

Population structure, reproduction and exploitation of the greater forkbeard *Phycis blennoides* (Brünnich, 1768) from the Algerian basin[★]

Zakia Alioua^{1,*}, Soumia Amira¹, Ghollame Ellah Yacine Khames², Ulla Fernandez-Arcaya³, Beatriz Guijarro³, Francesc Ordines³, Enric Massutí³ and Fatiha Zerouali-Khodja¹

¹ Fisheries Laboratory, Faculty of Biological Sciences, University of Sciences and Technology Houari Boumediene (USTHB), BP. 32, El-Alia Bab-Ezzouar 16111, Algiers, Algeria

² Pelagic-ecosystem Laboratory, Faculty of Biological Sciences, University of Sciences and Technology Houari Boumediene (USTHB), BP. 32, El-Alia Bab-Ezzouar 16111, Algiers, Algeria

³ Instituto Español de Oceanografía, Centre Oceanogràfic de les Balears, Moll de Ponent s/n, 07015 Palma, Illes Balears, Spain

Received 16 December 2019 / Accepted 13 October 2020

Handling Editor: Richard Nash

Abstract – The objective of this study was to determine the population distribution and some biological aspects for fish stock assessment of the greater forkbeard *Phycis blennoides* along the Algerian basin. The distribution of *P. blennoides* (3418 individuals) was studied using data collected between 170–779 m depth during two bottom trawl surveys developed on 2003 and 2004. Additionally, some biological parameters were obtained from 1050 individuals sampled from commercial fisheries in Algerian ports (i.e. Annaba, Azeffoun, Dellys, Cap Djinet, Zemmouri, Bouharoun, Algiers, La Madrague, Cherchell, Tenes and Mostaganem) during the period 2013–2017. *P. blennoides* sampled from bottom trawl surveys showed a depth related distribution with the largest individuals being found at 600–800 m depth and the smallest at shallower depths. Density and biomass varied with depth and density also with longitude, while biomass showed no pattern with longitude. Recruitment was recorded in the eastern sector of Algeria during winter, for individuals sampled by bottom trawl surveys. Young *P. blennoides* entered commercial fisheries in summer, with an overall sex ratio skewed towards males (1F:2.18M). The size at first maturity (L_{50}) was 24.30 cm and 30.39 cm for males and females, respectively. The age at 50% maturity was 2–3 years for specimens collected by a bottom trawl survey in 2003 and commercial fisheries, but 3–4 years for the bottom trawl survey in 2004.

Keywords: *Phycis blennoides* / density / biomass / maturity / exploitation / Algerian basin

1 Introduction

The general overfishing of Mediterranean stocks requires urgent management measures to ensure the sustainability of resources (Quetglas et al., 2017). Accurate assessment of population parameters related to life history characteristics, including reproductive and growth aspects, is an essential component of effective fisheries management (Brown-Peterson et al., 2011; Saborido-Rey and Trippel, 2013).

The greater forkbeard *Phycis blennoides* frequents muddy and sandy bottoms and is mainly targeted by trawl fishing and longlines (Matarrese et al., 1998). It has a wide spatial distribution, occurring in the Mediterranean (Cohen et al., 1990; Massutí et al., 1996; Rotllant et al., 2002; Ragonese et al., 2004; Dallarés et al., 2016) and the North-East Atlantic (Clarke, 2005), from Norway and Iceland (Astthorsson and Pálsson, 2000) to the White Cape in West Africa. It is a broadcast spawner (Rotllant et al., 2002) with a high total fecundity of 1643899 eggs/female (Fernandez-Arcaya et al., 2013). It is an iteroparous and gonochoristic species with external fertilization (Rotllant et al., 2002), similarly to *Phycis phycis* from the same genus (Vieira et al., 2016). The latter species presents a group-synchronous ovary development and is a batch spawner (Vieira et al., 2016), while oocytes of

[★] The R-code and data of the population structure and some biological parameters of this species used in this work are available from Alioua et al. (2020a) and can be obtained through SEANOE.

*Corresponding author: zakia.alioua@gmail.com

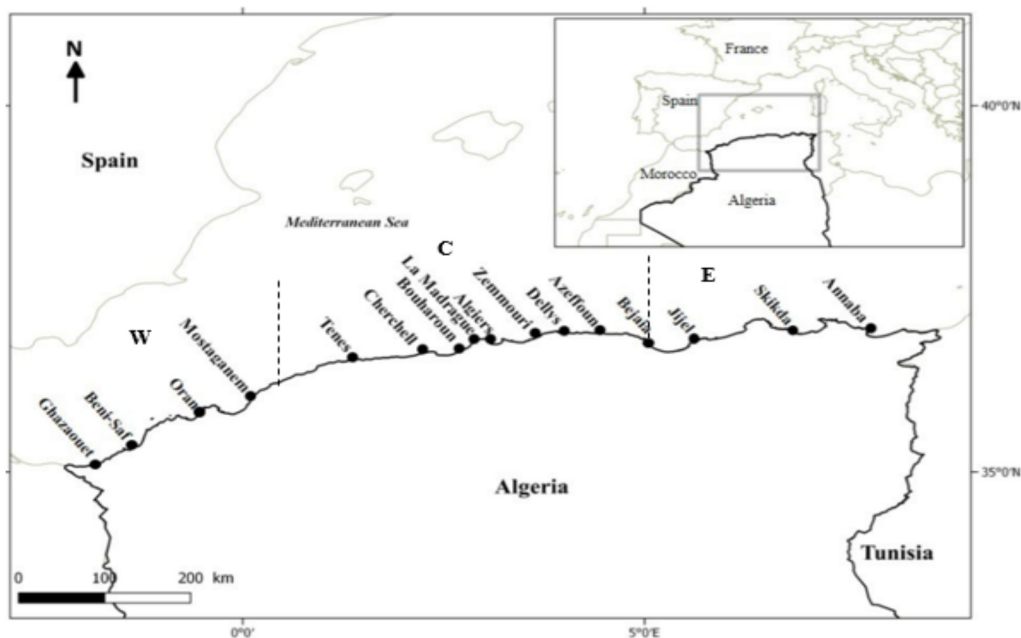


Fig. 1. Study area of *P. blennoides* with sampled landing ports (W: sector west, C: sector center, E: sector east).

P. blennoides do not exhibit synchronous development (Rotllant et al., 2002). Several authors have studied the biology of this species throughout the Mediterranean Sea, e.g. growth (Romdhani et al., 2016), recruitment patterns (Massuti et al., 1996; Matarrese et al., 1998; Lloret and Leonart, 2002), sexuality (Rotllant et al., 2002), diet composition (Sorbe, 1977; Macpherson, 1978; Sartor, 1995; Morte et al., 2002) and trophic level (Alioua et al., 2018). Moreover, the morpho-histology and histopathology of its digestive organs have recently been studied (Alioua et al., 2020b).

P. blennoides is a low value bycatch in mixed fisheries targeting hakes and shrimps in the Gulf of Lion and Valencia, (Sorbe, 1977; Morte et al., 2002). In contrast it is a species of economic interest in other Mediterranean fishing areas (FAO, 2005), for example on the Turkish coast (Tokaç et al., 2018), in the Catalan Sea (Massuti et al., 1996), and the central region of Algeria (Alioua et al., 2018), where it can fetch 11–15 USD per kg.

In Algeria, the presence of *P. blennoides* is very sporadic and the landed quantities are limited in space and time (Alioua et al., 2018). Moreover, scientific assessments of this species are lacking, with no official data available from fisheries services. For better stock management, it seems essential to define sustainable fishing levels and biological reference points. This study aims to contribute knowledge to improve fish stock management in Algeria. It provides informations on population structure, reproduction, growth and exploitation of *P. blennoides* along the Algerian coast.

The main objectives of this paper are as follow: (1) study density and biomass; (2) analyze the size frequency distribution; (3) characterize the reproduction (sexual maturity stages, physiological indices, histo-morphology and size at first maturity (L_{50})); (4) estimate growth parameters, exploitation rates and mortalities. For the analyses, we used data from two

scientific bottom trawl surveys conducted in 2003 and 2004; supplemented by additional biological data from commercial fisheries, collected 10 years later (2013–2017).

2 Materials and methods

2.1 Sampling

Samples were obtained with an experimental bottom trawl (GOC-73) during 160 hauls carried out between 40 and 779 m. Following the protocol generally used in the Mediterranean (MEDITS program; Bertrand et al., 2002), two bottom trawl surveys were performed in March 2003 and February-March 2004. A total of 3418 individuals of *P. blennoides* were caught between 170 and 779 m depth at three sectors along the Algerian coast: western area (W) from Mostaganem to Ghazaouet, central area (C) from Tenes to Bejaia and eastern area (E) from Bejaia to Annaba (Fig. 1, Table S1). Additionally, monthly samples were collected from commercial trawlers and longliners between 2013 and 2017 (December 2013 to June 2015; February to May 2016; December 2016; March to May 2017) at 11 Algerian ports: Annaba, Azeffoune, Dellys, Cap Djinet, Zemmouri, Bouharoun, Alger, La Madrague, Cherchell, Ténès and Mostaganem (Fig. 1, Table S2).

2.2 Population structure

2.2.1 Density, biomass and mean-weight

Numbers and biomass of *P. blennoides* were standardized to 1 km² for each trawl haul, accounting for speed and effective horizontal opening of the gear. To identify the geographical gradient of the distribution of this species, density (ind/km²),

biomass (kg/km^2) and mean-weight were determined by bathymetric range (<200 m, 200–300 m, 300–400 m, 400–500 m, 500–600 m, 600–700 m, 700–800 m) and for the three geographical areas (W: West, C: Central and E: East). Results from 2003 and 2004 were compared globally using the following statistics:

$$t^* = \frac{m_{2003} - m_{2004}}{\sqrt{\frac{s_{2003}^2}{n_{2003}} + \frac{s_{2004}^2}{n_{2004}}}}$$

where m is the average across total mean densities, total mean biomasses and total mean weights in each year, s^2 the variance of the mean and n the number of samples. An analysis of variance (ANOVA) was used to test the null hypothesis that there was no difference between the density, biomass and mean weight between bathymetric strata and sectors of both sampling years (2003–2004). The Tukey post-hoc test “Honest Significant Difference” was used when significant differences were detected. Prior and to minimize heteroscedasticity, the variable density was \log_{10} transformed and a Shapiro-Wilk test was performed to verify normality. To study the effect of depth and longitude, a linear model (LM) was used. In addition, a Generalized additive model (GAM) was also fitted to study the potentially non-linear the effects of longitude on community density and biomass. Cross-validation (GCV) was used to estimate the optimal degrees of freedom. The Akaike Information Criterion (AIC) proved useful as a coarse quantitative aid to choose between models (Wood, 2017). The GAM was implemented with R program version 1.1.383 (R Core Team, 2017) using the mgcv package (Wood, 2006). For studying the spatial distribution, densities, biomasses and mean-weights were mapped.

2.2.2 Size frequency distribution

To characterize population structure, the size frequency distributions of *P. blennoides* collected by the two bottom trawl surveys carried out in 2003 and 2004 were studied across depth. The size frequency distributions of commercial fisheries were represented by gender and season. A Kolmogorov–Smirnov test (KS) was used to compare length frequency distributions of *P. blennoides* from these surveys and commercial fisheries. Furthermore, a KS was used to analyse the difference between sexes and seasons for individuals collected from commercial fisheries.

2.3 Reproduction

For reproduction analysis, a total of 1050 individuals of *P. blennoides* captured from commercial fisheries were analysed. From each individual, the following informations were collected: total length (TL, 0.01 cm), eviscerated weight (W_{evi} , 0.01 g), liver weight (W_L , 0.01 g) and gonad weight (W_G , 0.01 g). Sex and sexual maturity stages were macroscopically determined after opening the abdominal cavity. Macroscopic stages of reproduction were determined using the four-stage scale of Rotllant et al. (2002) for gadiforms as follow: immature (thin/filamentous, transparent); early maturation

(small orange pink tube for ovaries, homogeneous tube with a white ivory colour for testes); advanced maturation stage (increased vascularization and volume, ovaries were long orange-red tube, semen is visible for testes); and ripe (much-reduced volume of the gonads richly vascularized: gravid ovaries, dark brown testes). Immature individuals with macroscopically undifferentiated gonads were excluded from reproductive analyses (Sanchez-Vidal et al., 2013).

