Biological, reproductive and population parameters of the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), on the Catalan coast (NW Mediterranean Sea)

Xabier Beorlegui Suárez

Eve Galimany Sanromà

Ricardo Santos Bethencourt

Bernat Hereu Fina

ICATMAR

Màster en Oceanografia i Gestió del Medi Marí

05/09/2025

INDEX

ABSTRACT

Fishing is a traditional and socio-economic important activity along the Catalan coast. The characterization of the resources is key for the sustainability of the ecosystems and the sector. But the biological parameters of the species may vary according to their exploitation or environmental parameters. Thus, this study investigates the biological, reproductive, and population parameters of the deep-water rose shrimp (*Parapenaeus longirostris*) along the Catalan coast (NW Mediterranean Sea) to provide updated data for sustainable fisheries management. With data from 2019 to 2024, including on-board sampling, laboratory analyses, and histological examination, the research characterizes size distribution, growth patterns, sex ratios, and the reproductive cycle of *P. longirostris*. Results reveal a significant increase in catches since 2016, accompanied by a population dominated by individuals exhibiting sexual dimorphism, with females growing larger and faster than males. The species has a prolonged reproductive period with year-round spawning activity, confirmed through gonadosomatic index trends and histological staging. The estimated size at first sexual maturity (L50) for females was 16.7 mm carapace length, lower than values reported in neighboring regions, indicating potential influences from fishing pressure and environmental changes. These findings, contextualized within ongoing climatic shifts such as warming and increased salinity, underscore the need for adaptive, region-specific management strategies that incorporate temporal and spatial protections to ensure the long-term sustainability of *P. longirostris* fisheries in the Mediterranean Sea.

Key words: *Parapenaeus longirostris*, deep-water rose shrimp, climate change effects, Mediterranean Sea, Catalan coast, population dynamics, gonadal cycle, histology, L50.

1. INTRODUCTION

The Mediterranean Sea has, for many centuries, been a rich and diverse ecosystem, home to a wide array of species. Fisheries have historically constituted a fundamental socioeconomic pillar for the populations inhabiting the region exploiting a broad number of species including fish, crustaceans and other organisms (Carreton et al., 2025; Colloca et al. 2017). According to FAO (2022) the fleet of fishing vessels that operated in the Mediterranean Sea added up to an amount of 73220 with a total capacity of 867400 gross tonnage (GT). However, the fleet is not equally distributed along its shores with fishing effort, in terms of number of vessels operating the Mediterranean's waters, being distinct in each country and fishing management area (GSA). For example, in Catalonia, which represents the half northern area of the GSA 6, fishing holds significant historical, cultural, and economic importance as elsewhere in the Spanish Mediterranean coast. In 2024, the Catalan fishing fleet consisted of 644 vessels, including 196 trawlers, 315 artisanal fishing boats, and 133 employing other fishing methods (agricultura.gencat.cat).

The different fishing vessels and gear target a broad variety of species and have a relevant role in the socioeconomics of the area. In detail, bottom trawlers in Catalonia accounted for 30.43% of the commercial fleet, contributed 33.70% of the total catch, and generated 58.6% of total revenue, resulting in an income of nearly €51.93 million in 2023 (ICATMAR, 2024). Bottom trawling, which is a multispecific type of fishery, can catch fish, cephalopods and crustaceans, among others, such as the deep-water rose shrimp (*Parapenaeus longirostris*). It is a demersal species with an extensive geographic range encompassing both Mediterranean and Atlantic waters (Sobrino et al., 2005). Its distribution includes the Mediterranean Sea, the eastern Atlantic from Portugal down to Angola, as well as the western Atlantic, extending from the northern coast of the United States (specifically the state of Massachusetts) to French Guiana (Holthuis, 1980). This species typically inhabits muddy or muddy-sandy substrates (Nouar and Maurin, 2001), with its distribution concentrated on the lower continental shelf and the upper continental slope. It is generally found at depths ranging from about 20 to 750 meters (Holthuis, 1980; Tom et al.,1988), although it is most abundant between 150 and 450 meters (Abelló et al., 1988, 2002b; Bombace, 1972; Lloris and Rucabado, 1998; FAO.2023; Mingote et al., 2024). *P. longirostris* exhibits a distinct size-related distribution pattern in relation to depth. Juvenile individuals, which are of lower commercial value, are typically found at shallower depths (100–200 meters), whereas larger specimens are generally located at depths greater than 200 meters (Bombace, 1972; Froglia, 1982; Mori et al., 1986; Tom et al., 1988;).

Understanding the biological traits of the species is key to develop best management practices to sustain fisheries as well as the exploited stock. The biology of the species is not static and it may change as environmental conditions also shift. This is specifically relevant in the Mediterranean Sea, which is considered a major climate change hotspot, becoming a region where both environmental and anthropogenic effects can have significant and far-reaching consequences (Giorgi, 2006). Among the changes documented in this area are warming and increased salinity (Adloff et al., 2015; Schroeder et al., 2017). These environmental trends are likely to modify the spatial distribution of marine species, representing one of the most noticeable impacts of climate change, with important implications for commercial fisheries and biodiversity (Bellard et al., 2012; Hastings et al., 2020; Perry et al., 2005). Specifically, it is well established that *P. longirostris* is strongly influenced by increases in temperature and salinity (Mingote et al., 2024). In fact, recent studies have shown that rising sea bottom temperatures and higher salinity levels are significantly correlated with changes in the distribution, abundance, and biological traits of *P. longirostris* in the Mediterranean. Moreover, Benchoucha et al. (2008), reported that salinity and temperature act as factors controlling the spawning of *P. longirostris* in the Moroccan Atlantic Region, where high salinity levels and high temperature seem to trigger the spawning of this species, while temperature seems to affect its catch levels.

The Mediterranean Sea has been exploited for centuries and has endured continuous and multiple human pressures throughout this time. As a result, it has undergone profound transformations and faced numerous challenges, many of which arise from unsustainable practices and the increasing impacts of climate change. Since 2019, to address the issue of unsustainable practices, a new management plan has been developed in the wester Mediterranean, resulting in a decrease of fishing effort and string regulation measures. However, climate change cannot be reversed forcing the need to study the biology and reproduction of the commercial species under the current climatic conditions to promote best management practices not just for the present, but also for the future.

In this regard, this study of *P. longirostris* in the Catalan coast has the main goal of defining the current biological parameters of the species to provide data for best management practices. The approach to the study was as follows: i) to study the historical catches of *P. longirostris*; ii) to update the biological parameters and size frequency distribution of the species; iii) to define its reproductive cycle and gonadosomatic index.

2. MATERIALS AND METHODS

2.1 Historical data

The analysis of the white rose shrimp fishery along the Catalan coast was carried out through a study of the historical evolution of landings (in tonnes) of *P. longirostris* from 2002 to 2024. Data were obtained from the MicroStrategy database provided by the Government of Catalonia, which records daily landings by species for each vessel selling at Catalan fish markets.

2.2 Study area

The study area encompasses the entire Catalan coastline, which extends over 580 km and represents the northern portion of the geographical subarea GSA 6. On board sampling campaigns aboard bottom trawling vessels were conducted from 2019 to 2024. These operations are conducted from a strategically selected network of nine commercial ports, chosen based on their high annual fishing revenues and their balanced geographic distribution across the three coastal zones (Carreton et al., 2025). The selected ports are, from north to south: Roses, Palamós, Blanes, Arenys de Mar, Barcelona, Vilanova i la Geltrú, Tarragona, L'Ametlla de Mar, and La Ràpita. In addition to their economic importance, these ports were selected to reflect the hydrographic and geomorphological diversity of the continental margin, encompassing both shelf and slope environments.

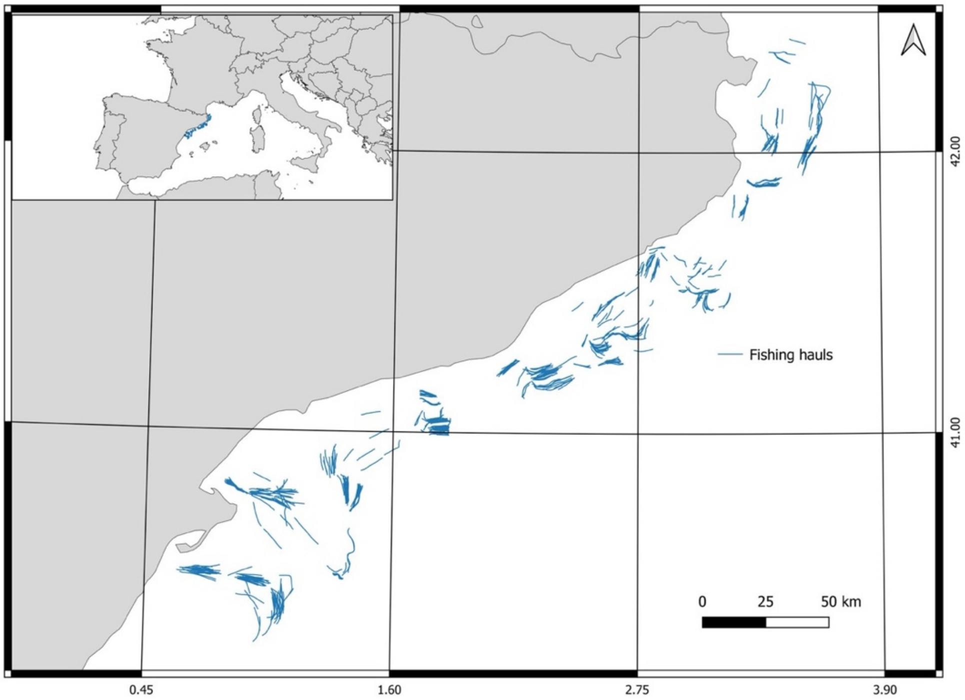

Figure 1. Spatial distribution of all fishing hauls conducted during 2024 in the Catalan coastline.

