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Fisheries Status and Growth of *Phycis blennoides* in Algerian Waters Using Length-based Methods (2003–2019): Signs of Stock Decline

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Abstract

The greater forkbeard (*Phycis blennoides*) is a demersal species of ecological and commercial importance along the Algerian coast, yet its stock status remains poorly understood due to limited biological and fishery data. This study represents the first application of the Length-Based Bayesian Biomass (LBB) estimator to assess the population dynamics and fisheries status of *P. blennoides* stocks in Algerian waters. Length frequency data from 8700 individuals collected during six scientific surveys, complemented by growth and length-weight data from 1050 individuals captured by commercial fisheries across 11 Algerian ports (i.e. Annaba, Azeffoun, Dellys, Cap Djinet, Zemmouri, Bouharoun, Algiers, La Madrague, Cherchell, Tenes and Mostaganem) between 2013 and 2017, were analyzed. Growth parameters were estimated using multiple software and empirical methods, revealing positive allometric growth and a growth performance index ϕ' was 3.124. Using length frequency distribution (LFD) from scientific survey and commercial fisheries as input data, the LBB estimated a length at first capture of 7.65 cm and indicated severe stock depletion, classifying the population as collapsed with a biomass ratio (B/B_{msy}) of 0.008 and fishing mortality greatly exceeding natural mortality (F/M= 23). The results suggest the urgent need for fisheries management interventions, including mesh size regulation and protection of juveniles, to promote stock recovery. Considering potential influences of environmental stressors and climate warming on distribution and abundance, continuous monitoring and further research are recommended. This study provides critical biological reference points and a baseline stock assessment to support sustainable management of *P. blennoides* in the southwestern Mediterranean.

Introduction

Hakes, cods, forkbeards, and greater forkbeards are key components of marine demersal ecosystems and are economically vital to fisheries. Ecologically, these species act as mid- to top-level predators, regulating benthic community structure and maintaining trophic balance through their diverse diets. In the Mediterranean Sea, the European hake (*Merluccius merluccius*) ranks among the most valuable demersal fish, generating high commercial catches and contributing to energy transfer across benthic and pelagic zones (Slimani et al., 2023). Similarly, the greater forkbeard (*Phycis blennoides*) plays an important ecological role in deeper shelf and upper slope communities as a carnivorous predator feeding on fish, crustaceans, cephalopods, and benthic invertebrates such as polychaetes placing it at a high trophic level (Alioua et al., 2018).

P. blennoides is mainly caught by demersal trawls and longline, of the continental slope (Matarrese et al., 1998). It exhibits a broad geographic distribution across the eastern Atlantic Ocean (Clarke, 2005) extending from Norway and Iceland (Astthorsson and Palsson, 2000) to Cape Blanc (West Africa), including the Mediterranean Sea (Cohen et al., 1990; Massutí et al., 1996; Rotllant et al., 2002; Ragonese et al., 2004; Romdhani *et al.*, 2013; Dallarés et al., 2016). This species inhabits sandy and muddy bottoms distributed over a wide range from shallow waters (Cohen et al., 1990) to deep continental slopes 1850 m depth (Rotllant et al., 2002). It showed a depth related size segregation with larger individuals found between 600-800 m and the smaller ones at shallower depths (Alioua et al., 2020a). Although *P. blennoides* is largely considered by-catch with low commercial value in the Gulf of Lion and Valencia (Sorbe, 1977; Morte et al., 2002), it holds greater economic interest along the Turkish coast (Tokaç et al., 2018), Catalan Sea (Massutí et al., 1996), and Algerian coast. However, landings remain limited in the central Algerian region, with discarded juveniles frequently recorded in ports such as Bouharoun (Alioua et al., 2018). Several factors including pollution, climate-driven distribution shifts, overexploitation, and discard fishing practices may contribute to the scarcity of *P. blennoides* landings in Algeria (Alioua et al., 2022). Notably, populations have been reported to move northwards with increasing biomass in colder shelf waters off Iceland (Astthorsson et al., 2012). Health assessments have also highlighted histopathological lesions (Alioua et al., 2020) and heavy metal accumulation (Alioua et al., 2022) in this species, raising concerns about environmental stressors.

Information on age, growth and reproductive biology of *P. blennoides,* is of great importance. Previous research on growth estimation (Casas and Piñeiro, 2000 and Romdhani et al., 2016) as well as otolith biometry-fish size relationships (Girgin and Başusta, 2023), diet composition (Macpherson, 1978 ;Morte et al., 2002; Sartor, 1995; Alioua et al., 2018) histopathology of its digestive organs (Alioua et al., 2020), reproduction (Rotllant et al., 2002;Benghali et al., 2014a;Alioua et al., 2020), recruitment pattern (Matarrese et al., 1998) and bathymetric distribution (Massutí et al., 1996) has been carried out in Mediterranean waters. However, stock assessments remain scarce, especially for data-poor fisheries such as those in Algeria.

In recent years, there is a growing need for stock assessment approaches suitable for data-limited situations (Armelloni et al., 2021; Barua et al., 2023; Meissa et al., 2021). Among these, the Length-Based Bayesian Biomass estimator (LBB) has received attention due its simplicity and efficiency, as it relies exclusively on length-frequency data (Wang et al., 2020b). This method has been widely applied to various fisheries, including the Indonesian deep demersal fishery (Dimarchopoulou et al., 2021), Northwest Pacific stocks (Wang et al., 2020a), the Bohai and Yellow Seas (Wang et al., 2020b) as well as Chinese, Mauritanian and Mediterranean stocks (Liang et al., 2020; Zhang et al., 2020 ; Meissa et al., 2021; Dia et al., 2022;Froese et al., 2018) and the Yangtze River Estuary (Zhai et al., 2022). Additionally, broader ecosystem-based approaches such as EcoScope introduce innovative assessment methods for data-poor fisheries and aim to integrate them alongside with biodiversity and conservation status across European Seas ("EcoScope Promoting effective and efficient ecosystem-based approaches to fisheries management," 2022).

In Algeria, artisanal fisheries predominate, with limited access to reliable fishery data. The Application of the LBB method offers an opportunity to assess *Phycis blennoides*, a species that has not yet been evaluated locally. Classified as "Not Evaluated" according to Froese and Pauly (2019), and lacking official assessment from national fisheries authorities. Evaluating the stock status of *P. blennoides* is crucial for designing new scenarios to determine sustainable fishing levels, guiding sustainable exploitation and improving the management of Phycidae resources in the Mediterranean. Thus, the present study aims to improve knowledge on the stock status of *Phycis blennoides* along the Algerian coast. It estimates key population parameters, including growth and length-at-capture, derives reference biomass indicators using the LBB model, and defines sustainable fishing levels. The results provide essential biological and fishery-specific information to support effective policy implementation and can serve as priors for future stock assessment models in the region. The specific objectives of this paper are to: (1) estimate growth and biological parameters including length-weight relationships, (2) apply the LBB method to derive fisheries reference points such as biomass ratios (B/B_0, B/B_{msy}), and (3) assess the current stock status of *P. blennoides* along the Algerian coast to inform data-poor fishery management strategies and provide useful insights on its stock.