2.3.1 Sex-ratio

Sex-ratios were compared across seasons and 3-cm size classes using a chi-square test (χ^2). A post hoc test was applied when significance was found applying the function pairwise Nominal Independence, using the rcompanion package (Mangiafico, 2018) in R software version 1.1.383 (R Core Team, 2017).

2.3.2 Reproduction indices and size at maturity

For each individual, the gonadosomatic (GSI), hepatosomatic (HSI) and somatic condition factor (K) indices were estimated using the following formulas:

$$\text{GSI} = \frac{W_G}{W_{\text{evi}}} \times 100; \text{HSI} = \frac{W_L}{W_{\text{evi}}} \times 100; K = \frac{W_{\text{evi}}}{\text{TL}^3} \times 100,$$

respectively; where W_G is the weight of the gonad, W_{evi} is the eviscerated weight, W_L is the weight of the liver and TL is the total length. The proportions of mature females by size were fitted by a logistic equation as described by Ashton (1972):

$$P_{\text{TL}} = \frac{1}{1 + e^{-(a+b\text{TL})}}$$

where: P_{TL} is the predicted proportion of mature females at a given total length (TL), and size at first maturity $L_{50} = -a/b$.

2.3.3 Histology

Histological sections were performed on a representative sample (different months and stages) of 151 gonads, covering the entire reproductive cycle. Gonads were fixed in 10% formalin, dehydrated by alcohol solutions with a programmed automat (Spin Tissue Processor STP 120 Myr), impregnated in melted paraffin for 24 h, embedded in paraffin, sectioned by 3 μm using a Leica RM2125 RT microtome and stained with hematoxylin-eosin. The microscopic analysis was carried out using a Premiere T3.15A microscope and a camera, connected to a computer. The image was processed using the TSView image analysis software (version 6.2.4.5. Tucsen, China). Microscopic stages were described using standard terminology from Brown-Peterson et al. (2011). Based on this histological screening, a few oocyte diameters were randomly measured without correcting, for shrinkage.

2.4 Growth

Growth consists in establishing a relationship between a measurable variable (length, weight) characterizing an individual and its age. This relationship was represented by

the von Bertalanffy model. From size frequency distributions of *P. blennoides*, age-length keys were obtained applying Bhattacharya's method using the FISAT II version 1.2.0 (Gayaniilo et al., 2005).

Using the size structure analysis of Powell Wetherall, asymptotic length (L_{∞}) and Z/K ratios were estimated by FISAT II version 1.2.0 (Gayaniilo et al., 2005). To estimate the growth rate (K), we used the empirical relationship between the growth performance index (Φ') and the asymptotic length L_{∞} : $\Phi' = \log_{10}K + 2\log_{10}L_{\infty}$ (Pauly and Munro, 1984). The parameter t_0 is included to adjust the equation for the initial size of the organism and is defined as the age at which the organisms would have had zero size. We used the empirical equation of Pauly (1979) to estimate t_0 of the von Bertalanffy growth function: $\log_{10}(-t_0) = -0.3922 - 0.2752\log_{10}L_{\infty} - 1.038\log_{10}K$.

2.5 Exploitation

To calculate exploitation indices, it is often impossible to obtain direct and accurate measurements of mortalities. Natural mortality (M) can vary with size, sex, parasitism, food availability and predation (Siegfried and Sansó, 2006). In this study, M was estimated using the empirical equation of Pauly implemented in FISAT II, assuming an average temperature of 13.08 °C for the habitat of *P. blennoides* (Cartes et al., 2016). Then, the equation developed by Djabali et al. (1994) for Mediterranean fishes and recommended by Bouaziz et al. (2014) was employed: $\log_{10} M = -0.0278 - 0.1172\log_{10}L_{\infty} + 0.5092\log_{10}K$. Fishing mortality (F) was estimated as $F = Z - M$ and the exploitation rate (E) as $E = F/Z$ (Pauly, 1983). Total mortality (Z) is considered to be the sum of several independent mortality rates. Z was obtained by the linearized catch curve using FISAT II software, version 1.2.2.2 (Gayaniilo et al., 2005).

3 Results

3.1 Population structure

The total average density of *Phycis blennoides* from the Algerian basin possibly decreased ($t^* = 2.284 > IC: 1.96$) between 2003 (412.52 ± 943.327 ind/km²) and 2004 (110.68 ± 191 ind/km²), though uncertainty of mean estimates was large making the confidence intervals of annual estimates overlap. For total average biomass, a slight non-significant decrease was observed (Tab. 1). Average mean-weight of *P. blennoides* was higher in 2003 than in 2004; though the difference was not significant ($p_{ANOVA} = 0.143$; Table S3).

The bathymetric distribution of *P. blennoides* showed different patterns for density, biomass and mean-weight (Table S3, Fig. 2). Mean densities had a modal distribution with a maximum between 300 and 500 m depth, but some variation between the two years, while biomass was highest between 600 and 800 m depth (Fig. 2A, 2B). Only four individuals were caught in 2004 between 100 and 200 m (Fig. 2A). Following the biomass pattern, mean-weight also increased with depth (Fig. 2C). A significant difference

Table 1. Total mean density (ind/km²), total mean biomass (kg/km²) and total mean weight (kg) of *P. blennoides* caught from bottom trawl surveys (BTS) along the Algerian coast.* Significant.

Parameters	BTS 2003	BTS 2004	t* > IC:1.96
Density	412.52 ± 943.32	110.68 ± 191.37	2.284*
Biomass	20.44 ± 20.3	6.09 ± 9.27	0.641
Mean-weight	0.13 ± 0.12	0.07 ± 0.06	0.373

between years was found for biomass at shallow depth (200–300 m) and on the slope (700–800 m) ($p_{ANOVA} = 0.04$). In contrast, the ANOVA showed no significant differences in terms of overall density, biomass and mean-weight between sampling years (Table S3).

During both years, the density of *P. blennoides* increased significantly with longitude (Fig. 2S), reaching its maximum in the eastern sector (Fig. 3a, 3b, 3c). For biomass, the variation was not significant across longitude for both years (Fig. 3c, 3d). The relationship between density and biomass showed a recruitment event in 2003 for a sampling station at 326 m in the east. This sampling station was characterized by a high density (>5000 ind/km²) and low biomass (<20 kg/km²). In 2004 at the same station relatively high density (876.22 ind/km²) and low biomass (<20 kg/km²) were also observed. Mean-weight was 2.24 g in 2003 and 8.81 g in 2004. Also in 2003; a station with large fish was observed at 625 m depth in the eastern sector, characterized by low density (<1000 ind/km²) and high biomass (>50 kg/km²) (Fig. 3a).

The spatial distribution was illustrated by mapping densities, biomasses and mean-weights of both years (Fig. 4).

Analysis of length frequency distributions showed that in both bottom trawl surveys, average length of *P. blennoides* on the slope was higher than on the continental shelf, indicating bathymetric segregation between adults and juveniles (Fig. S1). Juveniles (3–7 cm) were found between 200 and 600 m depth, while larger individuals were limited to the deepest areas (600–800 m), with a marked peak in 2003 between 200–400 m. Medium-sized individuals (~20 cm) were present in all depths for both years, with higher frequencies in 2004. Length-frequency distributions showed a general prevalence of small sizes as expected. Juveniles (<9 cm) were more abundant on the continental shelf (200–400 m depth) than on the slope, as well as in 2003 compared to 2004. Only four individuals were caught between 100–200 m in 2004 (6, 17, 18 and 26 cm). A small portion of larger sizes appeared between 600–800 m in both years (2003 and 2004).

The maximum observed size was 61 cm in 2003; 52 cm in 2004 and 62.7 cm for commercial fisheries (Fig. 5). Winter recruitment (~6 cm) was identified for fishes caught during the two bottom trawl surveys (2003 and 2004). Small individuals appeared in commercial fisheries at 12 cm in length during summer.

Seasonal length frequency distributions of *P. blennoides* from landings of commercial fisheries are shown in Figure 6. In autumn, sizes around 20 cm were common, representing high percentages of individuals (17.35% for 20 cm and 25.9%

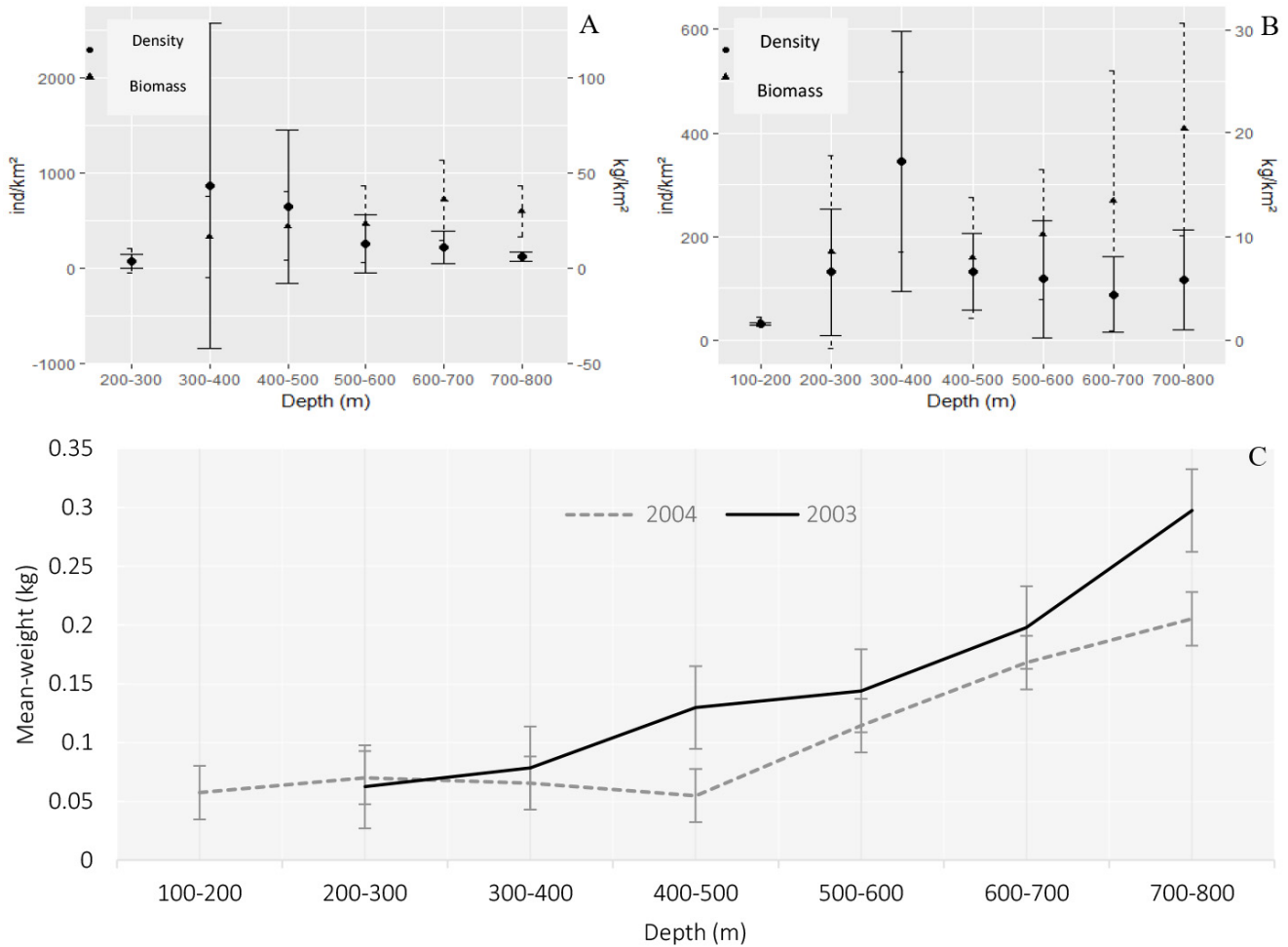


Fig. 2. Density (ind/km²), biomass (kg/km²) of *P. blennoides* with depth stratum (m) caught by the bottom trawl surveys in 2003 (A) and 2004 (B) along the Algerian coast and mean weight (kg) (C).

for 21 cm). Large individuals (>36 cm) appeared during winter and spring.