Based on the description from Carreton et al. (2025), distinct sampling depth strata were established along the Catalan coast (Figure 1). From Roses to Vilanova i la Geltrú, the designated depth intervals included the deep shelf (75–200 m), upper slope (200–500 m), and lower slope (500–800 m). In contrast, the southern three ports, characterized by unique geomorphological features and sedimentary composition, the sampling was stratified into coastal delta shelf (< 40 m), middle delta shelf (40–75 m), and deep shelf (75–200 m).

Table 1. Table summarizing all trawl hauls by depth stratum at different ports along the Catalan coast from 2019 to 2024.

	Roses	**Palamós**	**Blanes**	**Arenys de Mar**	**Barcelona**	**Vilanova i la Geltrú**	**Tarragona**	**L'Ametlla de Mar**	**La Ràpita**
Coastal delta shelf	0	0	8	0	0	7	0	21	23
Middle delta shelf	0	0	0	0	0	0	0	21	23
Deep shelf	23	22	23	23	24	16	20	22	23
Upper slope	23	22	23	23	24	23	20	1	0
Lower slope	22	22	14	23	24	23	20	7	0
Grand total	**68**	**66**	**68**	**69**	**72**	**69**	**60**	**72**	**69**

Each port was surveyed every trimester to collect data from the different seasons throughout the year.

2.3 Field sampling

The study specimens were collected using bottom trawl gear, which consists of a weighted net towed along the seafloor to capture demersal organisms. Each fishing campaign comprised three independent hauls, each with a duration of approximately 1.5 hours. For each haul, the start and end positions were recorded using GPS, along with the duration of the tow and the gear width. These parameters were employed to calculate the total swept area per haul, enabling the standardization of species biomass and abundance estimates.

The mesh size of the net measures 40 mm square except in Palamós, where a co-management plan establishes a 45 mm square mesh in the deepest fishing area.

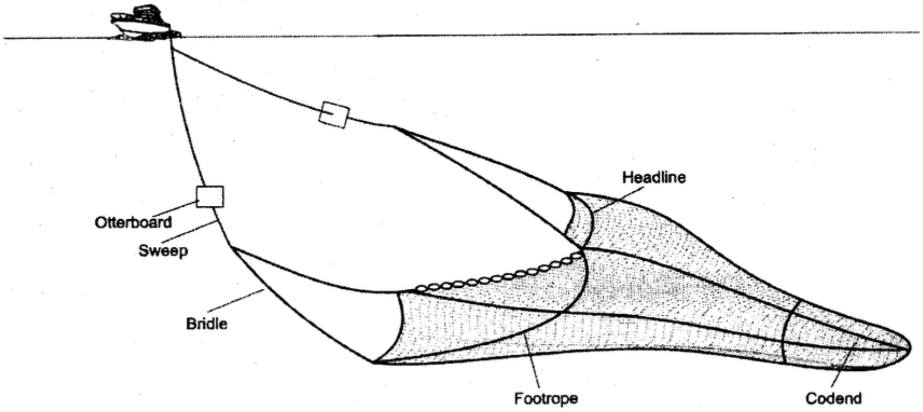

Figure 2. A bottom trawl net and its parts (Kumar and Deepthi, 2006).

The target species is the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846). From each trawl in which the target species was caught, all individuals were measured on board, and a subsample of thirty individuals was transported in a cooler with ice to the Institut de Ciències del Mar (ICM-CSIC) laboratory in Barcelona. The specimens were kept at a temperature of 4 °C until the following day.

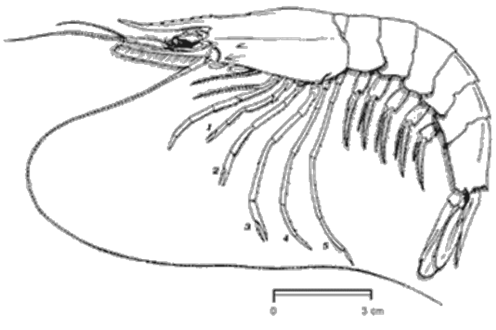

Figure 3. *P. longirostris*. Image from Fischer et al. (1987).

2.4 Laboratory sampling

In the laboratory, fundamental biological analyses were performed. Carapace length (CL) (0.01 mm) was measured using an electronic caliper. Each individual was weighed to the nearest 0.01 g, sexed, and the gonads were excised, weighed, and macroscopically staged in order to determine sexual maturity, adapting the classification stablished by Bianchini et al. (2010) (Table 2).

Table 2. Macroscopic stages determined and described of *P. longirostris* adapted from Bianchini et al. (2010) and ICES (2010).

Stages proposed	Name of the Stage	Macroscopic description	Colour
1	Immature	Ovaries not externally visible; thin, translucent, tubular over dorsal stomach, not extending to abdomen	Uncoloured
2	Developing/ Recovering	Ovaries visible without dissection; cephalic lobes begin covering sides, abdominal extensions present	Whitish, pale yellow, or cream orange
3	Maturing	Ovaries clearly visible; developed and turgid, lobes and extensions fill dorsal side. Gonads with granular appearance	Dark yellow, cream orange, or light green
4	Mature	Ovaries turgid, fully extended across dorsal area; lobes/extension well defined, eggs visible	Different tones of dark green

2.5 Histology

In order to validate the macroscopic determinations, a histological study of the *P. longirostris* was conducted in 2024, employing microscopic examination of female individuals to assess gonadal development.

From February to December 2024, twenty individuals were systematically selected for histological analysis. Sex was determined according to ICES guidelines (ICES, 2010), based on the external morphology of the first pair of pleopods. Macroscopic maturity stages were assessed exclusively in females. For each individual transported to the laboratory, the same measurements were recorded onboard the fishing vessel, i.e., carapace length, sex, and reproductive status. Additionally, the total weight of each specimen was measured both with and without pleopods to the nearest 0.01 g, and the isolated gonads were individually weighed with the same precision.

Following dissection, the gonads were fixed in Davidson solution. After 24 hours, the tissues were rinsed in tap water for 3 minutes and subsequently stored in 70% ethanol. For histological processing, the samples were dehydrated, embedded in paraffin, and sectioned at a thickness of 5 µm. The sections were mounted on glass slides, stained with hematoxylin-eosin, and examined under a light microscope. Sections were examined at 5x, 10×, and 40× magnifications, sexed and assigned to the following developmental stages, adapted from ICES (2010). Report of the Workshop on crustaceans maturity stages (WKMSC): Stage 1, immature, presence of oogonia and early primary oocytes (up to 90 µm length), with large nucleus and barely visible cytoplasm, scattered throughout the stroma without specific organization; Stage 2, maturing, the ovarian parenchyma becomes structured into germinative zone ranging from primary oocytes to late vitellogenic oocytes, including polyhedral cells with a round and visible nucleus; Stage 3, ripe, advanced late vitellogenic oocytes appear featuring cortical granules and a non-visible nucleus which may indicate an imminent spawning; Stage 4, spent, the ovarian tissue appears empty with only some residual oocytes; Stage 5, post-spent, may look similar to stage 2, albeit germinative zone is not fully packed with a higher abundance of primary oocytes.

2.6 Biological analysis

The biological analysis aimed at characterizing and updating the biological parameters of *P. longirostris* was carried out using data from trawl fishing operations conducted by ICATMAR between 2002 and 2024, both years included.

Size-frequency distributions of *P. longirostris* catches were obtained by calculating the mean abundance (ind/km²) across all trawl surveys and were presented both annually and for five different depth strata. The length–weight relationship of *P. longirostris* was calculated for both total and eviscerated weight, by sex, using the equation $W=aL^b$, where a and b are the species-specific growth parameters. Two regression models were compared to assess the effect of sex on the relationship between cephalothorax length and weight. Model 1 (logW ~ logL + Sex) assumes a common slope for both males and females, with the possibility of different intercepts whereas Model 2 (logW ~ logL * Sex) includes an interaction term, allowing for different slopes according to sex. An ANOVA test was applied to assess if significant differences in the length–weight relationship existed between sexes.