These findings provide key insights that will improve fisheries management efficiency and sustainability and offer a valuable case study for evaluating fish stocks under severe data limitations in small-scale fisheries in Algeria.

Material and Methods

Study Area

The Algerian coast extends over 1,622 km of the south-western Mediterranean coastline from the Moroccan to the Tunisian borders (Grimes et al., 2018). It is characterized by artisanal fisheries, which use relatively small amounts of capital and energy, relatively small (or none) fishing vessels, conducting short fishing trips close to the shore and mainly working for local consumption. In terms of fleet concentration, the West sector has the highest number of trawlers (347), followed by the Centre (183) and the East (158) (MPRH, 2017).

Sampling

Length frequency data (in cm) of 8700 individuals of *P. blennoides* sampled along the Algerian coast. These samples were obtained from six bottom trawl surveys conducted across three sectors (West, Centre, East) along the Algerian coast (Figure 1). They were performed in 2003 and 2004 by the Spanish institute of Oceanography (IEO) in collaboration with the Algerian Ministry of fisheries and in 2012, 2016, 2017 and 2019 by the National Research Centre and Development of Fisheries and Aquaculture (CNRDPA) (Table 1). Additionally, 1050 individuals of *P. blennoides* were collected by commercial fisheries (Figure 2) from 11 Algerian Ports (i.e. Annaba, Azeffoun, Dellys, Cap Djinet, Zemmouri, Bouharoun, Algiers, La Madrague, Cherchell, Tenes and Mostaganem), between 2013 and 2017 in three sectors. The western area (W) from Mostaganem to Ghazaouet, central area (C) from Tenes to Bejaia and eastern area (E) from Bejaia to Annaba. According to the fishermen of the Algerian ports, *P. blennoides* was captured from artisanal fisheries by longlines and mostly by bottom-trawl between 100-1300 m. A random sampling was conducted from December 2013 to June 2015. Additional sampling targeting large individuals was carried out during 2016 and 2017 (February to May 2016; December 2016; March to May 2017) to cover all size categories. Upon arrival at the laboratory, individuals were treated. For each individual, the total lengths (measured from the tip of the snout to the tip of the caudal fin: TL, ±1 cm) and total weights (TW, ±1 g) were recorded.

Growth Parameters for Commercial Fisheries

The asymptotic length (L_{inf}) and Z / K ratio for commercial fisheries were estimated using Powell-Wetherall size structure analysis implemented in FISAT II 1.2.0 (Gayanilo et al., 2005) and LFDA 5.0 (Kirkwood et al., 2001) software. The growth rate (K) was calculated from the empirical relationship with the growth performance index (ϕ') and the asymptotic length Linf, based on Pauly & Munro (1984) 's equation as follow: $\phi' = \log_{10} K + 2 \log_{10} L_{inf}$. For a comparison, we also used the method of (Froese & Binohlan, 2000) to estimate the asymptotic length (L_{inf}) from the maximum observed length (L_{max}) and K from the length (L_{50}) and age (t_{50}) at first maturity as follow: $\log_{10} L_{inf} = 0.044 + 0.9841 \times \log_{10}(L_{max})$; $K = -\ln(1 - \frac{L_{50}}{L_{inf}})/(t_{50} - t_0)$. The parameter t_0 is included to adjust the equation for the initial size of the organism and is defined as age at which the organisms would have zero size. The t_0 was derived using (Pauly, 1979) expressed as: $\log_{10}\text{-}t_0 = -0.3922 - 0.2752 \times \log_{10} L_{inf} - 1.038 \log_{10} K$.

We compared the growth parameters obtained by FISAT II, LFDA and Froese and Binohlan 's method and which approach or software performs adequate growth parameters of *P. blennoides.*

Length-Weight Relationship for Commercial Fisheries

The length-weight relationship of *P. blennoides* was analyzed to predict individual weights from measured lengths and evaluate the species' condition. It

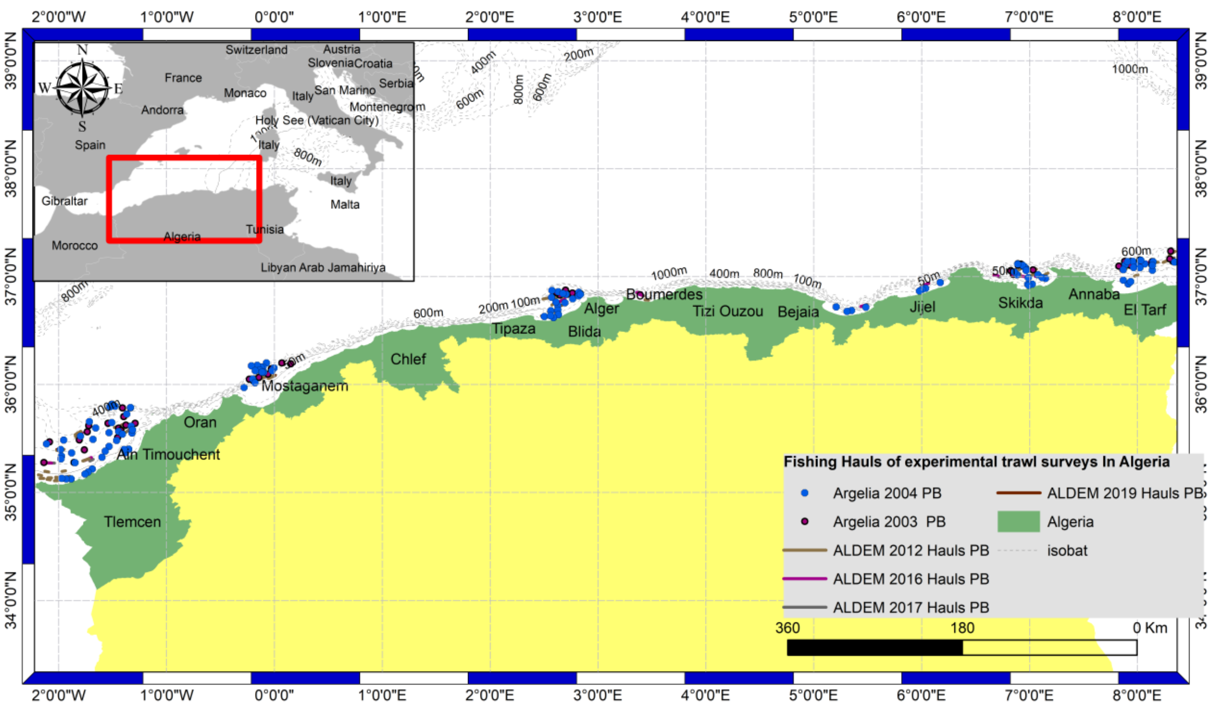


Figure 1. *P. blennoides* caught from six scientific surveys and detailed sampling points by sectors (W: West, C: Center, E: East).