The Kolmogorov Smirnov (KS) statistics showed no significant differences in size between *P. blennoides* caught from bottom trawl surveys in 2003 and 2004 ($p_{2003-2004}=0.3742$) and commercial fisheries ($p_{2003-CF}=0.4913$; $p_{2004-CF}=0.7225$). Note that sample size was higher for bottom trawl surveys in 2003 ($n=2064$) and 2004 ($n=1346$) than commercial fisheries ($n=1050$) (Fig. 5). For commercial fisheries, we did not observe any differences between seasons ($p_{summer-winter}=0.9794$; $p_{summer-autumn}=0.9627$; $p_{summer-spring}=0.2032$; $p_{autumn-winter}=0.9639$; $p_{autumn-spring}=0.9639$; $p_{spring-winter}=0.8079$) (Fig. 6). In contrast, significant differences in length frequency distributions occurred between sexes ($p=0.03273$) (Fig. 7).

3.2 Reproduction

Overall, the sex-ratio was skewed towards males (1F:2.18M, $\chi^2:6.92$). This was observed in all seasons (autumn

1:3.64; spring 1:2.15; summer 1:2.53; winter 1:1.60) with significant differences ($\chi^2:12.393$, $p=0.006$), between autumn- spring ($p=0.045$) and autumn-winter ($p < 0.01$). The sex-ratio varied with size ($\chi^2:107.85$, $p=4.161 e^{-16}$), with males dominating (1F : 2.72 M) for length classes smaller than 27 cm. Females were dominant (1 F : 0.17M to 1 F : 0.25M) between 27 and 39 cm (Fig. 7).

The gonado-somatic index (GSI) of males were higher than those of females (Fig. 8a). For males the maximum value was observed in winter, followed by summer, autumn and then spring. For females, highest GSI were in spring and summer, followed by winter and autumn (Fig. 8a). In males, the maximum hepato-somatic index (HSI) was reached in autumn and the minimum in spring, while the peak of somatic condition factor (K) was recorded in summer and the minimum in winter (Fig. 8b). The maximum HSI in females followed the same pattern as for males (Fig. 8c). For K equal values were reported in winter and autumn (Fig. 8c).

The seasonal development of macroscopic stages of *P. blennoides*'s reproduction are represented in Figure 9.

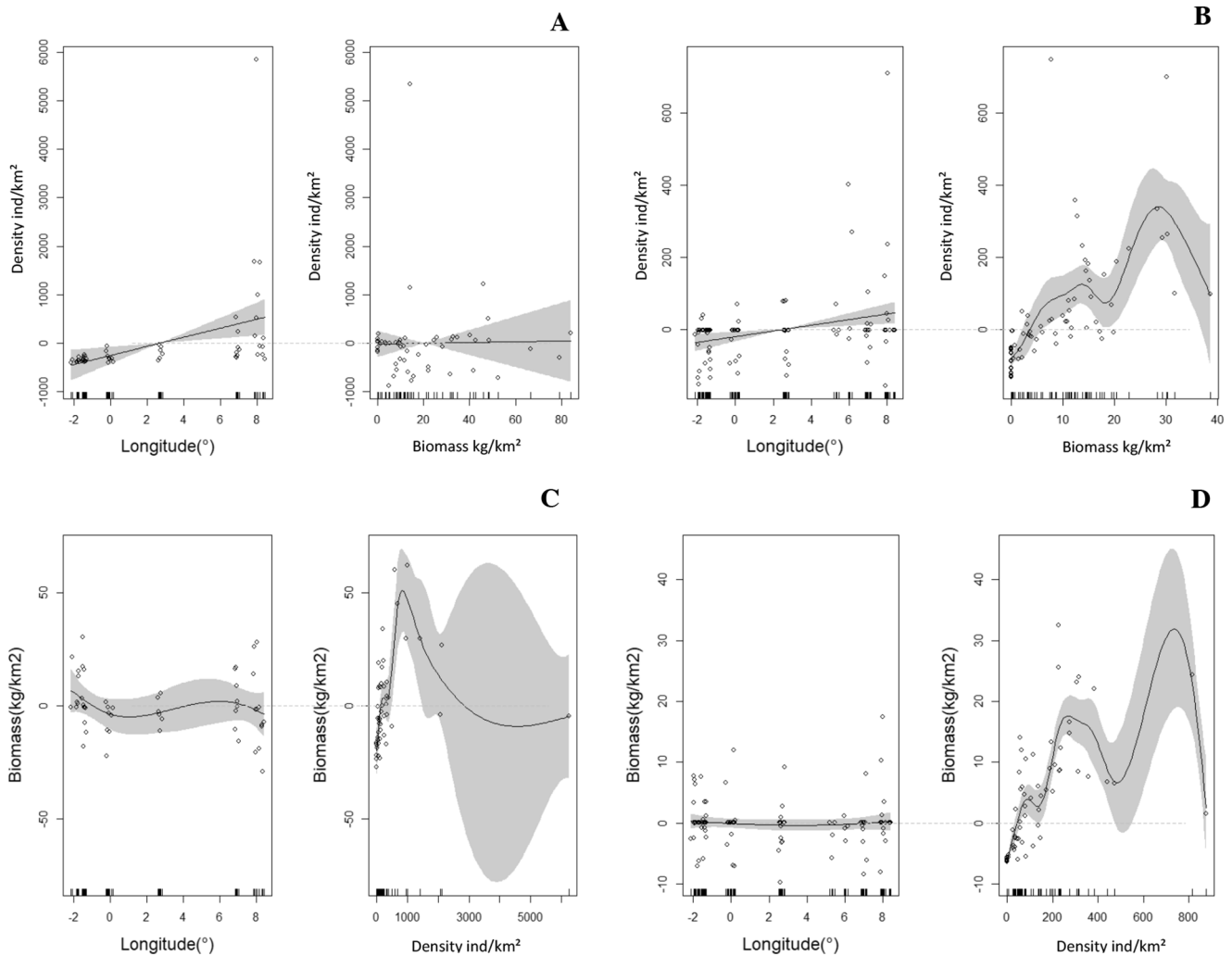


Fig. 3. Generalized additive model (GAM) of density (ind/km²) and biomass (kg/km²) of *P. blennoides* with longitude (°) caught by the bottom trawl surveys in 2003 (A, C) and 2004 (B, D) along the Algerian coast.

The sexual maturity stage evolution of this species revealed a spermatic emission all year round (Fig. 9a) and spring-summer spawning capable females (Fig. 9b). Furthermore, individuals in regressing phase appeared in winter and autumn for both sexes, in addition to spring for males (Fig. 9a). Immature specimens were found in all seasons. Considering developing stage, size at first maturity (L_{50}) was 24.30 cm for males and 30.39 cm for females (Fig. 10). The description of macroscopic stages of reproduction found in this study is summarized in Table 2.

Histological sections showed that the gonad structure of *P. blennoides* was similar to that found in most teleost species (Fig. 11). Male gonads presented four distinctive maturity phases in the Algerian greater forkbeard, in contrast to ambiguous ovaries development. Females had cystovarian ovaries characterized by paired lobes that were fused at the caudal end. At immature stage, the ovigerous leg contained primary growth oocytes with many oogonia (Oog) which are the smallest germinal cells of the oogenesis (Fig. 11a). Anatomically, enlarged ovaries contain blood

vessels during the developing phase. The histological sections through developing gonads showed oocytes increased in cytoplasmic and nuclear volume together, with the presence of initial vitellogenic oocytes (Vtg I) (109.07 μ m) and primary growth oocytes (PG) (Fig. 11b). In early maturing females, the oocyte as well as the nucleus became larger with light cytoplasm. At this stage, the gonads had initial vitellogenic oocytes (Vtg I) containing yolk protein (Fig. 11c). Regenerating ovaries found in the largest Algerian greater forkbeard were flaccid and dark. Their histological structure showed the presence of a thick ovarian wall (Ow) consisting of an outer mesothelium, a layer of smooth muscle, blood vessels and an inner layer of simple columnar epithelium (Fig. 11d). At this stage, primary growth oocytes were mainly present.

Among 200 analysed ovaries, only two spawning capable females were found. Immature/regenerating stages were mainly found for females. Nevertheless, eggs were not observed macroscopically in large females (>39 cm). In contrast to females, all maturing stages were observed in

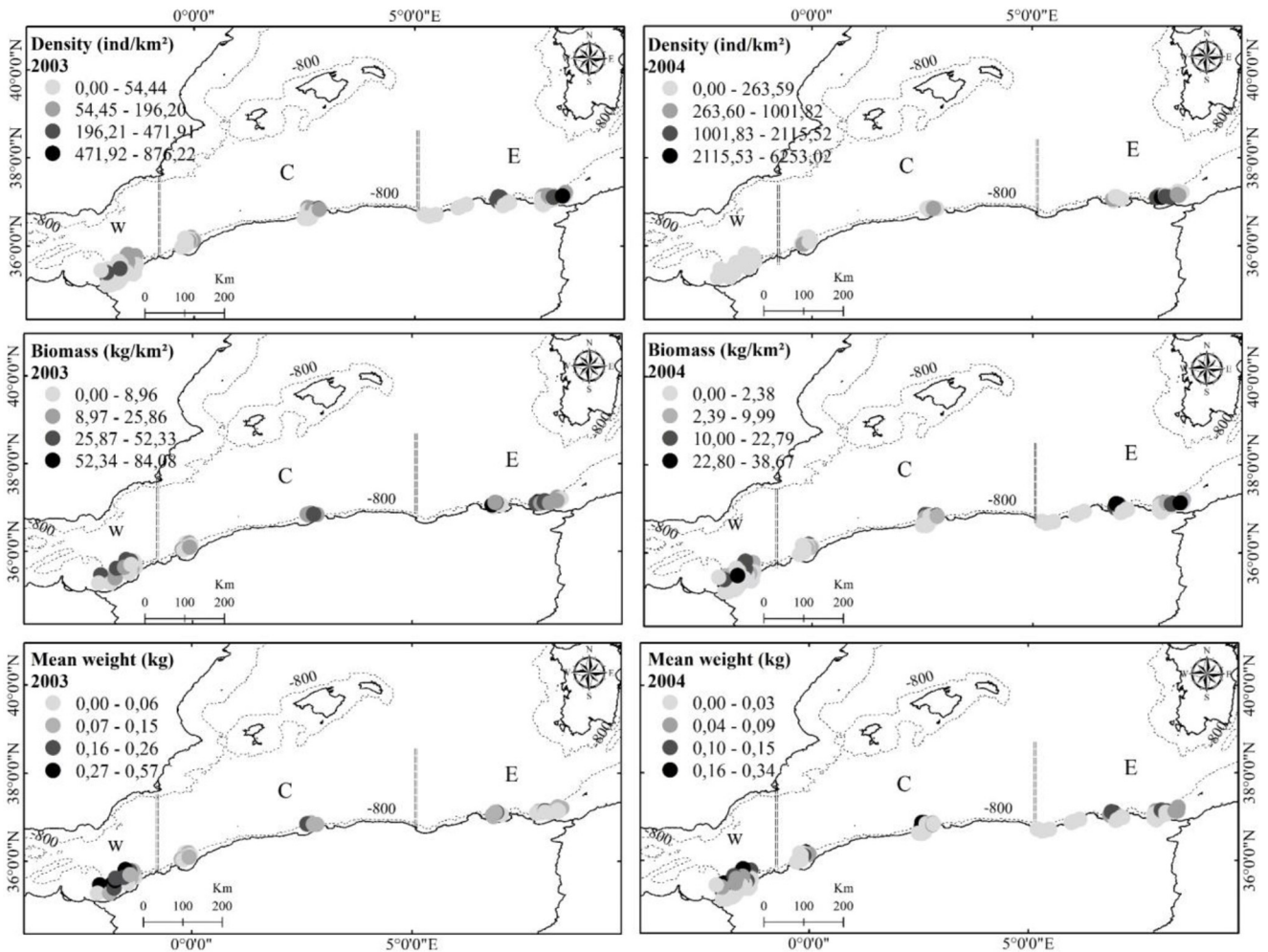


Fig. 4. Mapping density, biomass and mean-weight of *P. blennoides* caught by BTS (W: west, C: center, E: east).