Regarding the reproductive biology of *P. longirostris*, the sex ratio was evaluated both globally and for five depth strata. Furthermore, for the reproductive study, only females were analysed in terms of the proportions of sexual maturity stages across the different months of the year, as well as the gonadosomatic index (GSI), displayed together with the maturity stages. The GSI considers the relative weight of the gonads and serves as an indicator of the energetic investment of *P. longirostris* in reproduction. The GSI was defined by the following formula:

$$GSI = \frac{WG}{We} x\ 100$$

Where Wg is the weight of the gonad and We is the weight of the individual.

To analyse the size–age relationship, the Von Bertalanffy Growth Function (VBGF) was fitted using the following model:

$Lt = L\infty\ (1- e-k(t-t_0)$

Where $L\infty$ represents the asymptotic length (the theoretical maximum size), Lt is the predicted length at age t, k denotes the growth coefficient, and t_0 corresponds to the hypothetical age at which the organism would have zero length. (García-Rodríguez et al., 2009)

Finally, the size at first sexual maturity (L50) for female *P. longirostris*, was estimated from the proportion of mature and immature individuals. The L50 analysis for female *P. longirostris* was performed using the R software environment. Only individuals identified as females were included in the study, considering two variables: total body length in millimetres and sexual maturity status. Maturity status was recoded into a new binary variable (maturity), where 0 represented immature individuals (EstatSexual = 1) and 1 represented mature individuals (EstatSexual = 2, 3, 4).

The maturity model was fitted using logistic regression via the glm() function from R's base package, specifying a binomial family. The inflection point of the logistic curve, corresponding to L50 (the length at which 50% of individuals are mature), was estimated from the model coefficients using the following formula:

$$L_{50} = -\frac{\beta_0}{\beta_1}$$

Where:

β0: model intercept

β1: length coefficient

The 95% confidence interval for L50 was calculated using the delta method through the deltamethod() function from the msm package (Jackson, 2011). Visualization of the model fit was performed with the ggplot2 package (Wickham, 2016), displaying the logistic maturity curve, the L50 cutoff line, and the 50% maturity probability. Graphs were exported in high resolution using the ggsave() function.

The figures were plotted using R Studio, version 4.5.1. Various R packages were employed depending on the type of figure developed: the ggplot package was used for size-frequency distributions, ggplot2 for the length–weight relationship, *sizeMat* for calculating the size at first sexual maturity, and the TropFishR package, version 1.6.6., for length-frequency analysis and fisheries assessment. Additionally, the sex-ratio and reproductive cycle charts were generated using Microsoft Excel.

3. RESULTS

3.1 Historical catch data and fishing effort from 2002 to 2024 of *P. longirostris*

The historical series of landed catches and average first-sale price of *P. longirostris* from 2002 to 2024 revealed that landing volumes were notably low during the initial years of the series, remaining below 100 tonnes annually. However, starting in 2016, a substantial increase in catches was observed, consistently surpassing 200 tonnes and reaching a peak in 2021 with over 450 tonnes landed (Figure 4). Regarding the average first-sale price, it has remained relatively stable throughout recent years.

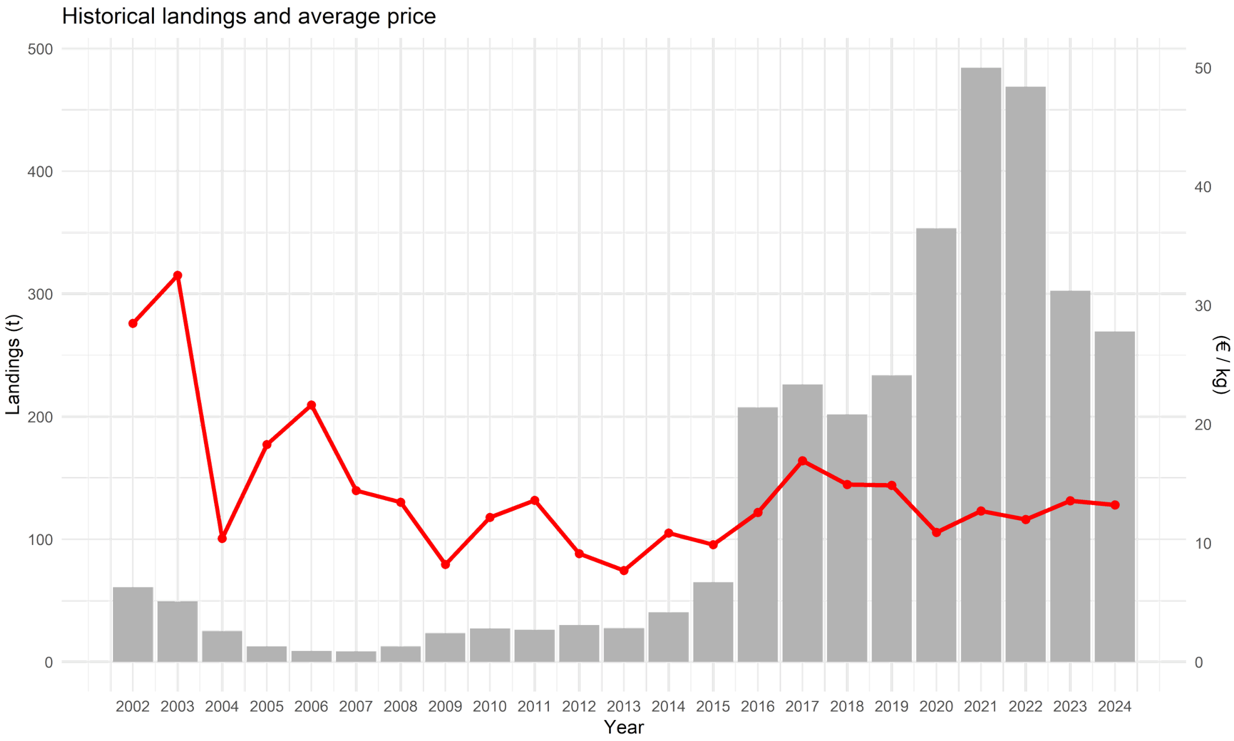

Figure 4. Annual series of landed catches (tonnes) in grey columns and average first-sale price (€/kg) in red dots at Catalan fish markets for *P. longirostris* during 2002 – 2024.

3.2 Population structure

3.2.1 Length–weight relationships in *P. longirostris*: comparative analysis of males, females, and combined individuals

The analysis of length-weight relationship parameters for *P. longirostris* from the Catalan coast, both for combined sexes and separately, indicated negative allometric growth (CL95 = 2.449 – 2.477; b < 3), as shown in Figure 5. The ANOVA test, comparing the regression models to assess the effect of sex on the relationship between cephalothorax length and weight, showed that the slopes were significantly different for both sexes (p = 0.0002).

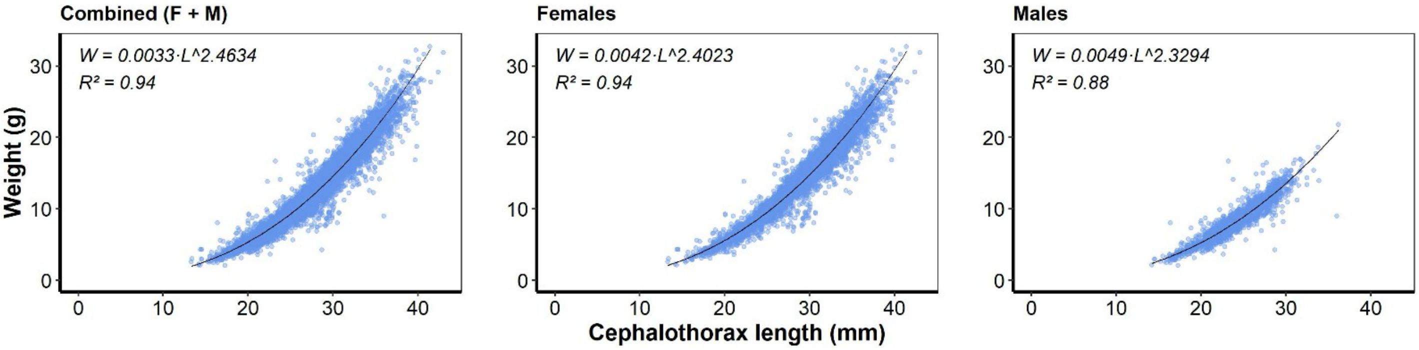

Figure 5. Relationship between cephalothorax length (CL, mm) and weight (g) in *P. longirostris*, shown for combined sexes (F+M), females, and males.

3.2.2 CL Length-abundance of *P. longirostris*

The following chart presented the frequency distribution of carapace length (CL) for *P. longirostris* across the entire Catalan coast (Figure 6). The data showed that the population (n = 35057 individuals), most commonly ranged from 8 mm to 50 mm in carapace length. The resulting distribution is clearly Gaussian (normal), with the relative maximum observed at approximately 28 mm.