Table 1. *P. blennoides* sampling design along the Algerian coast

Data source	Year	Depth	Caught	Halls	Bottom trawl	n	Analysis	L_{min}	L_{max}	Suitability for LBB
ARGELIA0203-DP	2003	200-800	170- 779	55	R/V Vizconde de Eza. (GOC-73)	2064	LBB	3	61	Yes
ARGELIA0204-DP	2004	40-800	170-759	116	R/V Vizconde de Eza. (GOC-73)	1346	LBB	4	52	Yes
Commercial fisheries	2013	[redacted]	[redacted]	[redacted]	[redacted]	27	Growth-LWR	17.6	30.4	No
Commercial fisheries	2014	[redacted]	[redacted]	[redacted]	[redacted]	666	Growth- LWR LBB	9.5	53.3	Yes
Commercial fisheries	2015	[redacted]	[redacted]	[redacted]	[redacted]	271	Growth-LWR	5.7	54.5	No
Commercial fisheries	2016	[redacted]	[redacted]	[redacted]	[redacted]	55	Growth-LWR	15.6	62.7	No
Commercial fisheries	2017	[redacted]	[redacted]	[redacted]	[redacted]	31	Growth-LWR	18.6	39.3	No
Commercial fisheries (Total)	2013-2017	[redacted]	100-1300	na	[redacted]	1050	Growth-LWR	5.7	62.7	No
ALDEM 2012	2012	23-780	[redacted]	100	Grine Belkacem	2367	LBB	6.5	42.5	Yes
ALDEM 2016	2016	25.9-653	[redacted]	62	Grine Belkacem	563	LBB	6	14	Yes
ALDEM 2017	2017	28-652	[redacted]	60	Grine Belkacem	707	LBB	7.5	30.5	No
ALDEM 2019	2019	26.5-531	[redacted]	67	Grine Belkacem	987	LBB	7	41	Yes

ARGELIA: Bottom trawl survey performed by the Spanish Institute (IEO) in collaboration with the Algerian Ministery of Fishereies. **ALDEM:** Demersal fisheries resources assessment campaign performed by the National Research Centre and Development of Fisheries and Aquaculture (CNRDPA). **Depth:** Depth of investigation in (m). **Caught:** Depth of caught of *P. blennoides* (m), **Halls:** Number of hauls. **na:** not available. **Bottom trawl:** trawl engine used in the sampling. **n:** Number of individuals. **LBB:** Length-Based Bayesian Biomass estimation method. **LWR:** length weight relationship. **L_{min}:** minimum length. **L_{max}:** maximum length (cm).

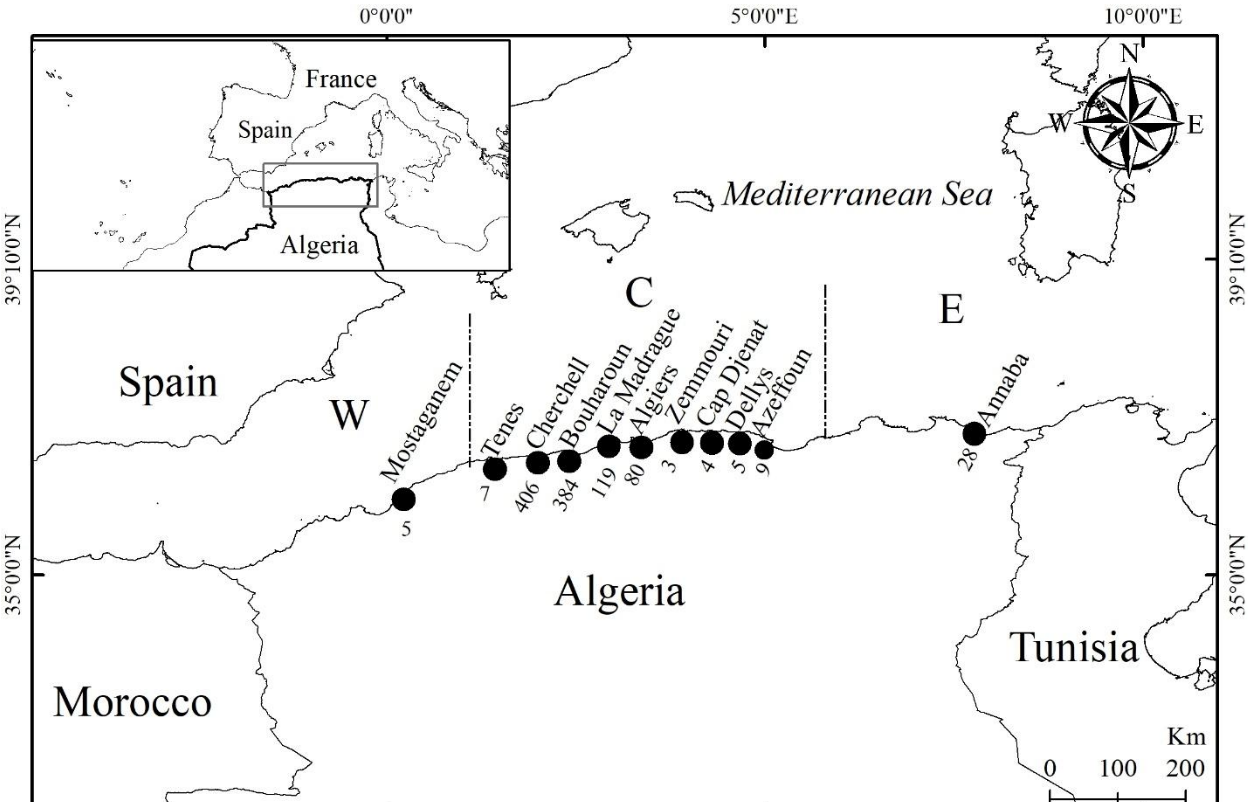


Figure 2. Sampling of *P. blennoides* from commercial fisheries by sectors with number of individuals in each port (W: west, C: Centre, E: East).

was fitted the exponential model $TW=aTL^b$ (Ricker, 1973), transformed to a linear regression after logarithmic conversion using a least squares regression as follow:

$$\text{Ln TW} = \text{b LnTL} + \text{Lna}$$

Where, b is the slope, Ln a is the intercept.

The retro-transformation of the mean value on the logarithmic scale by the exponential, underestimates the mean value on the initial scale (Ogle, 2013). To correct the mean value on the initial scale, a log-normal adjustment was applied to predict the weight at the original scale. We verified isometric versus allometric growth using hypothesis testing. If a fish grows without changing its body shape, it shows isometric growth (b = 3). When $b \neq 3$, it indicates allometric growth; b>3 means the fish becomes "plumper" as it grows. The HoCoef test was used to determine whether growth was isometric or allometric, with significance set at P<0.05, using the FSA package (Ogle et al., 2018) implemented on Rstudio version 1.1.383 (Core Team, 2017). The 95% confidence interval (CI) for the slope parameter (b) and associated p-values were calculated.