Table 2. Macroscopic and microscopic descriptions of the phases in the reproductive cycle of *P. blennoides*.

Stage	Macroscopic	Microscopic
Immature/Juvenile	Small gonads and often clear. Slightly pink for ovaries and transparent for testes. Filamentous and blood vessels indistinct.	Oogonia (14.13 μm) and primary growth oocytes (PG) 23.95 μm are present in the ovary (Fig. 11a). Thin ovarian wall and little space between oocytes. Testes of juvenile males contain compact homogeneous seminiferous tubules with spermatogonia (Spg: 3.62 μm) bounded by a thin layer of connective tissue (Fig. 11e)
Developing	Enlarging gonads with blood vessels and a color variation as maturity progresses. Pink to red and brown for females and white ivory for males.	Initial vitellogenic oocytes (Vtg I) (109.07 μm) are present with primary growth oocytes (PG) in ovaries (Fig. 11b & c). Spermatocysts evident along lobules. Spg, Spc, Spd, and Spz can be present in spermatocysts. Spz not present in lumen of lobules or in sperm ducts (Fig. 11f).
Spawning capable	Testes are large and white with reactive pressure on abdomen.	Testes presents a rupture and a confluence of seminiferous tubules to release spermatozoa (Spz: 1.06 μm) in the direction of the deferens duct (Fig. 11g & h).
Regenerating	Empty flanges inactive gonads much-reduced volume with no reaction to abdominal pressure and richly vascularized.	Only primary growth oocyte (62.90 μm) with thick ovarian wall (Fig. 11d). Proliferation of spermatogonia throughout testes and small amount of residual Spermatozoa occasionally present in lumen of lobules.

Note: Individuals capable of spawning/emission are only males.

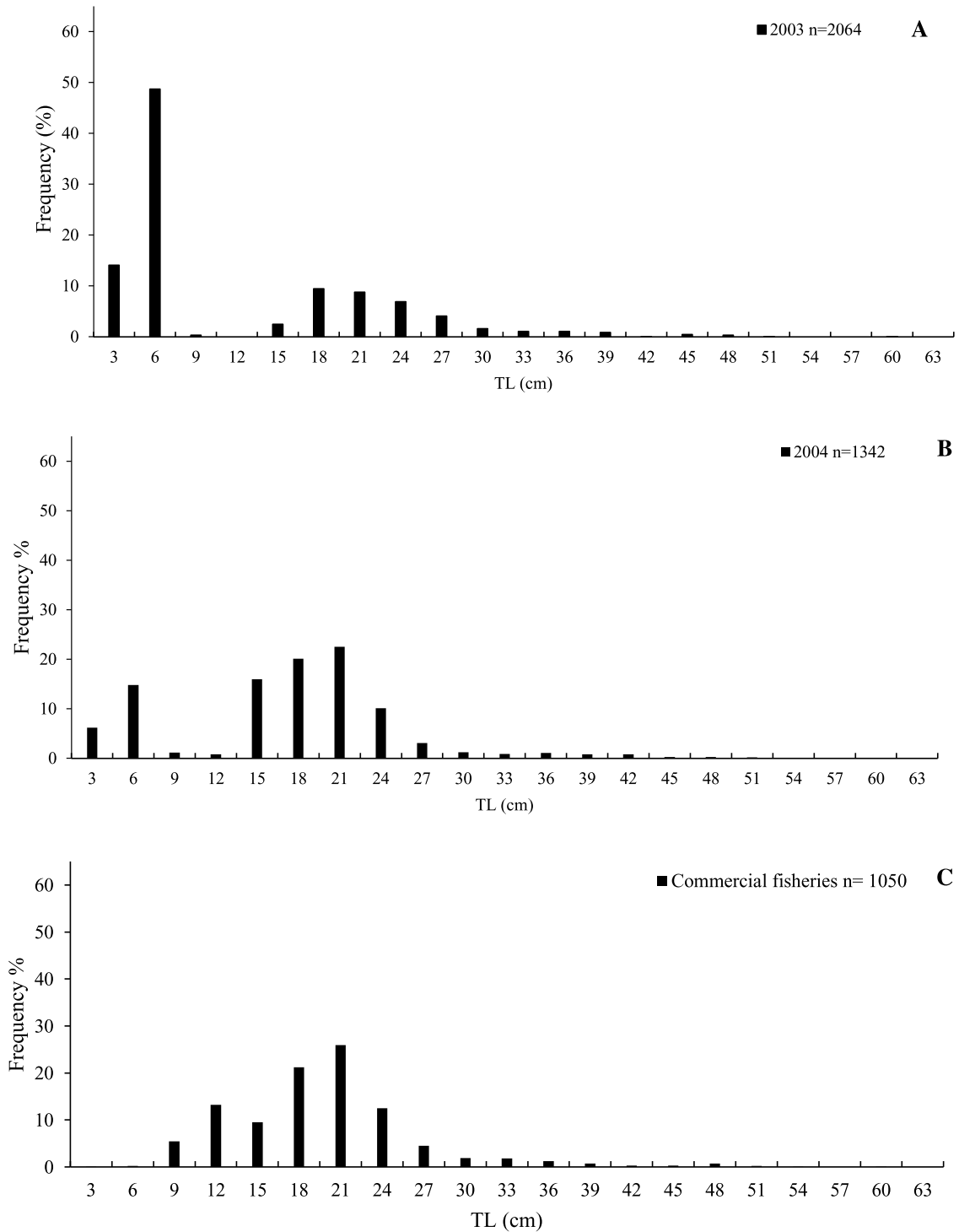


Fig. 5. Length frequency of *P. blennoides* caught from bottom trawl surveys in 2003 (A) and 2004 (B) and commercial fisheries in the algerian coast (n: number of individuals).

males. Juvenile greater forkbeard, had small and clear testes in primary stage, with spermatogonia (spg) as the largest germinal cells, mainly in the peripheral zone of the spermatogenic cyst (Fig. 11e). At developing stages, testes were ivory white, their spermatogonia, transformed by meiotic division into spermatocytes (Spcy) which are smaller,

occupied the periphery part of cysts then, became spermatids (Spd) (Fig. 11f). Males were ready for the spermatid emission when their testes showed spermatozoa (Spz). They were the smallest cells of spermatogenesis located at the central part of the cyst as small black spots (Fig. 11g). Males were reactive to abdominal pressure. The rupture and confluence of

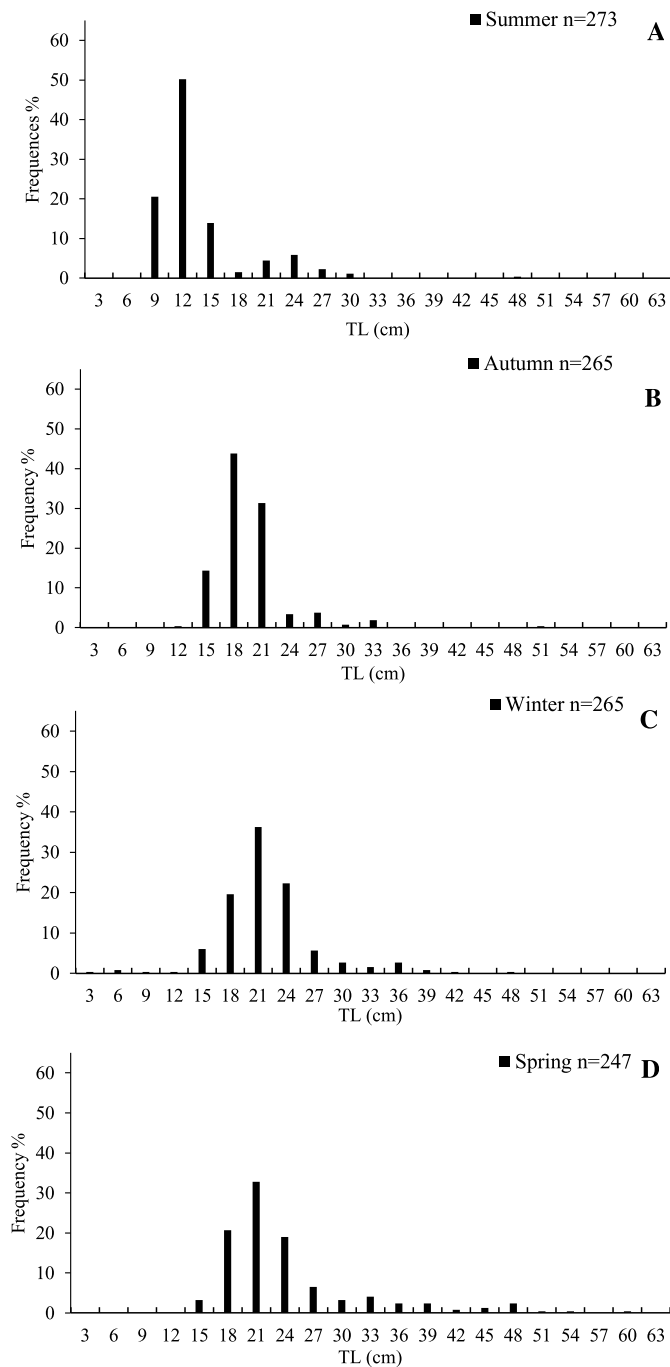


Fig. 6. Seasonal length frequency distribution of *P. blennoides* from landings of commercial fisheries (A: Summer, B: Autumn, C: Winter, D: Spring, n: number of individuals).

seminiferous tubules were observed to release their spermatozoa (Spz: $1.06 \mu\text{m}$) in the direction of the deferens duct (Fig. 1h).

3.3 Growth

The Bhattacharya method isolated seven age classes for the bottom trawl survey in 2003; eight for commercial fishing

individuals and nine for specimens from the bottom trawl survey in 2004 (Tab. 3). Age at 50% maturity was 2–3 years for *P. blennoides* collected by the bottom trawl survey in 2003 and commercial fisheries, but 3–4 years for the bottom trawl survey in 2004. Growth parameters for each sampling type and period are given in Table 4. The largest asymptotic length (L_{∞}) was observed for *P. blennoides* obtained from commercial fisheries, followed by individuals caught by the bottom trawl surveys in 2003 and in 2004. The opposite pattern was found for growth rate (K).

3.4 Exploitation

Natural mortalities (M) estimated by Djabali's equation were lower than those obtained by applying Pauly's empirical equation (Tab. 5). The lowest values of total mortality (Z) were found for the bottom trawl survey in 2003; followed by the bottom trawl survey in 2004 and commercial fisheries (Tab. 5). However, the Z estimated by the catch curve showed an optimal situation (E1) for *P. blennoides* collected by bottom trawl survey in 2003; corresponding to 49% of the exploited stock. The exploitation rate of *P. blennoides* increase from 2003 to 2004 (Tab. 5), testifying of two overfishing situations ($E2 > 0.5$).

4 Discussion

4.1 Population structure

Population dynamics refer to the processes responsible for changes in density or biomass of a population over time, and are monitored by a subset of possible population parameters (Pope et al., 2010). In this study, the biomass of the greater forkbeard showed distinct distribution pattern for adults and juveniles, with the later found mainly at shallower depths and the former deeper. This bathymetric distribution was already reported for the *Phycis* genus by several authors (Massuti et al., 1996; Matarrese et al., 1998; Rotllant et al., 2002; Fiorentino et al., 2003b; Santos et al., 2019). It suggests ontogenic migration with the older individuals moving deeper. Similarly to our findings, in the strait of Sicily the main nursery areas for *P. blennoides* have been observed between 200 and 400 m (Fiorentino et al., 2003b). Maximum density occurred in the 300–500 m depth stratum and maximum biomass at 600–800 m. In contrast, Massuti et al. (1996) registered maximum density at 200–400 m in the Northern Mediterranean. In the context of oligotrophic Mediterranean conditions, density, biomass and mean fish weight have been found to be significantly greater in the Balearic Sea than compared to the western and eastern Ionian Sea (D'Onghia et al., 2004) and similarly in Algeria. This could be attributed to the trophic resources available.