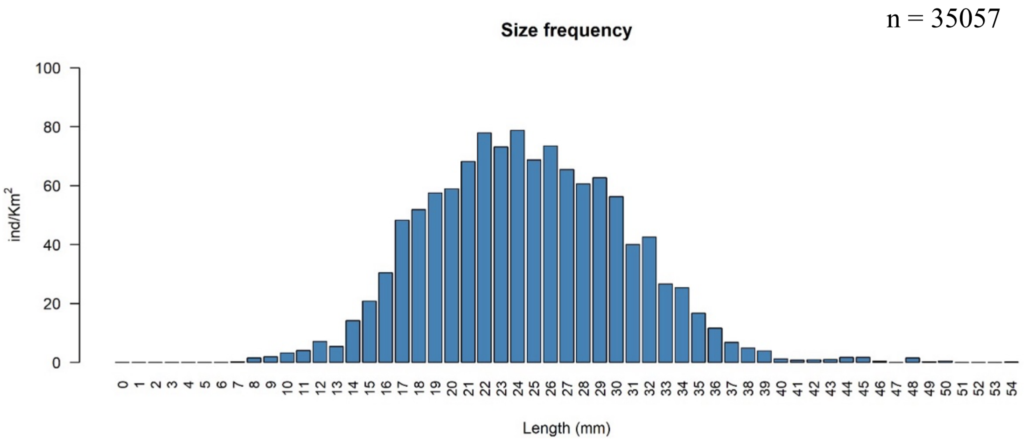

Figure 6. Length-frequency distribution of the population of *P. longirostris* from the Catalan Coast between 2019 and 2024.

3.2.3 CL Length-abundance by depth strata

The species was present in all the depths sampled; however, many differences were shown depending on the depth strata (Figure 7). In the first depth strata (coastal delta shelf) the individuals ranged from 17 mm to 28 mm CL and the maximum number of individuals per km^2 were almost 10 with 26 mm of carapace length (Figure 7). In the second one (middle delta shelf) individuals ranged from 8 mm to 50 mm CL, albeit the majority of the population studied was found between 14 mm and 35 mm. The graphic (Figure 7) shows a Gaussian (normal) distribution and the maximum number of individuals per km^2 were almost 130 with 19 mm of carapace length. In the third one (deep shelf) individuals ranged from 8 mm to 49 mm CL, while most of the population studied was found between 16 mm and 32 mm. The figure illustrates a normal distribution, the maximum number of individuals per km^2 were almost 120 with 22 mm of carapace length. In the fourth depth strata (upper slope) individuals ranged from 9 mm to 43 mm CL, despite the majority of the population studied was found between 21 mm and 34 mm. The figure displays a normal distribution and the maximum number of individuals per km^2 were almost 150 with 26 mm of carapace length. In the last depth strata (lower slope) individuals ranged from 14 mm to 45 mm CL with a maximum density of almost 7 individuals per km^2 at 28 mm carapace length. The highest abundance was found at depths of 200 m – 500 m, while the lowest abundances occur in the shallowest (coastal delta shelf) and the deepest (lower slope) strata (Figure 7).

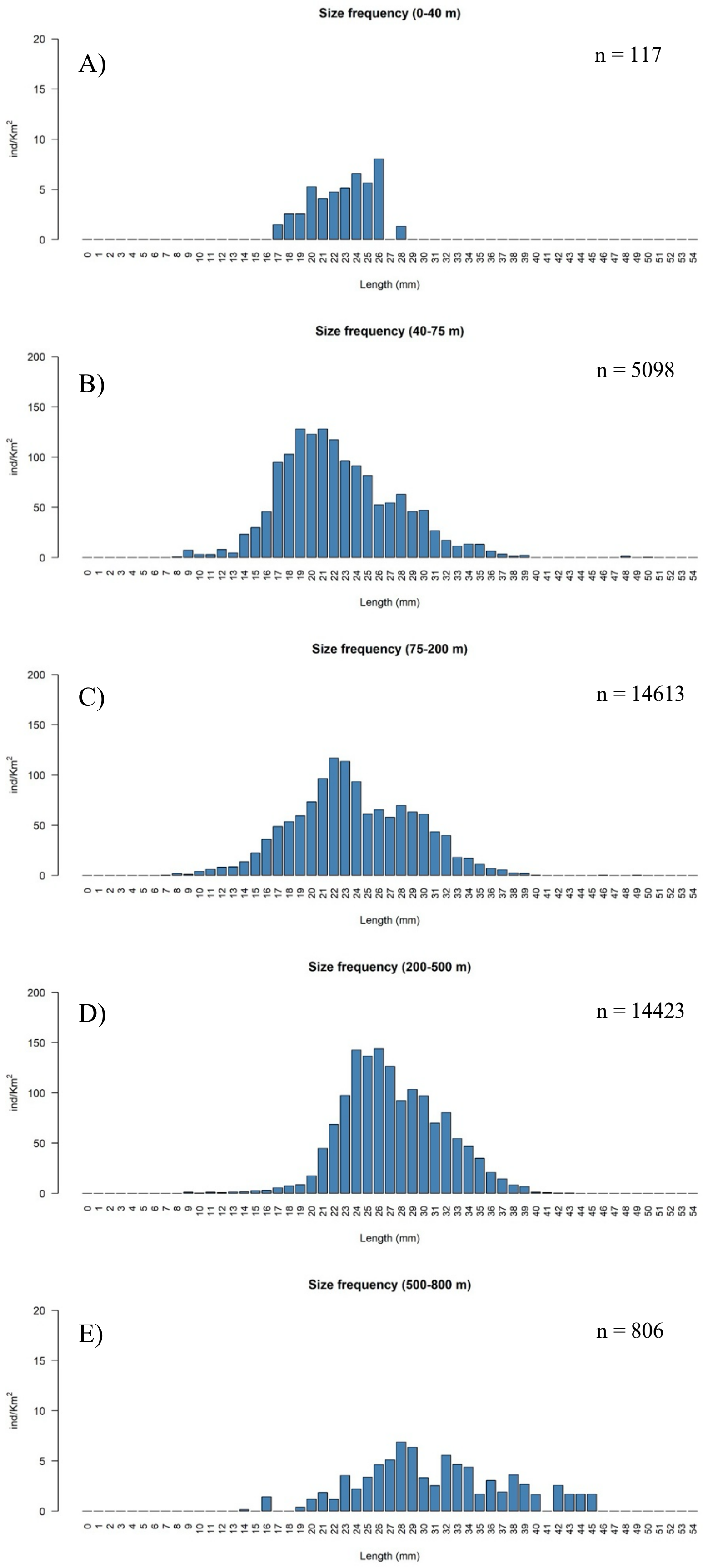
Size frequency (0-40 m)
A)
n = 117
ind/Km^2
0
5
10
15
20
Length (mm)
Size frequency (40-75 m)
B)
n = 5098
ind/Km^2
0
50
100
150
200
Length (mm)
Size frequency (75-200 m)
C)
n = 14613
ind/Km^2
0
50
100
150
200
Length (mm)
Size frequency (200-500 m)
D)
n = 14423
ind/Km^2
0
50
100
150
200
Length (mm)
Size frequency (500-800 m)
E)
n = 806
ind/Km^2
0
5
10
15
20
Length (mm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54

Figure 7. Spatial length-frequency distribution of *P. longirostris* from 2019 to 2024 in different depth strata. A, coastal delta shelf, < 40m; B, middle delta shelf, 40 m – 75 m; C, deep shelf, 75 m – 200 m; E, upper slope, 200 m – 500 m; D, lower slope, 500 m – 800 m (Carreton et al., 2025).

3.2.4 Population growth parameter

The von Bertalanffy growth parameters were estimated separately for females and males in order to analyse its different dynamics. For the asymptotic length ($L\infty$), females reached 47.34 mm, whereas males attained 41.02 mm. The growth coefficient (K) was 0.72 year^{-1} in females and 0.64 year^{-1} in males. T_0 differed the most between females (0.53) and males (0.20) compared to the other parameters. Finally, the growth performance index (ϕ') proposed by Pauly and Munro (1983) yielded values of 3.21 for females and 3.03 for males (Table 3).

Table 3. Growth parameters in females and males of *P. longirostris* calculated with data from 2019 to 2024.

PARAMETER	FEMALES	MALES
$L\infty$	47.34 mm	41.02 mm
K	0.72 year^{-1}	0.64 year^{-1}
T_ANCHOR	0.53	0.20
Φ' (PHIL)	3.21	3.03

3.3 Reproductive biology

3.3.1 Sex ratio and sex ratio by depth strata

Individuals of *P. longirostris* were caught year-round across a range of five diferent depths stratum. The global sex ratio (males:females) was 1:1.08, though it varied significantly depending on depth strata (Figure 8).

The most pronounced difference was observed at depths less than 40 m (n = 87), where females greatly outnumbered males, resulting in a sex ratio of 1:13.5. In the 40 – 75 m stratum (n = 36790), sex proportions were nearly equal, and this balanced trend continued in the 75 – 200 m (n = 27794) and 200 – 500 m strata (n = 171916), with only minor differences between males and females. In the deepest stratum (500 – 800 m), with a population studied of n = 103, females were also dominant, with a sex ratio of 1:1.64. Overall, Table 4 indicates a generally higher abundance of females across all depth strata, with the largest disparity in the shallowest waters, as shown in Figure 8.