Linear and Ponderal Growth for Commercial Fisheries

Growth trajectories were modeled using the von Bertalanffy equation (von Bertalanffy, 1938) expressed as:

$$L_t = L_{inf}\left(1-e^{-k(t-t_0)}\right).$$

Lt is the expected or mean length at time (or age) t, L_{inf} is the mean asymptotic length, K is the coefficient of the body growth rate ($year^{-1}$) and t_0 is a modelling artifact, representing the age where the mean length was zero. The weight growth curve was derived from the total weight-total length relationship providing estimates of expected body mass across ages for *P. blennoides* as follow:

$$W_t = W_{inf}\left(1-e^{-K(t-t0)}\right)^b$$

Where W_t is the weight at t time. The asymptotic weight Winf was estimated by the exponent b from the length-weight regression as follow:

$$Winf = a\, L_{inf}^{\ b}$$

Length-Based Bayesian Biomass Estimation Method (LBB)

The length-based Bayesian biomass (LBB) method enables assessment of data-poor stocks (Wang *et al.,* 2020b) based on length frequency data (LFD) (Froese et al., 2018). For this study, we used representative LFD collected from scientific surveys (ARGELIA 2003, ARGELIA 2004; ALDEM 2012, ALDEM 2016, ALDEM 2017, ALDEM 2019) and from commercial landings sampled monthly over one year (January–December 2014). Since the sampling process may affect data accuracy (Sultana et al., 2022), we carefully selected datasets to ensure reliability. Combining long-term survey data with one full annual cycle of commercial landings aimed to provide a more representative length-frequency distribution while minimizing potential sampling errors.

The following parameters can be obtained such as: the asymptotic length (L_{inf}), length at first capture L_c and optimal capture L_{c_opt}, relative natural mortality (M/K) and relative fishing mortality (F/K). Standard fisheries equations were used to approximate current exploited biomass relative to unexploited biomass (B/B_0) and maximum sustainable yield (B/B_{msy}) (Froese et al., 2018) in addition to yield per recruit (Y/R') (Froese et al., 2019).

In this method, it is assumed that the growth in length follows von Bertalanffy. When the species are completely selected by the gear, the curve is a function of total mortality (Z) relative to K expressed by the equation:

$$N_L = N_{Lstart}\left(\frac{L_{inf} - L}{L_{inf} - L_{start}}\right)^{\frac{Z}{K}}$$

Where, N_L is the number of *P. blennoides* survivors to length L, N_{Lstart} is the number at length L_{start} with all individuals entering the gear are retained by the trawl, and Z/K is the ratio of the total mortality Z to somatic growth rate. When a species has more than one year of length frequency data, the catch in numbers are made comparable between years by dividing both sides of the N_L equation (Liang et al., 2020). The lengths affected by partial selection are a function of the trawl selection curve, as given by the ogive (Froese et al., 2018) described as follow:

$$S_L = \left(\frac{1}{1 + e^{-\alpha(L-Lc)}}\right)$$

The fraction of individuals (S_L) is retained by the gear at length L, and α describes the steepness of the ogive. The length at which cohort biomass is at maximum can be obtained by the following equation:

$$L_{opt} = L_{inf}\left(\frac{3}{3+\frac{M}{K}}\right)$$

To calculate a proxy for the relative biomass that can produce maximum sustainable yield, the mean length at first capture that maximizes catch and biomass $Lc_{\_opt}$ is described as:

$$Lc_{\_opt} = \frac{L_{inf}\left(2+3=\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)}.$$

The LBB parameters were estimated by a Bayesian Monte-Carlo Markov Chain (MCMC) approach, implemented in the JAGS program (Plummer, 2003 *in* Froese et al., 2018; Froese et al., 2019), a Bayesian Gibbs sampler software. The analysis was performed in Rstudio version 4.2.0 (R Core Team, 2022) following the LBB user guide available in Geomar repository (https://oceanrep.geomar.de/id/eprint/44832/). All other input parameters were kept at their default values as described by (Froese et al., 2018). The status of *P. blennoides* was defined in reference to B/B_{MSY} and F/M and thresholds (Palomares et al., 2018 ; Kindong et al., 2022; Zhai et al., 2022) (Table 2).

Results

Fish size of *P. blennoides* from commercial fisheries ranged from 5.7 to 62.7 cm in total length and weighted from 1.27 to 1969.3 g in total weight, Figure 3). Commercial samples were mainly composed of medium and small-sized *P. blennoides.* Most individuals caught belonged to the 21–23 cm class, according to the length frequency distribution**.** The large size with specimens greater to 30 cm were rare in the commercial fisheries, with few individuals between 40 and 62 cm (Figure 3).

Growth Parameters

The commercial *P. blennoides* specimens ranged from 5.7 to 62.7 cm in length and 1.27 to 1969.3 g in weight. Most individuals belonged to the 21–23 cm class; specimens over 30 cm were rare. Table 3 summarizes the estimated growth parameters. The maximum length observed for *P. blennoides* sampled in this study was 62.7 cm. Its growth performance index ɸ' was 3.12. Growth parameters obtained for this population were different according to the used approach. The Powell-Wetherall method (LFDA software) yielded the highest estimate for L_{inf}, while values from FISAT II and Froese & Binohlan's approach were closely aligned (Table 3). Growth rate (K) and t_0 estimates were also consistent between FISAT II and Froese & Binohlan's method, indicating reliability across approaches (Table 3).

Table 2. Definition of fish stock status using B/B_{MSY} and F/M ratio

B/B_{MSY}	F/M	Stock Status
≥1	≤1	Healthy stocks (Zhai et al., 2022; (Kindong et al., 2022)
0.5–1.0	≤1	Recovering stocks
<0.5	≤1	Stocks outside of safe biological limits
$0.8< B/B_{MSY} \leq 1$		a slightly overexploited state (Kindong et al., 2022).
0.5-1.0	>1	Fully /overfished stocks (Zhai et al., 2022)
$0.5 \leq B/B_{MSY} \leq 0.8$		overfished (Kindong et al., 2022).
$0.2< B/B_{MSY} \leq 0.5$	>1	Stocks outside of safe biological limits (Zhai et al., 2022) heavily overfished state (Kindong et al., 2022).
$B/B_{MSY} <0.2$	>1	Severely depleted stocks (Zhai et al., 2022) a collapsed state (Kindong et al., 2022).