Density decreased significantly from 2003 to 2004; possibly due to fishing, sampling uncertainty or both. The number of fishing trawlers was 494 in 2009 (Roland, 2014) and increased to 688 in 2017. The West sector has the highest number of trawlers (347) followed by the Centre (183) and the East (158) (MPRH, 2017). In this study, a positive gradient of *P. blennoides* density was found from the western to the eastern Algerian coast. The shape of coast and the lower number of

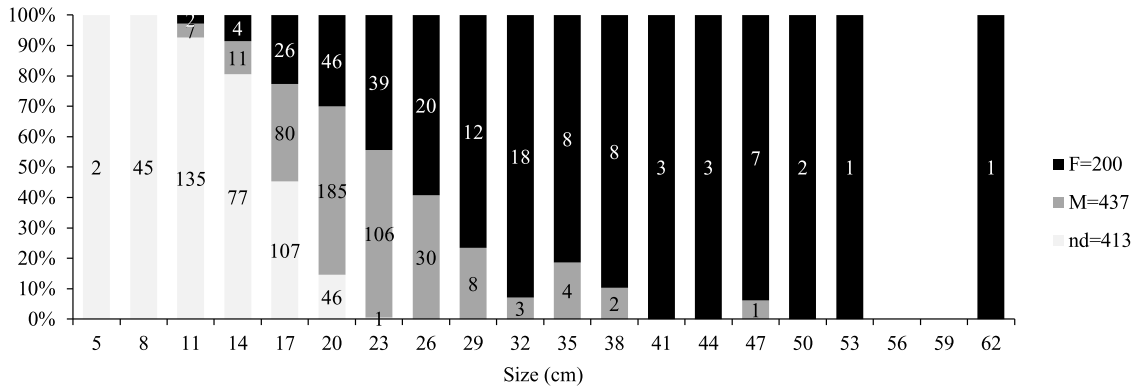


Fig. 7. Length frequency distribution of *P. blennoides* by sexes from landing of commercial fisheries (F: female, M: male, nd: undetermined, X axis: Lower limit of size class).

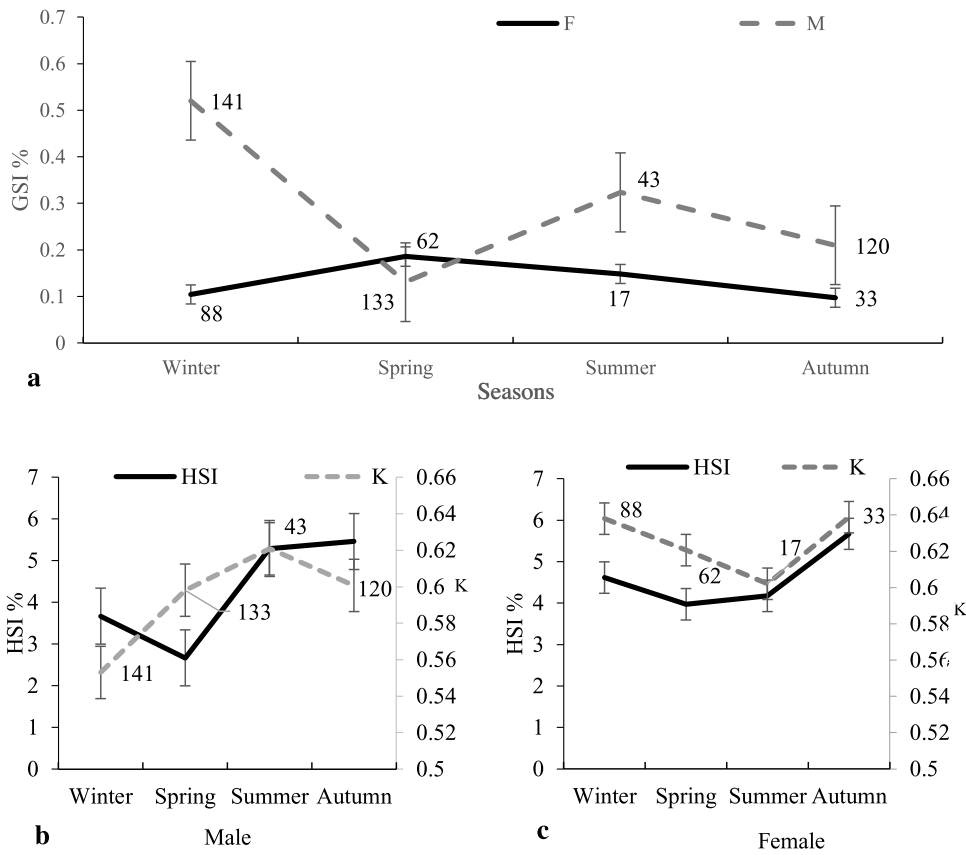


Fig. 8. Physiological indexes of *P. blennoides* from the Algerian coast (vertical bars are standard deviations). a) gonadosomatic index (GSI); b) hepatosomatic index (HSI) and somatic condition factor (K) for males; c) hepatosomatic index (HSI) and somatic condition factor (K) for females.

trawlers in the East might explain this pattern. As *P. blennoides* is of Atlantic origin, the Western sector has a helping flux of Atlantic-current with environmental enrichment. The high number of fishing trawlers in this sector (W) might have contributed to the reduction in density, biomass and mean weight of the species noted in 2004.

In this study, recruitment to commercial fisheries was observed in summer, similar to the north-western Mediterranean (Lloret and Leonart, 2002). In the survey, winter

recruitment was recorded, as was done by Massutí et al. (1996) and Matarrese et al. (1998). Mean biomass and mean weight slightly decreased from 2003 to 2004. A decrease of the Algerian greater forkbeard was also observed during data collecting from commercial fisheries between 2013 and 2017. This is also the case of Portuguese landings in the Atlantic according to ICES (2017). Additionally, juveniles of this species represent an important part of discards in shallower depths (Lorance, 2012). Then, discarded specimens were

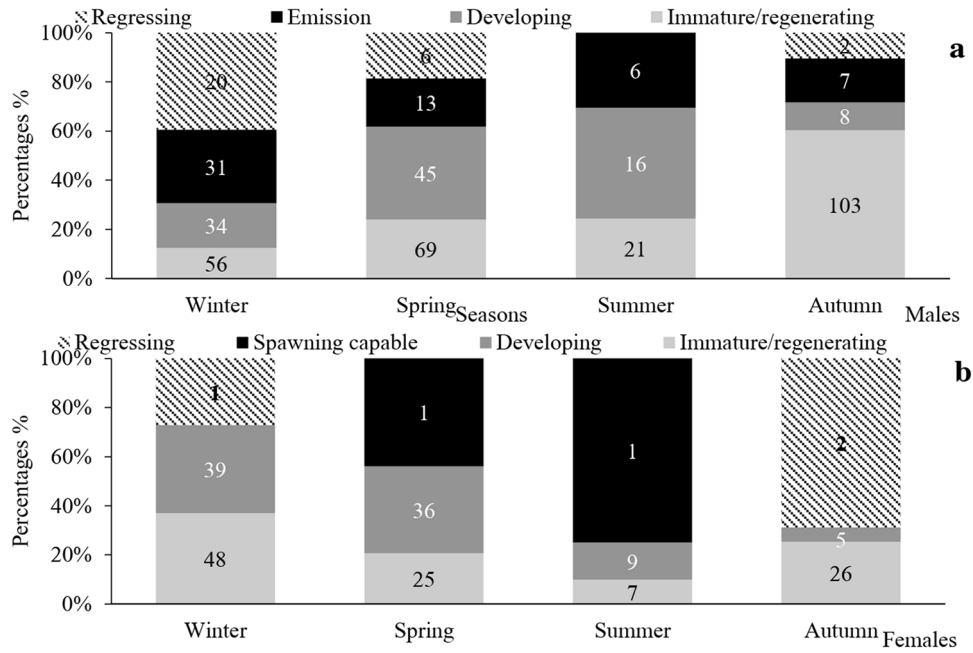


Fig. 9. Seasonal maturity stages of *P. blennoides* from the Algerian coast.

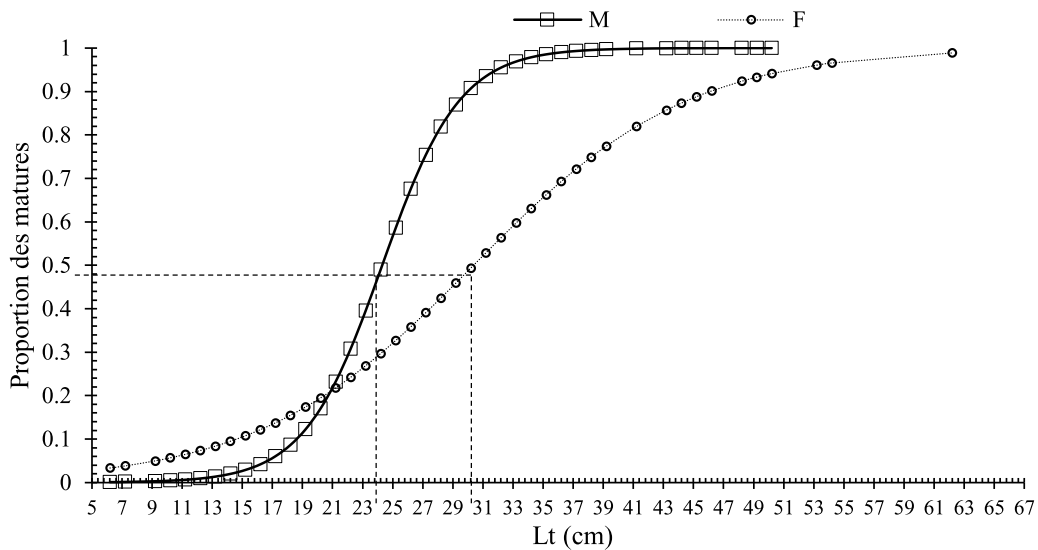


Fig. 10. Logistic regression model for the proportion of sexually mature males (M) and females (F) of *P. blennoides* (males $L_{50} = 24.30$ cm, females $L_{50} = 30.39$ cm).

observed many times in commercial landings of Bouharoun port in summer.

4.2 Reproduction

A difference in sex-ratio with size can be explained by females of many slope-dwelling fish becoming mature when they are reaching their maximum total length and then, somatic growth slows down (Gordon et al., 1995). The highly skewed sex-ratio (1F :4.02 M) in this study could be due to the origin of

specimens (commercial), which might be selected by the gear, but also that females may not inhabit the depth fisheries are operating in, as reported for other deep-sea species (Morley et al., 2004). Sex segregation has been observed by Gallardo-Cabello (1986) for *P. phycis* and *P. blennoides* and by Viana et al. (2000) for *Urophycis brasiliensis*. In contrast to this study, several authors have report equal sex ratios for greater forkbeard in the Mediterranean Sea (Benghali et al., 2014a; Matarrese et al., 1998; Rotllant et al., 2002; Fernandez-Arcaya et al., 2013).