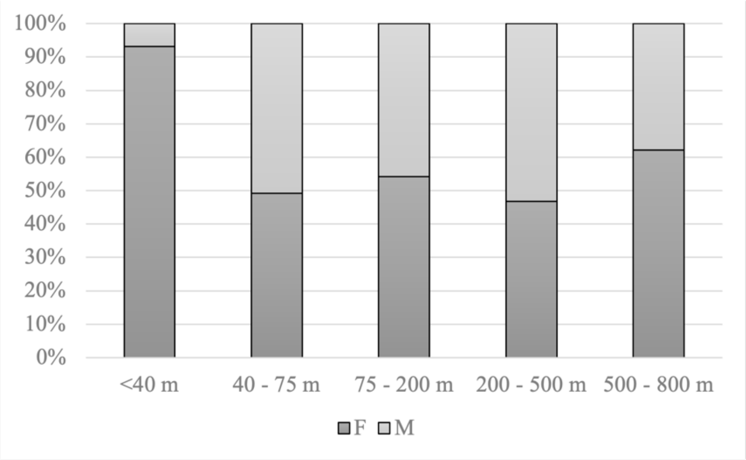

Figure 8. Relative abundance by sex of *P. longirostris* across different depth strata. F: females; M: males.

Table 4. Relationship between sex ratio and depth strata for *P. longirostris*.

Depth stratum	< 40 m	40–75 m	75–200 m	200–500 m	500–800 m
Sex ratio (M : F)	1:13.50	1:0.97	1:1.18	1:0.88	1:1.64

3.3.2 Reproductive period of *P. longirostris*

Specimens of *P. longirostris* captured (n = 5111) exhibited predominantly advanced sexual stages during different months, with most individuals in stage 3 (maturing) and stage 4 (mature). The months with the highest proportions of these stages were from May until the end of the year, with a notably high presence of stage 4 in May (33%), August (approximately 32%), and November

(35%). The months with the greatest number of individuals in recovering or developing stages (stage 2) were March and April, with nearly 60% and 45% respectively (Figure 9).

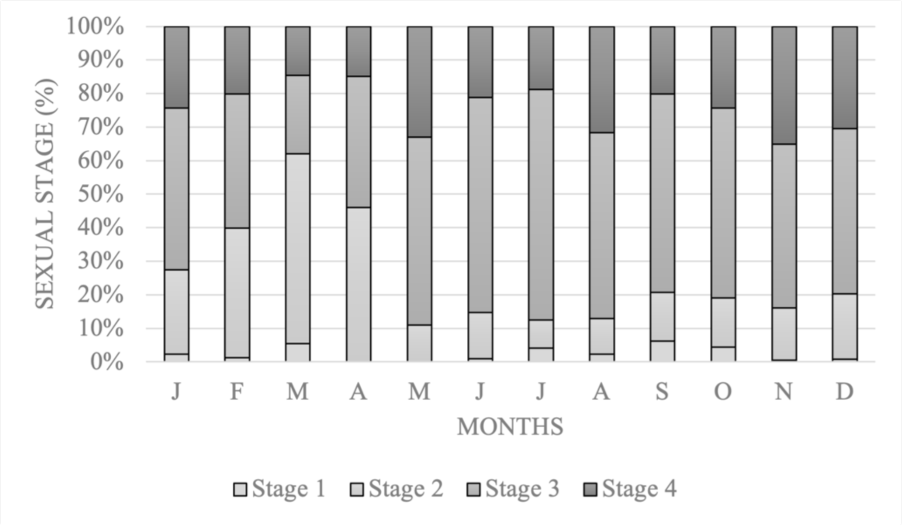

Figure 9. Proportion of sexual maturity stages in female *P. longirostris* throughout the months of the years 2022 until 2024. The data combine each year. The sexual maturity scale is defined as: 1, immature; 2, developing/recovering; 3, maturing; and 4, mature.

3.3.3 Gonadosomatic index

The gonadosomatic index (GSI) shows peak values in May and November, each with a GSI of 4.5 (Figure 10). The lowest values are observed in March and April, with GSIs of 2.3 and 2.7, respectively. From April onwards, the GSI remains relatively stable until January, when it begins to decrease again. Overall, reproductive activity, as indicated by GSI, is lower during the spring months (Figure 10).

Figure 10. *P. longirostris*, monthly average values and standard deviation of the gonadosomatic index (GSI) for females during 2022-2024.

3.3.4 Size at first sexual maturity (L50)

Figure 11 illustrates the size at first maturity (L50) of female *P. longirostris* (n = 5111) was 16.7 mm carapace length, while the grey shaded area represents the 95% confidence interval, indicating that the size at first maturity ranges between 16.03 mm and 17.41 mm carapace length.

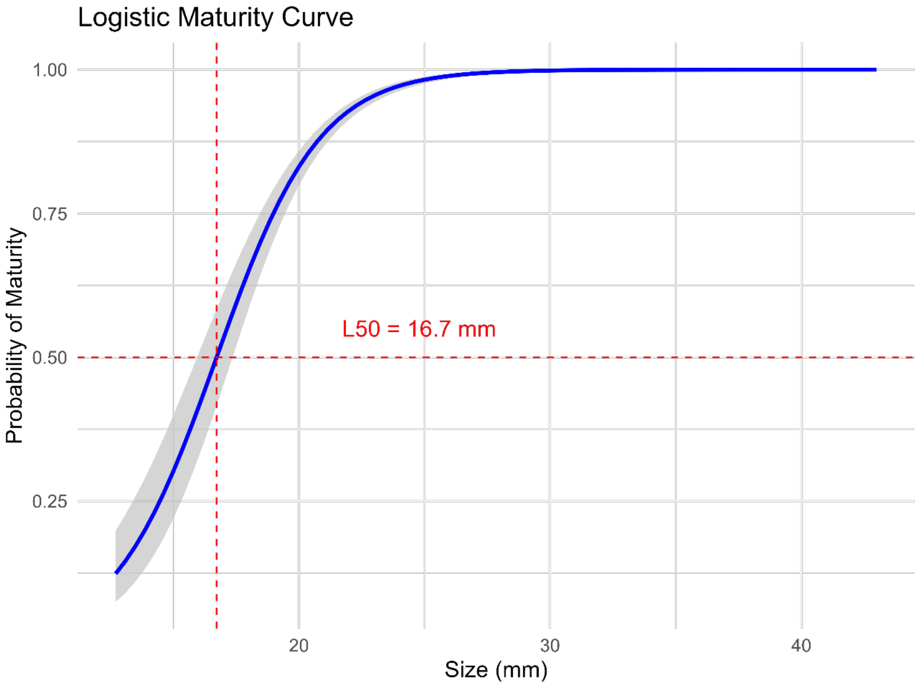

Figure 11. Representation of the maturity curve and the size at first maturity (red lines) of female *P. longirostris* from 2022 to date.

3.4 Histology

Although this current histology work is still in progress and not yet completed, ten samples from different months were observed. This allowed to microscopically differentiate every sexual stage of *P. longirostris* with the adapted criteria from ICES (2010). The stages that were photographed included stage 2 (maturing), stage 3 (mature), and stage 4 (spent) (Figure 12).

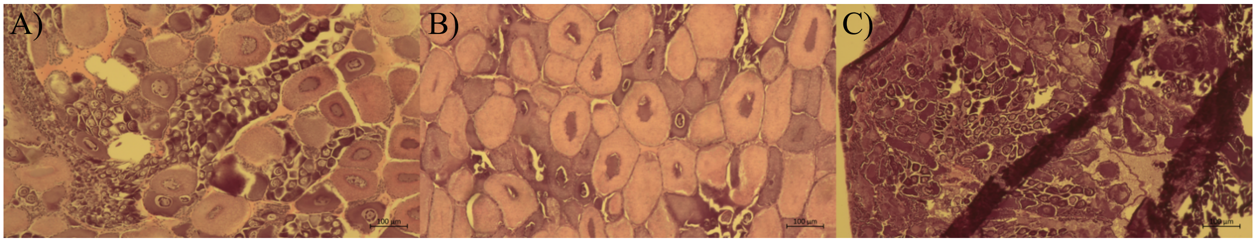

Figure 12. Female gonads with oocytes at three different developmental stages: maturing gonad at stage 2 (A); ripe gonad at stage 3 (B); spent gonad at stage 4 (C).

The individuals showed a constant presence in advanced maturity stages throughout the year, indicating that the species exhibits a prolonged reproductive cycle lacking a clearly defined single spawning period. However, an increase in the proportion of mature females was observed during certain months, including July, November, and December (Figure 13).