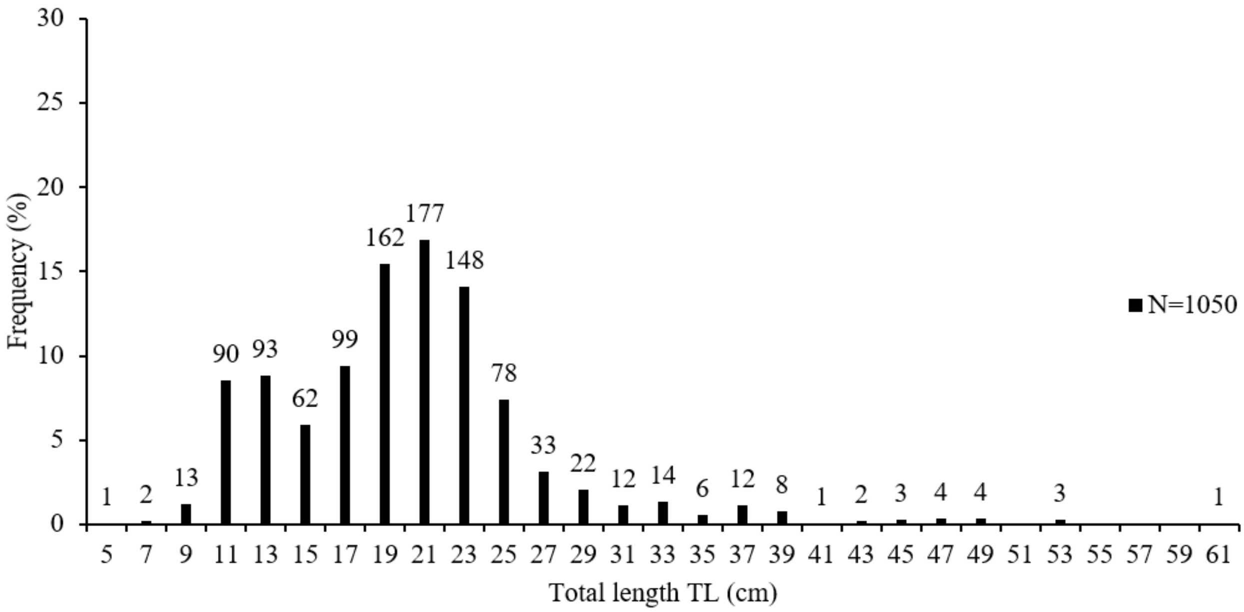


Figure 3. Length frequency distribution of *P. blennoides* collected from commercial fisheries in the Algerian coast (N: number of individuals) (2013-2017).

Length-Weight Relationship

Analysis of the length-weight relationship of P. blennoides sampled from commercial fisheries revealed a non-linear fit, with (R^2= 0.97, P<0.05) indicating a strong model fit (Figure 4a). The best-fit regression was Ln (TW) = -5.52 + 3.16 ×Ln (TL), corresponding to TW= 0,003$TL^{3.16046}$ on the original scale. Note that the value of a = $e^{\text{intercept}}$ = $e^{-5.52334}$ = 0.003. The test and the confidence interval for inference of slope (b) indicated growth for *P. blennoides* from the Algerian coast. The slope b ranged from 3.13 to 3.18 with a positive allometric growth (P<0.05). Predicted average weight for all 10 cm individuals averaged between 5.71 and 5.96 g with 95% confidence.

Linear and Ponderal Growth

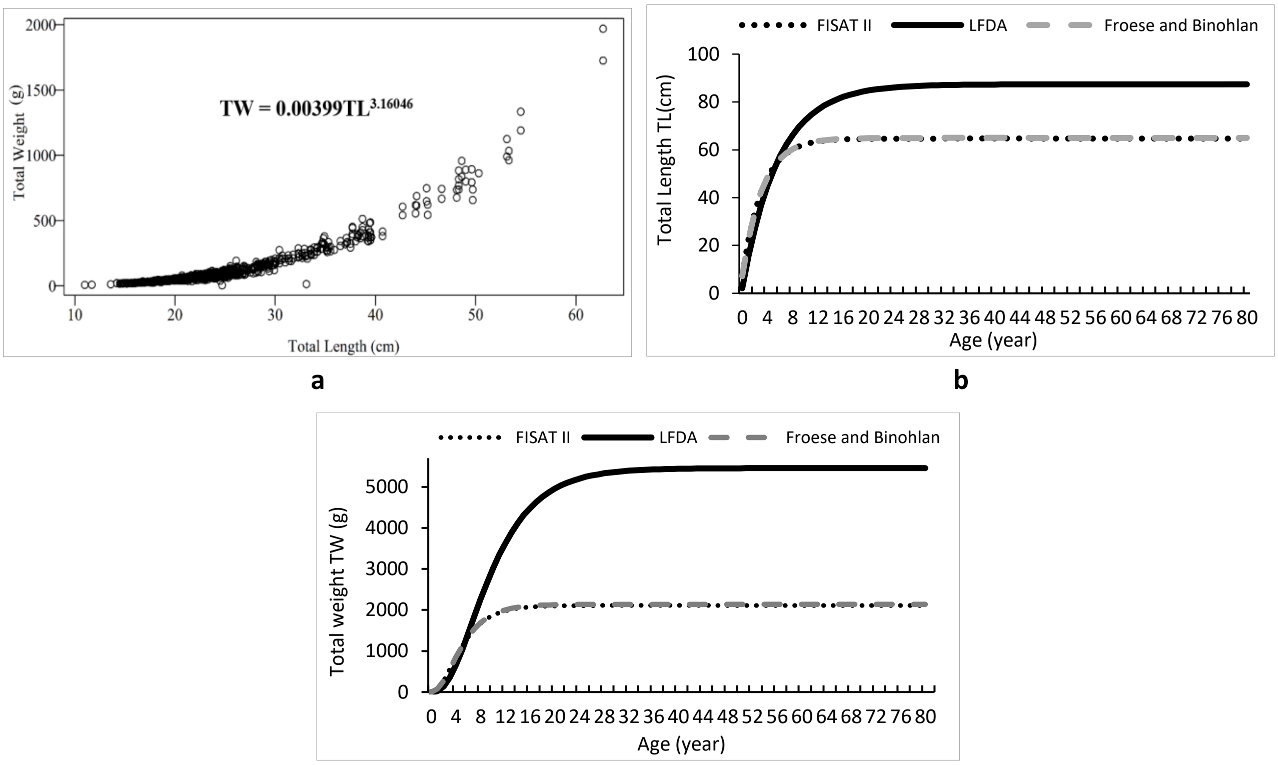
The estimated von Bertalanffy growth model parameters for commercial individuals of *P. blennoides,* in terms of length and weight, were presented in Table **3**, Figure 1b and 4c. Parameters derived from the LFDA software predicted higher asymptotic size and asymptotic weight than those from FISAT II or Froese & Binohlan's method (Table 3, Figure 1). The resulting growth curves showed similar overall trends but differed in slope and maximum observed size.

Length-based Bayesian Biomass Estimation Method (LBB*)*

LBB modelling was conducted using the most robust and representative length frequency samples available to address data shortages. To ensure data quality, years with substantial bias or insufficient sample sizes were excluded, specifically ALDEM 2017 and commercial fisheries data from 2013, 2015, 2016, and 2017. This selection maximized the representativeness of the length-frequency dataset while minimizing potential errors. The final dataset included length-frequency distributions from ARGELIA (2003, 2004), ALDEM (2012, 2016, 2019), and commercial samples collected over a full annual cycle (January–December 2014) (Table 1).

Table 3. Growth parameters and natural mortalities of *P. blennoides* estimated by several approaches. L_{inf}: asymptotic length (cm), K: growth rate ($year^{-1}$), t_0: size when age is zero

	Growth parameters				
Approaches	L_{inf}	W_{inf}	K	t_0	Z/K
FISAT II software	64.69	2110.193	0.318	-0.374	1.631
LFDA software	87.38	5457.565	0.174	-0.139	5.80
Froese and Binohlan 's method	64.96	2138.154	0.315	-0.371	/



c

Figure 1. Length-weight relationship von Bertalanffy growth curves of *P. blennoides* sampled from commercial fisheries in the Algerian coast. a: Length-weight relationship*,* b: Length-age curve*,* c: Weight-age curve.