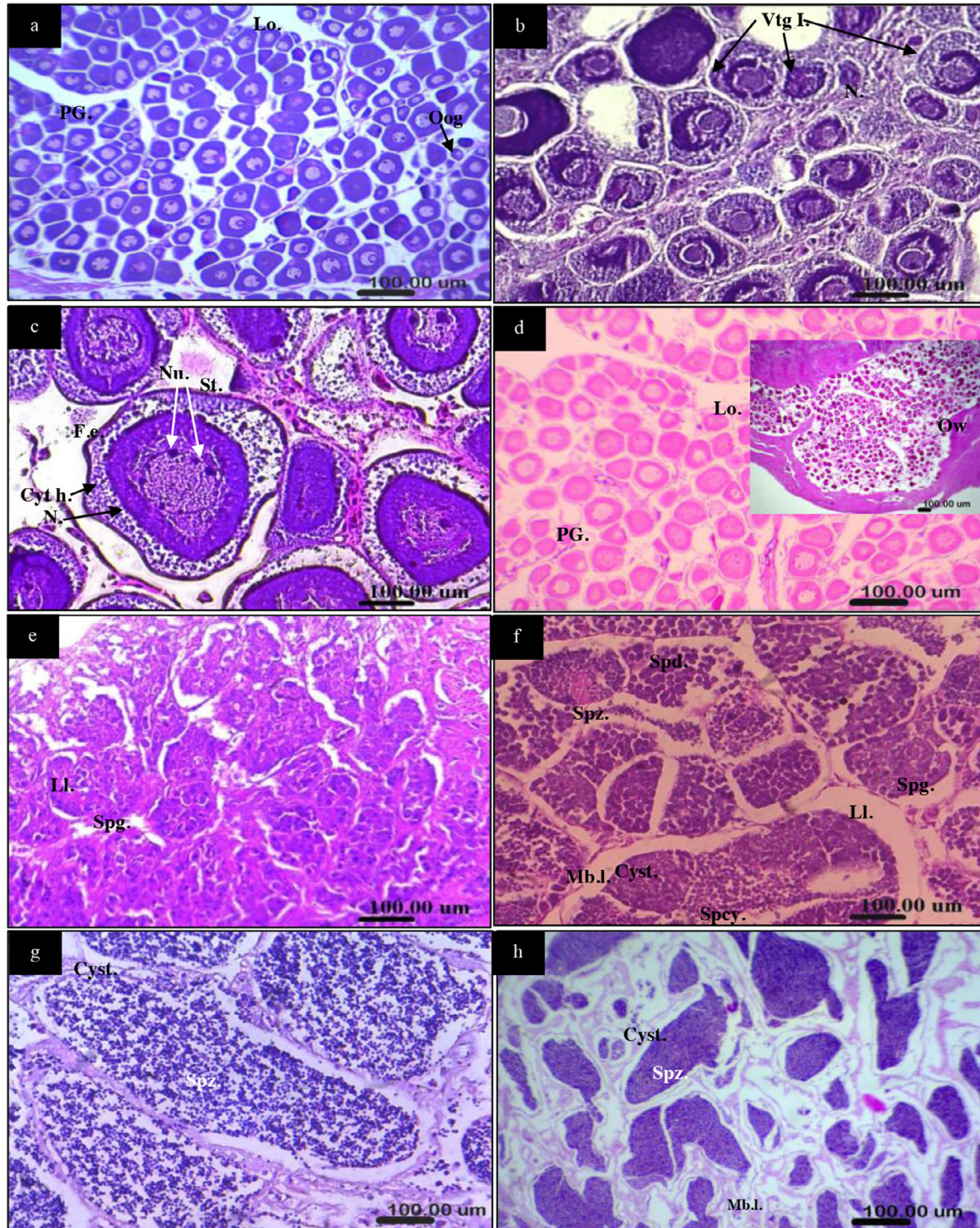


Fig. 11. Abbreviation: Oog. Oogonia, PG. Primary growth oocyte, Nu. Nucleoli, F.e. Follicular envelope, Lo. Ovarian lumen, VtgI. Primary vitellogenic oocyte, N. Nucleus, Cyt.h. Heterogeneous cytoplasm, St. Ovarian stroma, Ow. Ovarian wall, Spg. Spermatogonia, Ll. Lobular lumen, Cyst. Cyst, Mb.l. The basal membrane of the lobule, Spcy. Spermatozoa, Spd. Spermatid, Spz. Spermatozoa. Histological sections through the gonads of *P. blennooides* showing different development phases (scale: 100 µm). a. General view of immature female (Gx10, caught 30/04/15, TL: 53.1 cm; WG: 3.86 g, GSI: 0.396). b. Developing female (Gx40, caught 21/12/15, TL: 27.3 cm; WG: 0.12 g, GSI: 0.601). c. Early maturing female with initial stage of vitellogenesis and yolk protein (Gx40, caught 29/06/15, TL: 45.1 cm, WG: 3.9 g, GSI: 0.601). d. Histological section through the gonad of the biggest female sampled (Gx10, caught 23/04/2016, TL: 62.7 cm, WG :10.54 g, GSI: 0.61). Thick ovarian wall (Gx4) in regenerating ovaries. e. Immature male with spermatogonia cells (Gx40, caught 10/02/15, TL: 23.6 cm, WG: 0.02 g, GSI: 0.024). f. Male regenerating stage with the appearance of spermatids and spermatozoa (Gx40, caught 26/08/14, TL: 26.1cm, WG: 0.72 g, GSI: 0.373). g. Developing testes (Gx40, caught 6/01/15, TL: 21.1cm, WG: 0.5 g, GSI: 0.990). h. Mature testes with emission of spermatozoa (Gx10, caught 06/01/2015, TL: 24.1 cm, WG: 1.23 g, GSI: 2.13).

The reproductive biology of this species has been analysed in the Mediterranean. Its spawning period varies between areas. In the western Ionian Sea, the peak of reproduction occurs between November and January (Matarrese et al., 1998). Similarly, *P. blennoides* females are mature during autumn in the Balearic Sea (Rotllant et al., 2002) while they are mature in September on the western Algerian coast (Benghali, 2015). Spermatic emission happens between August and March in the western Ionian Sea (Matarrese et al., 1998) and from summer to early autumn in the western Mediterranean (Rotllant et al., 2002). Spawning in the Ionian Sea is observed from November to January (Matarrese et al., 1998). In the Balearic Sea, Rotllant et al. (2002) registered an active reproductive period from autumn to summer, where females spawn in autumn and males release their sperm from summer

to early autumn. In the western Algerian coast, the reproductive period of both sexes was observed in September (Benghali, 2015). According to the gonadosomatic index of our study, a peak is found in spring for females, while maturity stages showed regressing females in both winter and autumn. Spermatic emission was registered from summer to winter in this study, similar to the Ionian Sea (Matarrese et al., 1998).

In this study, the somatic condition factor underwent important changes throughout the year for both sexes. Male condition was lowest in winter, while it was lowest in summer for females. This might indicate that *P. blennoides* stores energy in muscle tissue to meet the energy expenditure caused by reproduction, making it a “fatty type” fish. This is similar to most Gadidae species: e.g. *Trisopterus luscus* (Alonso-Fernandez et al., 2008).

The description of gonadal development stages is very important for understanding gonad dynamics and evaluation of species reproductive mechanisms (Amira et al., 2019). Values of sexually mature individuals from this work differ from findings reported in previous studies. *P. blennoides* mature earlier in the Balearic Sea ($\sigma L_{50}= 19.31$; $\text{♀ } L_{50}= 24.7$ cm) (Rotllant et al., 2002) and along the western Algerian coast ($L_{50\text{♀}}= 24.7$ cm) (Benghali et al., 2014b). Also, 50% of males are mature at 19 cm in the Ionian Sea (Matarrese et al., 1998). Thus, L_{50} of greater forkbeard reported for females by these authors is almost 7 cm smaller than our findings. In contrast, the estimated L_{50} value for female Algerian greater forkbeard (30.39 cm) is closer to values recorded in the Atlantic, e.g. 32 cm (Clarke, 2005) and 33 cm (Cohen et al., 1990). Further, in the south-eastern Ligurian sea few mature individuals of *P. blennoides* have been found in autumn: females ranged between 40 and 63 cm and males between 20 and 26 cm (Rustighi et al., 2004).

No females with eggs have been observed throughout the study period. This finding allows us to consider *P. blennoides* as skipped spawners. Difficulties in the identification of

Table 3. Mean age-at-length of *P. blennoides* sampled by bottom trawl surveys (BTS) in 2003 and 2004 and from commercial fisheries (TL: total length in cm) off Algeria.

Age	Sampling		
	BTS 2003 TL	BTS 2004 TL	Commercial fishery TL
0	6.08	7.11	13.01
1	21.9	17.61	21.68
2	28.62	22.22	28.72
3	38.81	25.14	34.34
4	46.71	31.5	38.37
5	52.98	37.29	44.7
6	56.96	40.32	48.39
7	62.63	46	53.7
8		47.5	59.03
9		51.67	

Table 4. Growth parameters of *P. blennoides* estimated by FISAT II software. L_{∞} : asymptotic length (cm) obtained by Powell Wetheral’s method. K: growth rate (year^{-1}) obtained applying the equation of Pauly and Munro (1984). t_0 : size when age is zero, L_{max} : Maximum observed size in cm.

Sampling	L_{∞}	K	t_0	Z/k	L_{max}
Bottom trawl survey in 2003	60.5	0.358	-0.419	1	61
Bottom trawl survey in 2004	52.77	0.433	-0.489	1.291	52
Commercial fisheries	64.69	0.318	-0.374	1.631	62.7

Table 5. Exploitation indices for *P. blennoides* from the Algerian coast. Natural mortality from Djabali’s equation (M1) and Pauly’s equation (M2); Zc: total mortality from converted catch curve using FISAT II software; F1: fishing mortality using M1 and Zc; F2: fishing mortality using M2 and Zc; E1 and E2 exploitation rates using Zc.

Sampling	M 1	M2	Zc	F1	E1	F2	E2
Bottom trawl survey in 2003	0.39	0.53	1.04	0.65	0.62	0.51	0.49
Bottom trawl survey in 2004	0.44	0.62	1.68	1.24	0.74	1.06	0.63
Commercial fisheries	0.36	0.48	2.05	1.69	0.82	1.57	0.77

Table 6. Biogeographic comparison of mortalities and exploitation rates of *P. blennooides*. Natural mortality (M), total mortality (Z), fishing mortality (F), and exploitation rate (E).

Authors	Region	M	Z	F	E
(Campillo 1992)	Gulf of Lion, France	0.7	0.83	0.13	0.15
(Fiorentino et al., 2003a)	Strait of Sicily, Italy	0.43	0.4	/	/
(Ragonese et al., 2004)	Sicily	♀0.35 ♂0.58	0.88 1.41	0.53 0.83	0.60 0.59
(Clarke 2005)	North-est Atlantic	0.12	/	/	/
(Benghali 2015)	West of Algeria	0.571	2.114	1.543	0.72

fecundity, deficient diet and poor nutritional condition can lead to skipped spawning (Rideout and Tomkiewicz, 2011). This phenomenon may considerably affect stock-recruitment and stock-biomass relationships. This process has been found in *P. phycis* from the Portuguese coast (Vieira et al., 2016). The time and energy required for reproduction is better channelled into growth and survival, to increase future success rather than exacerbating already low energy reserves by spawning in the current year. Moreover, the reproductive potential including the frequency of spawning omission, will play an important role in effective management (Rideout et al., 2006).

4.3 Growth

P. blennooides is an economically important species as are the other Phycidae family members with relatively little information available for growth parameters in the southern Mediterranean (Romdhani et al., 2016). The largest individuals observed in this study were larger than those sampled in Tunisian waters ($L_{\max}=47.7$ cm) (Romdhani et al., 2016), western Algeria ($L_{\max}=43.5$ cm) (Benghali et al., 2014a) and along the south western Spanish coast ($L_{\max}=47.8$ cm) (Torres et al., 2012). However, our L_{\max} values are close to lengths obtained for the Northern Spanish Shelf (55 cm and 67 cm) (Ruiz-Pico et al., 2017), the Balearic Islands ($L_{\max}=60$ cm) (Rotllant et al., 2002), the eastern Ligurian Sea ($L_{\max}=63$ cm) (Rustighi et al., 2004) and the Ionian Sea ($L_{\max}=70.3$ cm) (D'Onghia et al., 1998). In contrast, L_{\max} of our study is lower than the largest specimen caught north off the Iberian Peninsula ($L_{\max}=81$ cm) (Casas and Piñeiro, 2000). The variability of L_{\max} is linked to different biotic and abiotic environmental parameters.

Due to sexual dimorphism in size in *P. blennooides* as reported by Cohen et al., (1990); Rotllant et al., (2002), most researchers treated growth separated by sex. However, greater forkbeard from Tunisian waters does not show sexual dimorphism in growth (Romdhani et al., 2016), even though differences in growth between sexes are a common feature among Phycidae (Casas and Piñeiro, 2000). Therefore, we combined sexes in this study.