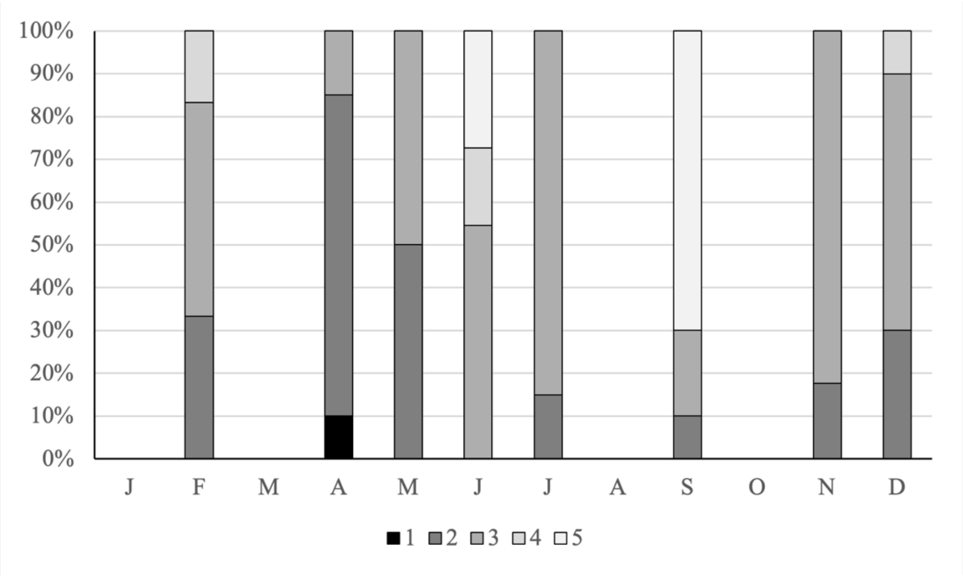

Figure 13. Preliminary results with the proportion of the five sexual maturity stages in female *P. longirostris* at a microscopic level throughout the months of 2024.

4. DISCUSSION

The integration of historical landing data, population and reproductive analyses, as well as considering the ongoing fishing pressures and climate change, is crucial for understanding and managing of commercial fisheries. In this sense, this current study demonstrates a marked increase in catches since 2016, a trend already observed in other areas of the Mediterranean as reported by Mingote et al. (2024), Sbrana et al. (2019), and Vaquer-Sunyer and Barrientos (2020), who highlighted a northward expansion of the species and an increase in local abundance since 2015.

This rising trend culminated in the 2021 peak of more than 450 tonnes, which underscores the economic and ecological importance of the species. Its subsequent decline in catches reflects a stabilization of the resource, followed by a price stabilization. Together with new regulations (EU Reg. 2019/1022) implemented since 2019 (Carreton et al., 2025; Mingote et al., 2024), have suggested a transition towards more sustainable exploitation, although, as evidenced by studies in Sicily (Bianchini et al., 2010) and other Mediterranean regions, whereas the Gulf of Alicante (García-Rodríguez et al., 2009) and North African coasts (Nouar and Maurin, 2001) the effects of regulation require long-term monitoring to ensure stock recovery.

The observed size distribution of the study, with a modal length around 24 mm CL, and normal pattern on the Catalan coast are consistent with regional and pan-Mediterranean studies, revealing pronounced spatial heterogeneity in population structure according to depth and fishing pressure. The greatest abundance between depths of 200-500m aligns with the average bathyal preferences reported in other studies (Abelló et al., 2002; D'Onghia et al., 1998; Froglia 1982; Sobrino 2005), that revealed an increase in mean size with increase in depth. As occurs in other penaeid shrimp species where the smaller individuals are found closer to the coast (Okpei et al., 2021).

The growth parameters calculated in this current study, with $L\infty$ values (47.34 mm in females and 41.01 mm in males) and K (0.72/0.64 year^{-1}), are consistent with results obtained in other nearby or Mediterranean regions, such as the Gulf of Alicante (García-Rodríguez et al., 2009), which reported an $L\infty$ of 47.0 mm in females and 36.0 mm in males. Similarly, in a southern zone, the Gulf of Cadiz, female values were 44 mm and 33 mm in males (Sobrino, 1998). Compared to other

regions or seas, the results obtained in this study were very similar, such as in the Ionian Sea, where L∞ values of 47.7 mm in females and 35.5 mm in males were reported (D'Onghia et al., 1998); in the Central Tyrrhenian Sea, values of 44.4 mm in females and 35.5 mm in males were obtained (Ardizzone et al., 1990); In the Marmara Sea, a more recent study found L∞ values of 41 mm in females and 36.8 mm in males (İhsanoğlu and İşmen, 2020). Further comparisons with populations in the Atlantic Ocean displayed similar estimates, with L∞ values were 44 mm in females and 36 mm in males (Ribeiro-Cascalho, 1988), reinforcing the consistency with the findings of the present study. Nonetheless, considering the scarcity of recent growth parameter data in areas close to this study region, it is important to highlight a notable difference in the L∞ values compared to other studies, with higher values observed in the present study. These findings may suggest an improvement in environmental conditions and density-dependent effects, indicating a possible population recovery. An elevated L∞ is often interpreted as a sign of better population status, reinforcing the notion of population improvement due to ongoing environmental changes (Carreton et al., 2025).
One important parameter to consider is the growth coefficient (K), which refers to the population growth rate. In both sexes, it shows higher values than those reported in the previously mentioned studies (47.34 mm; 41.02 mm). This fact, together with the value of (3.21; 3.03) in Pauly's parameter(ϕ'), indicates a very rapid population growth (Table 3). In our case, this is consistent with the rapid expansion of the species and with other biological parameters obtained in this study on the white shrimp, such as the allometry and the L50 of the species.

This study reports the presence of sexual dimorphism in growth patterns. Sexual dimorphism has already been confirmed in comparative studies throughout the Mediterranean, where the sex ratio is biased towards females, which grow faster and attain larger sizes than males (Froglia, 1982; García-Rodríguez et al., 2009; Levi et al., 1995). Albeit, one study did not coincide with this work in statistical differences in proportion, that is the case of the one undergone in the Marmara Sea, Turkey (İhsanoğlu and İşmen, 2020).

The negative allometric growth ($b < 3$), reiterated in these results, is a widely acknowledged trend among deep-sea crustaceans, reflecting responses to environmental and dietary conditions (Torres et al., 2017). This phenomenon is consistent with a life-history strategy characterized by rapid growth, early maturity, and high reproductive frequency, which favors a more pronounced increase in length relative to body mass. Negative allometric growth thus represents an r-selected life strategy focused on promoting rapid population growth. This trend has been observed in different studies such regions as the Gulf of Alicante (García-Rodríguez et al., 2009), North Africa (Nouar, Maurin, 2001), and more recently in Algeria (Ladjama et al., 2024), as noted by Mingote et al. (2024), underscored the significance of temperature shifts in the study area on population growth.

The sex-ratio results indicated a global ratio of 1:1.08, with a slightly higher number of females than males in the studied population, consistent with most previous studies on this species. As expected, shifts in sex ratio were observed with depth, showing a predominance of females at shallow depths and a higher proportion of males on the upper slope. These findings align with results from several studies (Ardizzone et al., 1990; Froglia, 1982; Spedicato et al., 1996), including observations such as “males were more abundant than females in the deepest hauls” (Guijarro et al., 2009), thereby supporting the habitat segregation hypothesis. Nevertheless, in this study, there was a higher presence of females in the deeper strata (500–800 m) compared to males, with a sex ratio of 1:1.64.

The prolonged reproductive cycle, with a maximum proportion of females in mature stages from May to the end of the year, show two clear peaks in May-August and November, as observed in Sobrino et al. (2007), with a study from 1993 to 1998. Similar trends were reported in the Tyrrhenian Sea (Mori et al., 2000) and the Adriatic Sea (Bombace, 1972), where mature females are present year-round but predominantly in spring and autumn. Similarly, Sobrino and García (1994), indicated continuous spawning throughout the year on the coasts of Morocco, with two peaks of maximum intensity at the end of spring and in autumn. Additional evidence that may reinforce these results has been reported in other areas, such as the coasts of Portugal by Ribeiro-Cascalho and Arrobas (1987); they indicated that mature females were more abundant in June–July and in October–December. The observed gonadosomatic index (GSI) values, coupled with the high proportion of individuals in advanced maturity stages, reinforce the presence of intense reproductive periods. This information is valuable for justifying temporal fishery regulations aimed at maximizing stock protection by preserving the spawners.

All stages proposed by ICES (2010) were identified in the histological study, with specimens showing advanced gonadal development observed throughout the months analysed, reflecting that *P. longirostris* reproduces year-round (Figure 13). This continuous presence of mature stages, alongside variations in maturity proportions, indicates a prolonged reproductive cycle with possible peaks dispersed over the year. Nevertheless, further analysis of additional samples is needed to better define the reproductive cycle, discern differences between macroscopic and microscopic staging, and to recognize and understand reproductive stages such as the early maturation processes. This, in turn, would contribute to refining the estimation of biological parameters such as L50 in the future, parameters needed to feed stock assessment models.

