values in females in spring and summer, especially in spawning individuals, indicated that intensive feeding activity takes place during the spawning season and supports liver lipid reserves for vitellogenin synthesis, as typically occurs in income breeders. Nonetheless, female body condition was found to decrease in spawning specimens, suggesting that food intake is insufficient to support egg production and/or spawning activity, thereby impacting muscle energy reserves. Overall, this suggests a mixed capital-income breeding strategy in *L. cavillone*, as described for other Triglidae species in the Mediterranean, such as *T. lyra* (Abdulrasol et al. 2018).

Stomach content analysis indicated that small-sized crustaceans are the main prey of *L. cavillone* in our area, as has been found elsewhere (Caragitsou and Papaconstantinou 1990, Colloca et al. 1997, Terrats et al. 2000). Among crustaceans, mysids and amphipods were the most important prey in terms of numerical importance, while Lophogastridae (i.e. *Lophogaster typicus)* was the most important taxon in terms of volumetric importance. *Lophogaster typicus* was also the most important prey found in previous studies conducted in the Mediterranean, not only for *L. cavillone* but also for other species of gurnards (Kartas 1973, Colloca et al. 1994, 2003). The dominance of these prey indicates that *L. cavillone* feed on suprabenthos, which is known to show maximum abundances in the study area in summer (Cartes et al. 2011) and is considered an easy-capture prey due to its low mobility. Similarly, *L. typicus* is among the most abundant suprabenthic species at shelf break depths in the study area (Ramón et al. 2014), overlapping with the bathymetric distribution of *L. cavillone*. In the Balearic Islands, *L. cavillone* showed a wide niche breadth, indicating a generalist foraging strategy. Triglids are known to search for prey on the sediment using the free radii of their pectoral fins (Whitehead et al. 1986). However, the diet of *L. cavillone* included suprabenthos as an important food resource, and even some pelagic species that usually reach the bottom (e.g. siphonophores, euphausiids and megalopa larvae), reflecting its opportunistic behaviour, although some exceptions have been reported (Labropoulou and Machias 1998). The trophic level estimated in this study (3.35), together with previous results (3.29, Moreno and Matalallanas 1983, 3.30, Colloca et al. 1994, 3.43, Labropoulou and Machias 1998), show that *L. cavillone* feeds at a similar trophic position across the Mediterranean, indicating a similar ecological function.

Lepidotrigla cavillone showed a bathymetric distribution range between 56 and 176 m, with the highest abundances around 120 m depth, similar to the findings for the species in the whole Mediterranean, where it shows a range from 36 to 187 m and a similar optimum depth (Colloca et al. 2019). The low presence of *L. cavillone* shallower than 60 m may be related to the preference of triglids for sandy-mud bottoms (Labropoulou and Machias 1998). In the Balearic Islands, red algae beds predominate down to 90 m depth (Ordines and Massutí 2009). *L. cavillone* shows the highest abundances on the southwest coast off Mallorca, even on the shallow continental shelf (<100 m depth), but, coinciding with the preferences of triglids, this area shows a predominance of sandy bottoms with the lowest biomass values of red algae for this stratum in the Balearic Islands (Ordines et al. 2015).

This study contributes to the biological knowledge of an important component of the demersal fish communities of the continental shelf of the Balearic Islands. Although *L. cavillone* is not a target species of the bottom trawl fleet, this study may be considered as a further step towards implementing an ecosystem approach in the assessment and management of Western Mediterranean fisheries.

SUPPLEMENTARY FILES

The following supplementary material is available through the online version of this article:

Table S1. Age-length key of *L. cavillone* from the Balearic Islands.

Figure S1. Mean cumulative number (Sobs±sd) of prey items per stomach sample for *L. cavillone* analysed during the study period (2007–2017) in the Balearic Sea.

DATA AVAILABILITY

The data are held by the authors and are available upon request from the corresponding author.

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DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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AUTHORSHIP CONTRIBUTION STATEMENT

Maria Valls: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing, review and editing. **Marina Bibiloni-Socias:** Data curation, Formal analysis, Investigation, Software, Visualization, Writing original draft. **Beatriz Guijarro:** Conceptualization, Formal analysis, Methodology, Software, Visualization, Funding acquisition, Project administration, Writing, review and editing. **Rosario Donínguez-Petit:** Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing, review and editing. **Fransesc Ordines:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Funding acquisition, Project administration, Writing, review and editing.

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