The results obtained by the LBB method were shown in Table 4. Size frequencies were plotted, and each curve provided estimates of Z/K and asymptotic length L_{inf} for each year (Figure 5). Values of Z/K ranged from 1.81 to 44.3 and L_{inf} from 46 to 53.3 cm. The size at first capture of *P. blennoides* estimated by the LBB method was 7.65 cm (Figure 2a). Its $L_c/Lc_{\_opt}$ was 0.29 and a size at first maturity of Lm_{50}=38.3 cm. The LBB also estimated L_{inf} and Z/K for data collection and represent 2003 (Figure 2b) and 2019 (Figure 2c). The prior value of L_{inf} was 51.9 cm for a prior Z/K ratio of 2.6. According to the general reference points, the optimal size (L_{opt}) of *P. blennoides* was 36 cm and its optimal catch size (L_{c_opt}) was 35 cm. The ratio of fishing mortality to natural mortality was upper than unity (F/M= 23) with a ratio B/B_{msy} of 0.008 indicating severely depleted stocks with collapsed state based on the value of B/B_{MSY} (Table 2). In order to each equilibrium of mortalities (F=M) the L_{mean} should be 21.3 cm (Figure 6d). The ratio F/M increase over the years (Figure 6e), while B/B_0 decreased (Figure 6f). The biomass from 2003 to 2012 was above 0.2 but it decreased in recent years showing a strong biomass loss.

Discussion

This study contributes to a better understanding of *P. blennoides*, an economically valuable species for which information regarding growth and exploitation in the southern Mediterranean remains limited (Romdhani et al., 2016). It offers important data on the population dynamics of this species in Algerian waters. The use of von Bertalanffy growth models in wild fish is common in fisheries population studies. Also, the way of determining growth parameters which can describe accurately growth, is widely discussed according to the method used. Here, estimation methods were compared using identical input data for *P. blennoides,* revealing that LFDA software produced the largest asymptotic lengths, far exceeding the maximum observed length (L_{max}= 62.7 cm). The maximum observed length (L_{max}) values exceeded prior studies from Tunisia (L_{max}=47.7 cm) (Romdhani et al., 2016), western Algeria (L_{max}=39 cm) (Benghali, 2015), and southwestern Spain (L_{max}=47.8 cm) (Torres et al., 2012), but matched data from the Balearic (L_{max}=60 cm) (Rotllant et al., 2002), Ligurian (L_{max}=63 cm) (Rustighi et al., 2004) and Ionian Seas (L_{max}=70.3cm) (Matarrese et

Table 4. Results of LBB for *P. blennoides* from the Algerian coast between 2003-2019. L_{inf} in cm: asymptotic length, SD: Standard deviation, L_{opt}: optimal length in cm, L_c: length at first capture in cm, L_{c_opt}: length of optimal capture in cm, M/K: relative natural mortality, F/K: relative fishing mortality, B/B_0: current exploited biomass relative to unexploited biomass, B/B_{msy}: maximum sustainable yield, Y/R': yield per recruit

Global LBB parameters (Prior) 2003-2019
Linf prior= 51.9, SD=0.52 cm Lmax=62.7, median Lmax=52
Z/K prior= 2.6, SD=7,
M/K prior=1.5, SD=0.15
F/K prior= 1.11 (wide range with tau=4 in log-normal distribution)
Lc prior= 7.65, SD=0.77 cm,
alpha prior=40.3, SD=4, Lm50=38.3 cm
General reference points (Median across years)
L_{inf}= 52.7 (51.2-53.4) cm
L_{opt}= 36 cm,
L_{opt}/L_{inf}=0.65
L_{c_opt} = 35 cm,
L_{c_opt}/L_{inf}=0.66, L_{mean} if F=M 21.3 cm
M/K= 1.4 (1.12-1.59)
F/M= 11.7 (9.56-14.9),
F/K=16.7 (16-17.6),
Z/K=18.2 (17.5-19)
B/B_0= 0.005 (0.0025-0.0068), B/B_0 F=M Lc=L_{c_opt} 0.37
Y/R'= 0.00019 (8.9 e^{-5}-0.00026) (reduced because B/B_0 < 0.25), Y/R' F=M Lc=L_{c_opt} 0.051
Estimates for 2019 (Mean of last 3 years with data)
Lc50= 10.1 (10.1-10.2) cm,
Lc/Linf=0.2 (0.2-0.2)
Lc95= 13, alpha=1.03 (1.01-1.05)
L_{mean}/L_{opt}= 0.37,
Lc/L_{c_opt}=0.29,
L95th=43.5 cm,
L95th/L_{inf}=0.85,
Mature=0.1%
F/M= 23 (19-30), F/K=28 (26-29), Z/K=29 (28-30)
Y/R'=0.00011 (8e-5-0.00015) (reduced because B/B_0 < 0.25)
B/B_0= 0.003 (0.0022-0.004), best LF fit year 2014= 0.199 (0.055-0.38)
B/B_{msy}= 0.008 (0.0059-0.0.11)