The size at first maturity (L50) of *P. longirostris* has been reported to vary geographically and seasonally (Guijarro et al., 2009), as summarized in Table 5. Previous studies in the central Mediterranean report L50 values ranging between 20 mm and 26 mm carapace length (CL) in females (De Ranieri et al., 1986; Mori et al., 2000). Slightly higher values have been identified in other regions, such as 22 mm CL in the Tyrrhenian Sea (Mori et al., 2000), and between 24.5 mm and 27.7 mm CL along the Atlantic coasts of Morocco (Sobrino, García, 1994).

Table 5. Comparative table of different studies carried out in different locations with size parameters of *P. longirostris*: n: total number of female individuals; L50: size at 50% maturity.

Study Area	Year	n	L50 (mm CL)	Studies
Central Mediterranean	1986 - 2000	-	20 - 26	De Ranieri et al., 1986
Tunisian coasts	1973	-	20.1	Azouz, 1973, Abelló et al., 2002
Gulf of Alicante	2001 - 2006	-	25.6	García-Rodríguez et al., 2009
Marmara Sea, Turkey	2011 - 2014	36288	18.07	İhsanoğlu and İşmen, 2020
Tyrrhenian Sea	1995	-	≈ 22	Mori et al., 2000
Atlantic coast of Morocco	1994	-	24.5 - 27.7	Sobrino and García, 1994
Gulf of Cadiz	1993 - 1998	2903	22.2	Sobrino and García, 2007
Portuguese coast (Div IXa)	1997 - 2008	-	≈ 24	Silva (INRB/IPIMAR), ICES. 2010
Central Mediterranean (Sicily)	1994 - 2007	-	22.4 (MEDITS); 20.6 (GRUND)	Ragonese (IAMC-CNR, Sicily) ICES. 2010
Catalan coast	2022 - 2024	5111	16.7 (95% CI: 16.03–17.41)	**Present study**

The integration of biological insights, such as growth rates, sexual dimorphism, sex ratio variance, and reproductive cycle, within the environmental context highlights the critical need for tailored management strategies. Notably, the effects of warming and increased salinity on the distribution, abundance, and traits of *P. longirostris* mirror patterns identified in the literature as characteristic of Mediterranean “early-warning species” for global change (Carreton, 2025; Colloca et al., 2014). The species’ phenotypic plasticity and reproductive sensitivity underscore the importance of adaptive management and ongoing environmental monitoring to anticipate population responses under shifting conditions.

Effective conservation must incorporate spatio-temporal protections aligned with reproductive periods, depth-specific population structures, and the species’ environmental sensitivities. The influence of temperature and salinity on spawning, initially documented by Sobrino and García (1994), has been reinforced by Mingote et al. (2024), who found that elevated temperatures and salinity are linked to changes in reproduction and distribution of *P. longirostris* in the NW Mediterranean. These findings strengthen the case for integrating climate projections into management plans to ensure sustainable exploitation. Continued regulatory measures including temporal fishery closures, size limits based on updated L50 estimates, and habitat protections grounded in local depth distributions are essential for maintaining viable populations and productive fisheries within the context of rapid environmental change.

5. CONCLUSIONS

Biological research and monitoring, such as in this study, are essential for sustainable resource management, specially for those species that are affected by climate change and new environmental conditions. Key conclusions are as follows:

- Since 2016, catches along the Catalan coast have significantly increased, reflecting broader Mediterranean trends and highlighting the species' ecological and economic importance.
- Size distribution (modal CL ≈ 24 mm) and population structure show spatial heterogeneity related to depth, with higher abundance at intermediate depths.
- Growth parameters ($L\infty$ and K) are consistent with other Mediterranean and Atlantic studies, with females growing larger than males, confirming sexual dimorphism.
- The sex ratio is slightly female-biased, with depth-related variability, indicating habitat segregation by sex.
- Gonadosomatic index, maturity stages, and histology confirm year-round reproduction, with female L50 at 16.7 mm, lower than in nearby regions.

Overall, these biological, reproductive, and ecological findings, together with the consideration of climate and exploitation factors, emphasize the need for adaptive, region-specific, and ecosystem-based management strategies that incorporate spatio-temporal protections to ensure the long-term sustainability of this valuable resource.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to Eve Galimany and Riki Santos-Bethencourt for their unwavering dedication, patience, and invaluable guidance throughout the development of this work. Their support has been essential in shaping this project into what it is today. I also wish to acknowledge not only their current mentorship but also their important role in encouraging my academic journey in oceanography, as they were instrumental in motivating me to pursue this master's degree through the university internship opportunities at ICATMAR.

I am deeply thankful for the opportunity they provided to study this species from multiple biological, population, and behavioral perspectives, which has greatly enriched my understanding and experience.

Furthermore, I wish to extend my heartfelt thanks to those in my personal circle whose encouragement and support have inspired me to persevere, work diligently every day, and never give up.

ACTIVITIES UNDERTAKEN DIRECTLY BY THE STUDENT

The activities carried out directly by the student included the histological processing of the samples, which encompassed dehydration for paraffin embedding, sectioning the samples, and performing the staining procedures. Additionally, the student thoroughly observed the prepared slides using a a microscope and captured photographs in the laboratory.The student was also responsible for processing the data obtained from these observations and those collected throughout the year from different samples and hauls, conducting a statistical study and analysis of the results. Finally, the student undertook the writing of this Master’s Final Project.

6. REFERENCES

Abelló P, Abella A, Adamidou A, Jukic-Peladic S, Maiorano S, Spedicato M T (2002) Geographical patterns in abundance and population structure of *Nephrops norvegicus* and *Parapenaeus longirostris* (Crustacea Decapoda) along the European Mediterranean coasts. Scientia Marina, 66, 125–141.

Abelló P, Valladares F J, Castellón A (1988) Analysis of the structure of decapod crustacean assemblages off the Catalan coast (North-West Mediterranean). Marine Biology, 98, 39–49.

Adloff F, Somot S, Sevault F, Jordà G, Aznar R, Déqué M, Herrmann M, Marcos M, Dubois C, Padorno E, Alvarez-Fanjul E, Gomis D (2015) Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. Climate Dynamics, 45, 2775–2802.

Ardizzone G D, Corsi F (1997) Atlante delle risorse ittiche demersali Italiane. Biologia Marina Mediterranea, 4, 479.

Ardizzone G D, Gravina M F, Belluscio A, Schintu P (1990) Depth-size distribution pattern of *Parapenaeus longirostris* (Lucas, 1846) (Decapoda) in the central Mediterranean Sea. Journal of Crustacean Biology, 10, 139–147.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impacts of climate change on the future of biodiversity. Ecology Letters, 15, 365–377.

Benchoucha S, Berraho A, Bazairi H, Katara I, Benchrifi S, Valavanis V D (2008) Salinity and temperature as factors controlling the spawning and catch of *Parapenaeus longirostris* along the Moroccan Atlantic Ocean. In: Essential Fish Habitat Mapping in the Mediterranean. Springer, Netherlands, pp. 109–123.

Bianchini M L, Distefano L, Ragonese S (2010) Reproductive features of the deep-water rose shrimp, *Parapenaeus longirostris* (Crustacea: Penaeidae), in the Strait of Sicily. Mediterranean Marine Science, 1, 81-92.

Bombace G (1972) Considerazioni sula distribuzione delle popolazioni di livello batiale con particolare riferimento a quelle bentonectoniche, Pubblicazioni della Stazione zoologica di Napoli, 39, 7-21.

Carreton M, Galimany E, Blanco M, Garriga Panisello M, Colmenero A, Balcells M, Bustos F, Mingote M, López-Pérez C, Francisco D, Puigcerver-Segarra X, Pujol-Baucells M, Ramírez J, Ribera-Altimir J, Rico A, Rojas A, Sala-Coromina J, Santos-Bethencourt R, Silvestre M (2025) Understanding the spatio-temporal variability of fisheries data for better bottom trawling management practices in the Catalan margin (NW Mediterranean Sea). Marine Policy, 172, 106512.

Colloca F, Mastrantonio G, Jona Lasinio G (2014) *Parapenaeus longirostris* (Lucas, 1846) an early warning indicator species of global warming in the central Mediterranean Sea. Journal of Marine Systems, 138, 29-39.

Colloca F, Scarcella G, Libralato S (2017) Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems. Frontiers in Marine Science, 4, 244.

De Ranieri S, Biagi F, Mori M (1986) Note sulla biologia riproduttiva di *Parapenaeus longirostris* nel Tirreno settentrionale. – Nova Thalassia, 8, 627-628.

D'onghia G, Matarrese A, Maiorano P, Perri F (1998) Valutazione di *Parapenaeus longirostris* (Lucas, 1846) (Crustacea, Decapoda) nel Mar Ionio. Biologia Marina Mediterranea, 5, 273-283.

FAO. 2023. The State of Mediterranean and Black Sea Fisheries 2023 – Special edition. General Fisheries Commission for the Mediterranean. Rome.