Longevity of fish exploited by fisheries is one of the most critical biological parameters (Beverton, 1992). *P. blennooides* on the Algerian coast was found to live up to seven years (bottom trawl survey in 2003) or nine years (bottom trawl survey in 2004 and commercial fisheries), depending on the data source, in contrast to six years in Tunisia (Romdhani et al., 2016). This is much less than the 14 years found in the north and northwest of the Iberian Peninsula (Casas and Piñeiro,

2000) and the 11 years for individuals of 59 cm in the Strait of Sicily (Fiorentino et al., 2003a).

Compared to previous works, whatever the method and samples used in our study, all asymptotic length (L_{∞}) and t_0 estimates were lower than values obtained for Iberian Peninsula; conversely for K. Asymptotic length for combined sexes estimated in Tunisia was 65.73 cm (Romdhani et al., 2016) which is close to our L_{∞} values for bottom trawl survey in 2003 and commercial fisheries.

Conversely to K, t_0 in our study was different from values obtained for Tunisian coast (Romdhani et al., 2016) and the Strait of Sicily (Ragonese et al., 2004). Observed differences can be due to different size compositions of the populations (Romdhani et al., 2016) and method used for estimating growth parameters. These results also indicated that bias and precision were influenced by fish life history type, which may allow for standardization of field collection methods across a wide range of fish species. Any factor that acts to obscure modal structure makes length frequency analysis more difficult (Bjorndal and Bolten, 1995). Fish growth, i.e., the size increment with time, varies greatly with food quality and availability, temperature and other environmental factors and the fish will reach the different stages in development more dependent on size than on age (Amara and Lagardère, 1995; Aritaki and Seikai, 2004; Sæle and Pittman, 2010). Furthermore, factors include long spawning season, variation in individual growth rates that result in variation in length-at-age, cessation or near cessation of growth in older age classes, and high rates of exploitation (Bjorndal and Bolten, 1995). Geographic location and some environmental condition, such as the date and time of capture, index of condition, disease and parasites loads can also affect age estimates (Bagenal and Tesch, 1978).

The estimated age at 50% maturity corresponded to 3–4 years for individuals sampled by the bottom trawl survey in 2004 and 2–3 years for the bottom trawl survey in 2003 and commercial fisheries. This is in agreement with 3–4 years reported before for the Mediterranean Sea (Muus and Nielsen, 1999).

4.4 Exploitation

In this study, estimated total mortality values exceeded 1, similarly to values reported for the western Algerian coast (Benghali et al., 2014a) and Sicily (Ragonese et al., 2004) (Tab. 6). The estimates might have been influenced by the dominance of juveniles in our samples. Estimated natural mortality is comparable to Ragonese et al. (2004). The

reliability of estimated M was confirmed using the M/K ratio reported to be within the range of 1.12–2.25 for most fishes (Beverton and Holt, 1959). Natural mortality depends closely on growth parameters, which differ according to the approach used. Moreover, the stock structure of *P. blennooides* is complex and requires further studies (ICES, 2017). However, the main issue in estimating fishing mortality F from Z is the actual impossibility to get reliable, consistent, precise, unbiased and verifiable M estimates when dealing with “mature and long-time steady-state overfished” stocks (Ragonese and Jereb, 2018). This is the case for the majority of Mediterranean demersal fish stocks (Farrugio et al., 1993; Leonart and Maynou, 2003).

Demersal fisheries are characterized by high fishing pressure on few young age classes, which leaves only a reduced fraction of the adult population at sea (Fiorentino et al., 2003a). For *P. blennooides*, the amount of juveniles discarded by fisheries is larger than the landings of adult fishes (Lorance, 2012). Indeed, trawl mesh size affects stocks. A comparative analysis was made in the northern Tyrrhenian Sea to compare the catches and 0.3 kg were captured with 62.5 cm mesh size (Sbrana et al., 2007).

The presence of this species is very sporadic on the Algerian market, and the landed quantities are limited in space and time (Alioua et al., 2018). As immatures are present throughout the year in the catches, the annual sperm emissions with a peak of GSI in winter and summer, the short laying period (spring, summer) when the sexual activity of females is highest in spring with the absence of females able to lay eggs, suggest reproductive difficulties and therefore pressure on the population. As a result, egg fertilization is less frequent and can lead to poor recruitment and inefficient renewal of this stock. However, the development of a database with multi-year monitoring could permit estimating spawning stock biomass by modal prediction, taking into account the spawning period. Lastly, *P. blennooides* should be capable of renewal if caught individuals are larger than 30 cm.

5 Conclusion

Stock assessment of *P. blennooides* is necessary to define its status. The IUCN Red List considered it as Least Concern in 2015, but today, *P. blennooides* is no longer listed, known as “Not Evaluated” according to FishBase. Our study should be useful to design new scenarios for sustainable exploitation of Phycidae in the Mediterranean. We also suggest the use of mark and recapture techniques to determine age and analyse growth rates more accurately, to confirm that females grow faster than males.

Supplementary Material

Fig. S1. Length frequency of *P. blennooides* caught from 52 hauls in 2003 (A) and from 109 hauls in 2004 (B) (n: number of individuals).

Fig. S2. Linear model (LM) of log density of *P. blennooides* with depth (m) and longitude (°) caught by the bottom trawl surveys in 2003 (A1, A2) and 2004 (B1, B2) along the Algerian coast (*:significant).

Fig. S3. Residual plot of linear model (LM) of log density of *P. blennooides* with longitude (A1, B1) and depth (A2, B2) caught by the bottom trawl surveys in 2003 (A1, A2) and 2004 (B1, B2) along the Algerian coast.

Table S1. Sampling of *P. blennooides* from bottom trawl surveys.

Table S2. Sampling of *P. blennooides* from commercial fisheries (pooled sampling: 2013–2017).

Table S3. Density (ind/km²), biomass (kg/km²) and mean-weight (kg) of *P. blennooides* across depth (m) caught from bottom trawl surveys in 2003 and 2004.

Table S4. Density, biomass and mean-weight of *P. blennooides* by sectors caught from bottom trawl surveys in 2003 and 2004.

Table S5. Generalized additive model (GAM) of density (ind/km²) and biomass (kg/km²) of *P. blennooides* with longitude (°) caught from bottom trawl surveys in 2003 and 2004 along the Algerian coast.

The Supplementary Material is available at <https://www.alr-journal.org/10.1051/alr/2020021/olm>.

Acknowledgments. The authors would like to thank the master and PhD students of the Faculty of Biological Science especially KHELIFA Kenza, MOKHTARI Sonia, MANSEUR Hakim, BOUFEKANE Bilal, BENSARI Billel, LAMALI Imene, MABCOUT Narimene Ouiza and MOULAI Amina; for helping in collecting commercial samples and the histological study. We express our gratitude to the Department of Ecology and Environment (USTHB) for the internship financial at the Spanish institute of Palma (Instituto Español de Oceanografía). Also, we would like to express our acknowledgements to Verena Trenkel (co-editor-in-Chief, Aquatic Living Resources) and two anonymous referees for their useful comments.

References

- Alioua Z, Amira S, Derbal F, Rachedi M, Bahbah L, Zerouali-Khodja F. 2018. Diet composition and trophic level of greater forkbeard *Phycis blennooides* (Gadiform: Phycidae) from the Algerian coast. *Croat J Fish* 76: 135–144.
- Alioua Z, Amira S, Khames GEY, Fernandez-Arcaya U, Guijarro B, Ordines F, Massuti E, Zerouali-Khodja F. 2020a. Density, biomass and some biological parameters of the greater forkbeard, *Phycis blennooides* caught along the Algerian coast. SEANO. <https://doi.org/10.17882/76699>
- Alioua Z, Amira S, Semiane N, Zerouali-khodja F. 2020b. Morphohistology and histopathology of the digestive organs of the deep-water fish greater forkbeard, *Phycis blennooides*. *Fish Aquat Life* 28: 99–112
- Alonso-Fernandez A, Domínguez-Petit R, Bao M, Rivas C, Saborido-Rey F. 2008. Spawning pattern and reproductive strategy of female pouting *Trisopterus luscus* (Gadidae) on the Galician shelf of north-western Spain. *Aquat Living Resour* 21: 383–393.
- Amara R, Lagardère F. 1995. Taille et âge au début de la métamorphose chez la sole (*Solea solea* (L.)) du golfe de Gascogne. *ICES J Mar Sci* 52: 247–56