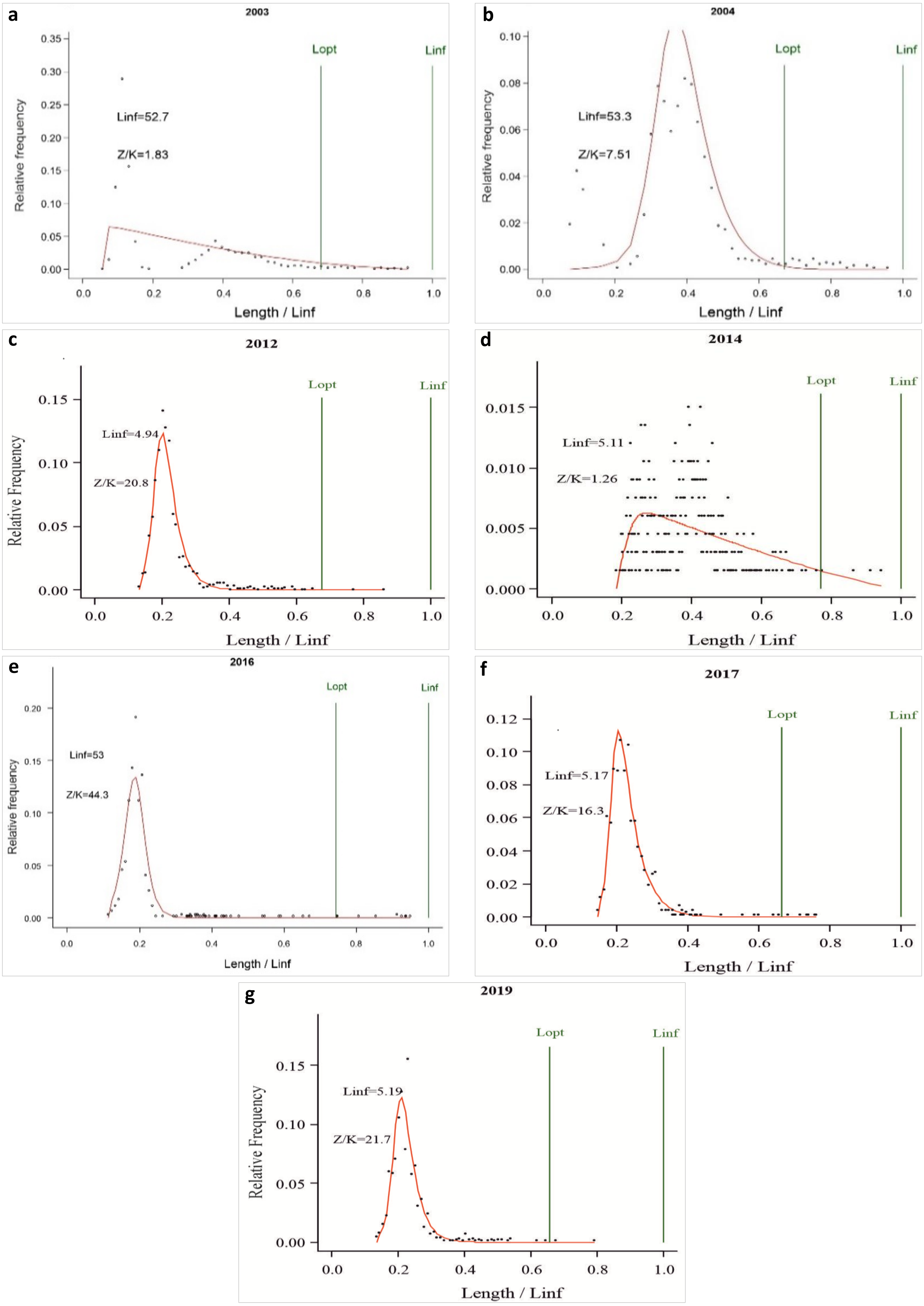


Figure 5. Size frequency data by year providing estimation of Z/K and L_{inf} for *P blennoides* sampled from the Algerian coast. a: specimens sampled from ARGELIA03 survey in 2003, b: specimens sampled from ARGELIA04 in 2004, c: specimens sampled from ALDEM in 2012, d: commercial fisheries sampled during 2014, e: specimens sampled from ALDEM during 2016, f: specimens sampled from ALDEM during 2017, g: specimens sampled from ALDEM in 2019.

al., 1998). However, L_{max} of this study was lower than the largest specimen caught in north of the Iberian Peninsula (L_{max}=81 cm) (Casas and Piñeiro, 2000). Variability in growth parameters likely reflects environmental and ecological factors such as predation, food availability, and temperature (Amara and Lagardère, 1995) (Aritaki and Seikai, 2004)(Sæle and Pittman, 2010). Such factors include long spawning season, variation in individual growth rates and high rates of exploitation (Bjorndal and Bolten, 1995). Higher K values suggest rapid growth; lower $t_0$values may indicate early recruitment. The growth rates (K) estimated using Froese and Binohlan 's method and FISAT II were similar, suggesting relatively fast growth for *P.* blennoides. In contrast, the value obtained using LFDA (K = 0.174) indicated slower growth. Populations experiencing very high exploitation often exhibit a reduced modal structure at the larger size classes, which can lead to overestimates of K and underestimation of the number of age classes (Terceiro et al., 1992). A similar pattern was observed for t_0, as it was derived using (Pauly, 1979)'s equation, which directly depends on K values.

The growth performance index of this study aligns with populations from the Strait of Sicily and the Iberian Peninsula and confirms strong model consistency. However, it was higher than values recorded in Tunisia and in the western Algeria and (Table 5). Regarding the slow K rate reported by LFDA, this deep-sea fish exhibited a historical size of 110 cm (Cohen et al., 1990) that was close to L_{inf} estimated by LFDA. Consequently, this software had the best performance with our data than previous methods (FISAT II, Froese & Binohlan).

Due to the automatization in the obtention of L_{inf} using LFDA software, values of Z/K obtained from Powell Wetherall 's method were superior to those of FISAT II, which their points can be chosen by software users of FISAT II. Consequently, different values of L_{inf} for the same length distribution can be obtained by different users of FISAT II, which is not the case of LFDA program. Compared to previous works, whatever the method used, all asymptotic lengths (L_{inf}) and t_0 were lower than values obtained in Iberian Peninsula (Casas and Piñeiro, 2000) and conversely for K.

The Froese & Binohlan (2000) 's method was added for a new exploration to the population analysis of growth parameters. Then, asymptotic lengths obtained by FISAT II and Froese and Binohlan 's method were close to L_{inf} from Tunisia of 65.73 cm analysed for combined sexes (Romdhani et al., 2016). Our value of Φ' was close to growth performance index obtained for females of the Strait of Sicily (Ragonese et al., 2004) but