Fischer W, Bauchot M L, Schneider M (1987) Fiches FAO d'identification des espèces pour les besoins de la pêche. (Révision 1). Méditerranée et mer Noire. Zone de pêche 37. Volume I. Végétaux et Invertébrés. Publication préparée par la FAO, résultat d'un accord entre la FAO et la Commission des Communautés Européennes (Projet GCP/INT/422/EEC) financée conjointement par ces deux organisations. Fischer W, Bauchot M L, Schneider M (Eds) Rome, FAO, Vo1.1, 267-268.

Froglia C (1982) Contribution to the knowledge of the biology of *Parapenaeus longirostris* (Lucas) (Decapoda, Penaeidae). Quaderni del Laboratorio di Tecnologia della Pesca, 3, 163-168.

García-Rodríguez M, Gil J L P, Barcala E (2009) Some biological aspects of *Parapenaeus longirostris* (Lucas, 1846) (Decapoda, Dendrobranchiata) in the gulf of Alicante (SE Spain). Crustaceana, 82, 293-310.

Giorgi F (2006) Climate change hot-spots. Geophysical Research Letters, 33, L08707.

Guijarro B, Massutí E, Moranta J, Cartes J E (2009) Short spatio-temporal variations in the population dynamics and biology of the deep-water rose shrimp *Parapenaeus longirostris* (Decapoda: Crustacea) in the western Mediterranean. Scientia Marina 2009, 73, 183-197

Hastings R A, Rutterford L A, Freer J J, Collins R A, Simpson S D, Genner M J (2020) Climate change drives poleward increases and equatorward declines in marine species. Current Biology, 30, 1572-1577.e2.

Holthuis LB (1980) FAO species catalogue, Vol. 1. Shrimps and prawns of the world. An annotated catalogue of species of interest to fisheries. FAO Fisheries Synopsis, 125, 1-261.

ICATMAR (2023) Institut Català de Recerca per a la Governança del Mar. Evolució econòmica de les captures del sector pesquer a Catalunya: Comparativa 2022-2023 (ICATMAR, 24-03), 198 pp, Barcelona.

ICATMAR (2024) Institut Català de Recerca per a la Governança del Mar. Evolució econòmica de les captures del sector pesquer a Catalunya 2024 (ICATMAR, 25-04), 209 pp, Barcelona.

ICES. 2010. Report of the Workshop on crustaceans (*Aristeus antennatus, Aristaeomorpha foliacea, Parapenaeus longirostris, Nephrops norvegicus*) maturity stages (WKMSC), 19-23 October 2009, Messina, Italy. ICES CM 2009/ACOM:46, 77 pp.

İhsanoğlu M A, İşmen A (2020) Biological traits and population dynamic of *Parapenaeus longirostris* (Lucas, 1846) in the Marmara Sea, Turkey. Ege Journal of Fisheries and Aquatic Sciences, 37, 275-283.

Imene Ladjama, Bensaâd-Bendjedid, Lamia, Touati, Hassen, Tahri, Mardja, Baba Ahmed, Fédia (2024) Length -Weight Relationship, Body Condition and Growth Parameters of the Deep-Water Rose Shrimp *Parapenaeus longirostris* (Decapoda, Dendrobranchiata) in GFCM-GSA04 (Central and Eastern Algeria). Egyptian Journal of Aquatic Biology and Fisheries, 28, 791-804.

Jackson C (2011) Multi-state models for panel data: The msm package for R. Journal of Statistical Software, 38, 1-28.

Kumar A B, Deepthi G R (2006) Trawling and by-catch: Implications on marine ecosystem. Current Science, 90, 922-931.

Levi D, Andreoli M G, Giusto R M (1995) First assessment of the rose shrimp, *Parapenaeus longirostris* (Lucas, 1846) in the central Mediterranean. Fisheries Research, 21, 375-393.

Lloris D, Rucabado J (1998) Guide FAO d'identification des espèces pour les besoins de la pêche. Guide d'identification des ressources marines vivantes pour le Maroc. FAO, Rome.

Mingote M G, Galimany E, Sala-Coromina J, Bahamon N, Ribera-Altimir J, Santos-Bethencourt R (2024) Warming and salinization effects on the deep-water rose shrimp, *Parapenaeus longirostri*s, distribution along the NW Mediterranean Sea: Implications for bottom trawl fisheries. Marine Pollution Bulletin, 198, 115838.

Mori M, Belcari P, Biagi F (1986) Distributione e sex-ratio di *Parapenaeus longirostris* (Lucas) nel Tirreno settentrionale. Nova Thalassia, 623-625.

Mori M, Sbrana M, De Ranieri S (2000) (cf. b). Reproductive biology of female *Parapenaeus longirostris* (Crustacea, Decapoda, Penaeidae) of the north Tyrrhenian Sea (western Mediterranean). Atti della Società Toscana de Scienze Naturali, Memorie, Serie B, 107, 1-6.

Nouar A, Maurin C (2001) Nature of and typical populations on the characteristic facies of substratum of *Parapenaeus longirostris* (Lucas, 1846) along the Algerian coast. Crustaceana, 74, 129-135.

Okpei P, N. Resources, Okyere I (2021) Habitat distribution, species composition and size structure of penaeid shrimps (Decapoda: Dendrobranchiata: Penaeidae) in inshore waters of Ghana, Journal of Fisheries and Coastal Management, 23–33.

Pauly D, Munro J (1983) A simple method for comparing the growth of fishes and invertebrates. Fishbyte, 1, 5–6.

Perry A L, Low P J, Ellis J R, Reynolds J D (2005) Climate change and distribution shifts in marine fishes. Science, 308, 1912–1915.

Ribeiro-Cascalho A, Arrobas I (1987) Observations on the biology of *Parapenaeus longirostris* (Lucas, 1846) from the south coast of Portugal. Investigación Pesquera, 51, 201–212.

Ribeiro-Cascalho A (1988) Biologia, ecologia e pesca dos peneídeos de profundidade *Parapenaeus longirostris* (Lucas, 1846) e *Aristeus antennatus* (Risso) da costa portuguesa, 1-171. (Dissertação para provas de acesso à categoria de Investigador Auxiliar, INIP).

Ribera-Altimir J, Rico A, Rojas A, Sala-Coromina J, Santos-Bethencourt R, Silvestre M (2025) Understanding the spatio-temporal variability of fisheries data for better bottom trawling management practices in the Catalan margin (NW Mediterranean Sea). Marine Policy, 172.

Sbrana M, Zupa W, Ligas A, Capezzuto F, Chatzispyrou A, Follesa MC, Gancitano V, Guijarro B, Isajlovic I, Jadaud A, Markovic O, Micallef R, Peristeraki P, Piccinetti C, Thasitis I and Carbonara P (2019) Spatiotemporal abundance pattern of deep-water rose shrimp, *Parapenaeus longirostris*, and Norway lobster, *Nephrops norvegicus*, in European Mediterranean waters. Scientia Marina, 83, 71–80.

Schroeder K, Chiggiato J, Josey S A, Borghini M, Aracri S, Sparnocchia S (2017) Rapid response to climate change in a marginal sea. Scientific Reports, 7, 4065.

Sobrino I (1998) Biología y pesca de la gamba blanca (*Parapenaeus longirostris*, Lucas 1846) en el atlántico nororiental, 1-218. (Ph.D. Thesis, University of Sevilla).

Sobrino I, Garcia T (1994) Biology and fishery of the deepwater rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), from the Atlantic coast. Scientia Marina, 58, 299-305.

Sobrino I, García T (2007) Reproductive aspects of the deep-water rose shrimp *Parapenaeus longirostris* (Lucas, 1846) in the Gulf of Cadiz (southwestern Iberian Peninsula). Boletín del Instituto Español de Oceanografía, 23, 57-71.

Sobrino I, Silva C, Sbrana M, Kapiris K (2005) A review of the biology and fisheries of the deep water rose shrimp, *Parapenaeus longirostris*, in European Atlantic and Mediterranean waters (Decapoda, Dendrobranchiata, Penaeidae). Crustaceana, 78, 1153–1184.

Spedicato M T, Lembo G, Silecchia T, Carbonara T (1996) Distribuzione e biologia di *Parapenaeus longirostris* (Lucas, 1846) nel Tirreno centro-meridionale. Biologia Marina Mediterranea, 3, 579-581.

Tom M, Goren M, Ovadia M (1988) The benthic phase of the life cycle of *Parapenaeus longirostris* (Crustacea, Decapoda, Penaeidae) along the Mediterranean coast of Israel. Hydrobiologia, 169, 339–352.

Torres M A, Vila Y, Silva L, Acosta J J, Ramos F, Palomares M L D, Sobrino I (2017) Length-weight relationships for 22 crustaceans and cephalopods from the Gulf of Cadiz (SW Spain). Aquatic Living Resources, 30, 12.

Vaquer-Sunyer R, Barrientos N (2020) Informe Mar Balear (2020) Impacto y seguimiento de las reservas marinas del mar Balear. Vaquer-Sunyer R, Barrientos N (Eds). Palma, Mallorca, España. ISBN: 978-84-09-18951-9.