- Amira S, Alioua Z, Harchouche K. 2019. Gonadal development and fecundity of bogue *Boops boops* (Linnaeus, 1758) (Sparidae) on the central Algerian coast. *Turkish J Zool* 43: 12–29
- Aritaki M, Seikai T. 2004. Temperature effects on early development and occurrence of metamorphosis-related morphological abnormalities in hatchery-reared brown sole *Pseudopleuronectes herzensteini*. *Aquaculture* 240: 517–530.
- Ashton WD. 1972. The Logit Transformation with Special Reference to Its Uses in Bioassay. New York: Hafner Publishing Co., Inc.
- Asthorsson OS, Pálsson J. 2000. New fish records and records of rare southern species in Icelandic waters in the warm period 1996–2005. ICES CM 2006/C: 20
- Bagenal TB, Tesch FW. 1978. Age and growth. In *Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook*, ed. T Bagenal, pp.101–136. Oxford, UK. No. 3. Bla ed.
- Benghali SM. 2015. *Biologie et dynamique de la population de la moustelle blanche Phycis blennoides (Brünnich, 1768) pêchée dans la région de Mostaganem*. University of Oran, Algeria. PhD Thesis, University of Oran, Algeria, 142p.
- Benghali SMEA, Mouffok S, Kherraz A, Boutiba Z. 2014a. Reproductive biology and growth of greater forkbeard *Phycis blennoides* (Brünnich, 1768) in Western Algerian Coasts (Osteichthyes, Gadidae). *J Biol Environ Sci* 2014: 389–98
- Benghali SMEA, Mouffok S, Kherraz A, Boutiba Z. 2014b. Some Aspects on the Reproductive Biology of Greater Forkbeard *Phycis blennoides* (Brünnich, 1768) in Western Algerian Coasts (Osteichthyes, Gadidae). *J Acad* 4: 94–98
- Bertrand JA, Gil de Sola L, Papaconstantinou C, Relini G, Souplet A. 2002. The general specifications of the MEDITS surveys. *Sci Mar* 66: 9–17.
- Beverton RJH. 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. *J Fish Biol* 41: 137–60
- Beverton RJH, Holt SJ. 1959. *A Review of the Lifespans and Mortality Rates of Fish in Nature, and Their Relation to Growth and Other Physiological Characteristics*. London. Ciba found ed.
- Bjorndal KA, Bolten AB. 1995. Comparison of length frequency analyses for growth parameters for a population of green turtles. *Herpetologica* 52: 160–67
- Bouaziz A, Kerzabi F, Brahmi B. 2014. Impact of the natural mortality (M) variability on the evaluation of the exploitable stock of sardine, *Sardina pilchardus* (Actinopterygii: Clupeiformes: Clupeidae) of the central region of the Algerian coast. *Acta Ichthyol Piscat* 44: 87–97
- Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre-Barbieri SK. 2011. A standardized terminology for describing reproductive development in fishes. *Mar Coast Fish* 3: 52–70
- Campillo A. 1992. Les pêcheries françaises de Méditerranée: synthèse des connaissances. *IFREMER Inst Fr Rech pour l'Exploitation la Mer*. 206
- Cartes JE, Dallarés S, Padrós F, Castañeda C, Moyà-Alcover CM, et al. 2016. The parasite community of *Phycis blennoides* (Brünnich, 1768) from the Balearic Sea in relation to diet, biochemical markers, histopathology and environmental variables. *Deep Sea Res Part I Oceanogr Res Pap* 118: 84–100
- Casas JM, Piñeiro C. 2000. Growth and age estimation of greater fork-beard (*Phycis blennoides* Brünnich, 1768) in the north and northwest of the Iberian Peninsula (ICES Division VIIIc and IXa). *Fish Res* 47: 19–25
- Clarke MW. 2005. A life history approach to the assessment of deep-water fisheries in the northeast Atlantic. *B. Deep Sea 2003 Conf. Gov. Manag. Deep. Fish. Part I Conf. Reports. Publisher FAO*. 153–165
- Cohen DM, Inada T, Scialabba N. 1990. Gadiform Fishes of the World: An annotated and illustrated catalogue of Cods, Hakes, Grenadiers and other Gadiform fishes known to date. *FAO Fish Synopsis* 125: 442
- D’Onghia G, Lloris D, Politou C-Y, Sion L, Dokos J. 2004. New records of deep-water teleost fish in the Balearic Sea and Ionian Sea (Mediterranean Sea). *Sci Mar* 68: 171–183
- D’Onghia G, Tursi A, Maiorano P, Matarrese A, Panza M. 1998. Demersal fishassemblages from the bathyal grounds of the Ionian Sea (middle-eastern Mediterranean). *Ital J Zool* 65: 287–292.
- Dallarés S, Moyà-Alcover CM, Padrós F, Cartes JE, Solé M, et al. 2016. The parasite community of *Phycis blennoides* (Brünnich, 1768) from the Balearic Sea in relation to diet, biochemical markers, histopathology and environmental variables. *Deep Res Part I Oceanogr Res Pap* 118: 84–100
- Djabali F, Mehailia A, Koudil M, Brahmi B. 1994. A reassessment of equations for predicting natural mortality in Mediterranean teleosts. *ICLARM Q* 33–34
- FAO. 2005. Deep Sea 2003: Conference on Governance and Management of deep-sea fisheries., p. 718. <https://books.google.fr/books?id=iWcTsC2LQ1cC&pg=PA158&lpg=PA158&dq=Phycis+blennoides+commercially+important&source=bl&ots=ogPkevJhd0&sig=0yxtighm22YaHIUryIEswz7KcxY&hl=fr&sa=X&ved=0ahUKewiJKKk-JTbAhUKtBQKHW1FC08Q6AEIRDAD#v=onepage&q&f=false>
- Farrugio H, Oliver P, Biagi F. 1993. An overview of the history, knowledge, recent and future research trends in Mediterranean fisheries. *SCI MAR* 57: 105–119
- Fernandez-Arcaya U, Murua H, Drazen JC, Recasens L, Ramirez-LLorda E, et al. 2013. Reproductive strategies of NW Mediterranean deep-sea fish community. *Rapp Comm int Mer Médit* 40: 458
- Fiorentino F, Gancitano S, Giusto GB, Rizzo P. 2003a. Assessing longevity of gadoids in the strait of Sicily on the basis of otolith reading. *Biol Mar MEDITS* 10: 814–818.
- Fiorentino F, Garofalo G, De Santi A, Bono G, Giusto GB, Norrito G. 2003b. Spatio-temporal distribution of recruits (0 group) of *Merluccius merluccius* and *Phycis blennoides* (Pisces, Gadiformes) in the Strait of Sicily (Central Mediterranean). *Hydrobiologia* 503: 223–236.
- Froese R, Pauly D, FishBase, [Online], Available at: <https://www.fishbase.de/summary/1340> [22 December 2019]
- Gallardo-Cabello M. 1986. Analisis del crecimiento de la brotola *Phycis blennoides* (Brünnich 1768) en el Mediterraneo occidental (Pisces: Gadidae). *An del Inst Ciencias del Mar y Limnol*.
- Gayanilo F, Sparre P, Pauly D. 2005. FAO-ICLARM stock assessment tools II (FiSAT II). Revised version. *User’s Guid. FAO Comput. Inf. Ser.* No. 8, Rev: 262
- Gordon JDM, Merrett NR, Haedrich RL. 1995. Environmental and biological aspects of slopedwelling fishes of the north Atlantic. In *Deep-Water Fisheries of the North Atlantic Oceanic Slope. NATO ASI Series*, p. Vol. 296. 1–26. Hopper, A. ed.
- ICES. 2017. Greater forkbeard (*Phycis blennoides*) in the Northeast Atlantic.
- Leonart J, Maynou F. 2003. Fish stock assessments in the Mediterranean: state of the art. *Sci Mar* 67: 37–49
- Lloret J, Leonart J. 2002. Recruitment dynamics of eight fishery species in the northwestern Mediterranean Sea. *Sci Mar* 66: 77–82.
- Lorance P. 2012. Répartition bathymétrique des espèces dites profondes. Ifremer, 23p.
- Macpherson E. 1978. Regimen alimentario de *Phycis blennoides* (Brünnich) and *Antonogadus megalokynodon* Kolombatovic

- (Pisces: Gadidae) en el Mediterraneo occidental. *Investig Pesq* 42: 455–66
- Mangiafico S. 2018. rcompanion: Functions to Support Extension Education Program Evaluation. R package version 2.0.0. <https://CRAN.R-project.org/package=rcompanion>
- Massuti E, Gordon JDM, Morata J, Swan SC, Stefanescu C, Merrett NR. 2004. Mediterranean and Atlantic deep-sea fish assemblages: differences in biomass composition and size-related structure. *Sci Mar* 68: 101–115
- Massuti E, Morales-Nin B, Lloris D. 1996. Bathymetric distribution and recruitment patterns of *Phycis blennooides* (Pisces: Gadidae) from the slope of the northwestern Mediterranean. *Sci Mar* 60: 481–488.
- Matarrese A, D'onghia G, Basanisi M, Mastrototaro F. 1998. Spawning and recruitment of *Phycis blennooides* (Brünnich, 1768) (Phycidae) from the north-western Ionian sea (Middle eastern Mediterranean). *Ital J Zool* 65: 203–209
- Morley SA, Mulvey T, Dickson J, Belchier M. 2004. The biology of the bigeye grenadier at South Georgia. *J Fish Biol* 64: 1514–1529.
- Morte MS, Redón MJ, Sanz-Brau A. 2002. Diet of *Phycis blennooides* (Gadidae) in relation to fish size and season in the western Mediterranean (Spain). *Mar Ecol* 23: 141–155
- MPRH. 2017. *Les données statistiques sur la production nationale des ressources halieutiques au niveau du port d'Alger en 2017*.
- Muus BJ, Nielsen JG. 1999. Sea Fish Scandinavian Fishing Year Book. Hedeheusene, Denmark.
- Pauly D. 1979. *Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula*. Christian-Albrechts Univ. Kiel, Germany.
- Pauly D. 1983. Some simple methods for the assessment of tropical fish stocks. *FAO Fish Tech Pap* 234: 52.
- Pauly D, Munro JL. 1984. Once more on the comparison of growth in fish and invertebrates. *Fishbyte* 2: 1–21.
- Pope LP, Lochmann SEL, Young MK. 2010. Methods for assessing fish populations. In *Inland Fisheries Management in North America*, eds. MC Quist, WA Hubert, pp. 325–351. Bethesda, Maryland. 3rd editio ed.
- Quetglas A, Merino G, González J, Ordines F, Garau A, et al. 2017. Harvest Strategies for an Ecosystem Approach to Fisheries Management in Western Mediterranean Demersal Fisheries. *Front Mar Sci* 4(106): 1–16
- R Core Team. 2017. R: A Language and Environment for Statistical Computing. <https://www.R-project.org/>
- Ragonese S, Andreoli MG, Bono G, Giusto GB, Rizzo P, Sinacori G. 2004. Overview of the available biological information on demersal resources of the Strait of Sicily. In *Report of the Expert Consultation on the Spatial Distribution of Demersal Resources in the Straits of Sicily and the Influence of Environmental Factors and Fishery Characteristics*, pp. 67–74
- Ragonese S, Jereb P. 2018. Total (Z) and natural (M) mortality computation by using the actual (exploited) and expected (unexploited) maximum age: the case of the Mediterranean demersal fish. *NTR-ITPP*. 84: 29
- Rideout RM, Morgan MJ, Lilly GR. 2006. Variation in the frequency of skipped spawning in Atlantic cod (*Gadus morhua*) off Newfoundland and Labrador. *J Appl Sci Eng* 63: 1101–1110
- Rideout RM, Tomkiewicz J. 2011. Skipped spawning in fishes: More common than you might think. *Mar Coast Fish* 3: 176–189
- Roland W. 2014. L'industrie de la Pêche et de l'Aquaculture en Algérie.
- Romdhani A, Ktari M-H, Dufour J-L, Mahe K, Francour P. 2016. Growth and age estimation of the greater forkbeard, *Phycis blennooides* (Actinopterygii: Gadiformes: Phycidae), from the Gulf of Tunis (central Mediterranean). *Acta Ichthyol Piscat* 46: 25–32
- Rotllant G, Moranta J, Massuti E, Morales-Nin B. 2002. Reproductive biology of three gadiform fish species through the Mediterranean deep-sea range (147–1850 m). *Sci Mar* 66: 157–166
- Ruiz-Pico S, Blanco M, Fernández-Zapico O, Preciado I, Punzón A, Velasco F. 2017. Results on Greater forkbeard (*Phycis blennooides*), Bluemouth (*Helicolenus dactylopterus*), Spanish ling (*Molva macrophthalma*) and Red seabream (*Pagellus bogaraveo*) of the Northern Spanish Shelf Groundfish Survey. Copenhagen.
- Rustighi C, Casotti M, Voliani A. 2004. Note on the biology and spatial distribution of *Phycis blennooides* in the South-eastern Ligurian Sea. *Biol Mar Medit*. 11: 624–628
- Saborido-Rey F, Trippel EA. 2013. Fish reproduction and fisheries. *Fish Res* 138: 1–4
- Sæle, Pittman KA. 2010. Looking closer at the determining of a phenotype? Compare by stages or size, not age. *J Appl Ichthyol* 26: 294–297
- Sanchez-Vidal A, Ramirez-Llodra E, Aguzzi J, García JA, López-Fernández P, et al. 2013. Reproductive biology and recruitment of the deep-sea fish community from the NW Mediterranean continental margin. *Prog Oceanogr* 118: 222–234
- Santos RVS, Silva WMML, Novoa-Pabon AM, Silva HM, Pinho MR. 2019. Long-term changes in the diversity, abundance and size composition of deep sea demersal teleosts from the Azores assessed through surveys and commercial landings. *Aquat Living Resour* 32: 1–20
- Sartor P. 1995. Regime alimentare di osteitti Gadiformi nel mar Tireno settentrionale. *Atti della Soc Toscana Sci Nat di Pisa*. 102: 59–67
- Sbrana M, Belcari P, Ranieri S, Sartor P, Viva C. 2007. of European hake (*Merluccius merluccius*, L. 1758) taken with experimental gillnets of different mesh sizes in the northern Tyrrhenian Sea (western Mediterranean). *Sci Mar* 71: 47–56
- Siegfried KI, Sansó B. 2006. Two Bayesian methods for estimating parameters of the von Bertalanffy growth equation. *Environ Biol Fishes*. 77: 301–308
- Sorbe J-C. 1977. Regime alimentaire de *Phycis blennooides* (Brunnich 1768) dans le sud du Golfe de Gascogne. *Rev des Trav l'Institut des pêches Marit* 41: 271–281
- Torres MA, Ramos F, Sorbino I. 2012. Length weight relationships of 76 species from the Gulf of Cadiz (SW Spain). *Fish Res* 127–128: 171–175.
- Viana F, Acuña A, Berois N, Danulat E. 2000. Testes morphology and reproductive aspects of male Brazilian codling (*Urophycis brasiliensis* Kaup 1858). *J Appl Ichthyol* 16: 134–135
- Vieira AR, Sequeira V, Neves A, Paiva RB, Gordo LS. 2016. Reproductive strategy of forkbeard, *Phycis phycis*, from the Portuguese coast. *Helgol Mar Res* 70: 3
- Wood SN. 2006. Review: Generalized Additive Models: An Introduction with R. *J Stat Softw* 16: 1–2
- Wood SN. 2017. *Generalized Additive Models: An Introduction with R Second Edition*. Boca Raton: CRC/Chapman and Hall. Second ed. 476p.

Cite this article as: Alioua Z, Amira S, Khames GEY, Fernandez-Arcaya U, Guijarro B, Ordines F, Massuti E, Zerouali-Khodja F. 2020. Population structure, reproduction and exploitation of the greater forkbeard *Phycis blennooides* (Brünnich, 1768) from the Algerian basin. *Aquat. Living Resour.* 33: 20