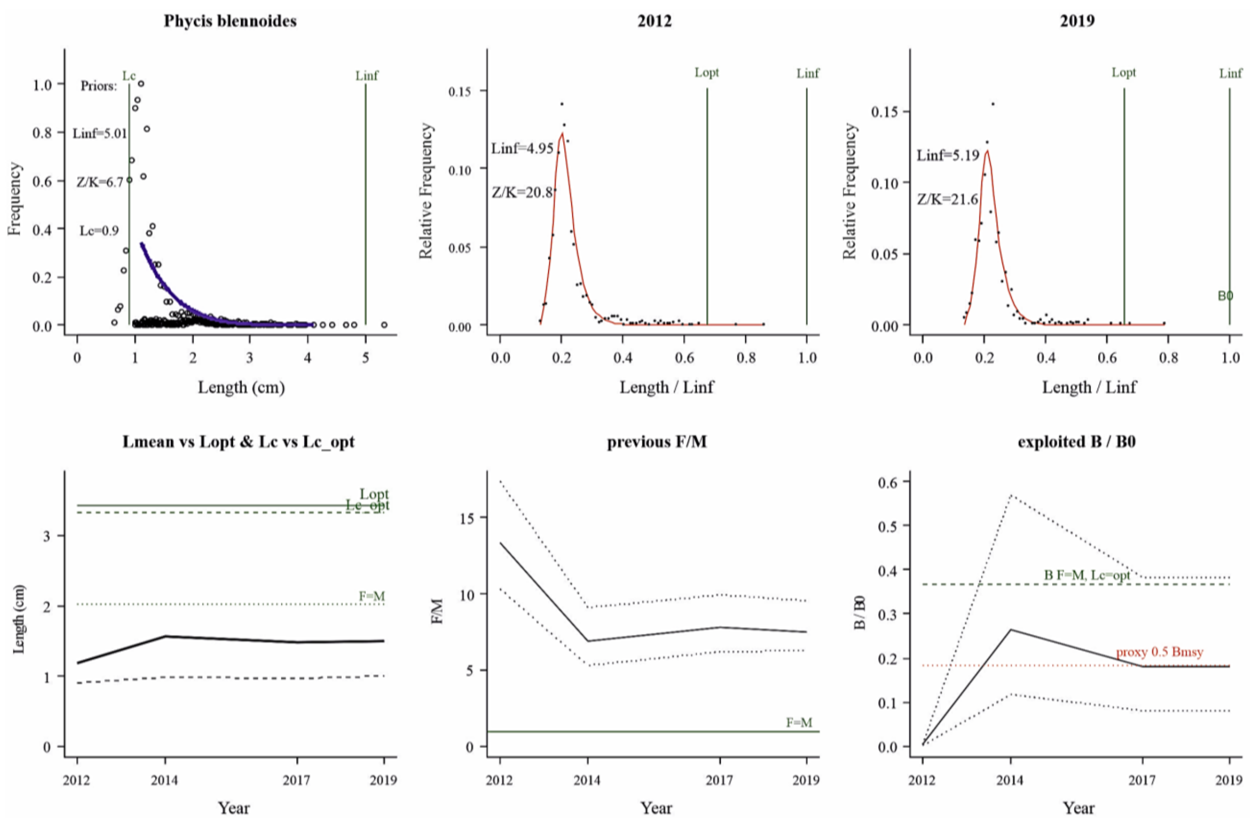


Figure 2. Graphs generated by the LBB method for non-biased samples of *P. blennoides* collected from the Algerian coast. a: Shows the accumulated size frequency data used to estimate the prior Lc, L_{inf} and Z/K. From L_{inf} and M/K, L_{opt} is calculated and shown as reference. b,c: Size frequency data for fiest and last year of sampling. Each curve provides estimates of Z/K and L_{inf}. d: L_{mean} (bold curve) relative to L_{opt} and L_c (lower dashed curve) relative to L_{c_opt}. Panel e: It shows the relative fishing pressure F/M (bold curve), with 95% confidence limits (dotted curves), with indication of the reference level where F = M (horizontal line). Panel f: Indicates the relative biomass B/B_0 (bold curve) with 95% confidence limits (dashed curves), with indication of a proxy for B_{msy} (dashed line) and a proxy of 0.5 B_{msy} (dotted line).

t_0 values differed from parameters obtained after aging otoliths in Tunisia (Romdhani et al., 2016) and the Strait of Sicily (Ragonese et al., 2004) conversely to K. Differences observed can also be due to the different size composition of populations (Romdhani et al., 2016) and the estimation method of growth parameters. In fact, any factor that acts to obscure modal structure makes length frequency analysis more difficult (Bjorndal and Bolten, 1995). These results also indicated that bias and precision was relatively influenced by fish life history type (Coggins et al., 2013), which may allow for standardization of field collection methods across a wide range of fish species.

The length-weight relationship is used in morphological comparisons among populations of the same species. Its parameters are valuable indications of fish body condition which permits comparisons of species growth rates between different regions. In this study, length-weight parameters also match FishBase records and Balearic Sea (Table 6) populations, consistently showing positive allometry (b>3). This positive allometry indicates that fish increase in weight at a faster rate than length.

Fisheries resources play a vital role in achieving sustainable development goals, supporting global food and security, and maintaining the health of marine ecosystems (Kalhoro et al., 2025). Successful fisheries management requires precise knowledge of biological stock characteristics (Coggins et al., 2013). Many stock assessment models depend on the collection of accurate age composition data. Furthermore, key parameters such as yield and biomass per recruit, as well as spawning biomass per recruit, are highly sensitive to variations in natural mortality (Bouaziz et al., 2014). For better stock management, it is essential to better control the production level to ensure its sustainability and renewal (Amira et al., 2019).Therefore, understanding these biological factors is essential to ensure sustainable exploitation and conservation of fish stocks.

Stock assessment generally requires fisheries-independent data sets, collected through scientific surveys. Such data are often scarce in data-poor regions like most North African coastal stocks, limiting the application of traditional stock assessment methods in these areas. However, the LBB method is a valuable tool for managing data-poor stocks, particularly when catch data are unreliable or missing, as it requires only length-frequency data (Froese et al., 2018) and offers insights into stock status and growth parameters (Kalhoro et al., 2025). This new approach recommended by Tobias Mildenberger, Marc Taylor and Rainer Froese (pers. com.) was tested on length frequency data of commercial fisheries for 14 Mediterranean stocks (Froese et al., 2018). It is currently applied by several working groups including Italian stock assessment scientists (CNR-IRBIM) (Gianpaolo Coro Com.Pers.) and the General Fisheries Commission for the Mediterranean in collaboration with the FAO through the (BlackSea4Fish project, 2021) and cited by 138 papers (Gianpaolo Coro Com.Pers.). According to (Froese et al., 2018 ; Froese et al., 2019), a relative biomass (B/Bmsy) below 0.2 indicates stock collapse, while values above 0.4 reflect a healthy stock status (Froese et al., 2019). In Algeria, the lack of reliable catch data complicates traditional assessment approaches. Our results, based on LBB outputs, reveal severe depletion of the *P. blennoides* stock, with fishing

Table 5. Biogeographic comparison of growth parameters (L_{inf} , K and t_0) and growth performance index (Φ') of *P. blennoides.* S: sexes, N: number of total individuals, T: total, Φ': growth performance index, L_{inf} : asymptotic length, K: growth rate, t_0: is a value used to calculate size when age is zero, N/A: not available.

Authors	Area	S	L_{inf}	K	t_0	Φ'	N
Fanciulli and Relini Orsi (1979)	France	♂	41.7	0.21	N/A	2.56	N/A
		♀	51.2	0.26	N/A	2.56	N/A
Nony (1983)	Italy	♀	42.1	0.9	N/A	3.20	N/A
		♂	28.4	0.8	N/A	3.20	N/A
Campillo (1992)	Gulf of Lion, France	♂	41.7	0.208	-0.771	N/A	N/A
		♀	51.1	0.258	-0.057	N/A	N/A
Petrakis and Papaconstantinou (1992)	Aegean Sea	T	65.8	0.128	–1.01	2.74	850
Casas and Piñeiro (2000)	Iberian Peninsula	T	112.7	0.0896	-0.518	3.06	918
Ragonese et al. (2004)	Strait of Sicily	♂	47.1	0.38	-0.03	2.93	N/A
		♀	68.1	0.22	-0.15	3.01	N/A
Rustighi et al. (2004)	East Ligurian Sea	♂	32.4	0.499	-0.36	N/A	N/A
		♀	61.8	0.211	-0.58	N/A	N/A
Clarke (2005)	Atlantic	T	N/A	0.08	N/A	N/A	N/A
Romdhani et al. (2016)	Tunisia	♂	44.74	0.313	-1.201	2.79	N/A
		♀	57.17	0.193	-1.578	2.80	N/A
Benghali et al. (2014b)	West of Algeria	♂	42.86	0.29	-0.9	2.61	432
		♀	37.5	0.36	-0.09	2.82	414
Present study	Algeria	T					1050
FISAT II			64.69	0.318	-0.374	/	
LFDA			87.38	0.174	-0.139	/	
Froese&Binohlan			64.96	0.315	-0.371	3.124	

mortality far exceeding sustainable levels and a biomass ratio (B/Bmsy) indicating a collapsed population. The F/M ratio further supports this finding, consistent with the classification (Palomares et al., 2018), (Kindong et al., 2022) and (Zhai et al., 2022) (Table 2). Additionally, a ratio of of Lc/Lc_opt<1 suggests growth overfishing**,** meaning that individuals are being harvested before reaching optimal size. To promote stock recovery, increasing the mesh size of fishing gear and restricting juvenile capture are strongly recommended. Moreover, continued monitoring of discards and environmental factors is also essential to understand the combined impacts of overfishing and pollution on species viability.

In this study, *P. blennoides* showed a severely depleted stock with collapsed scenario. However, the limited landed quantities of this species on the Algerian market (Alioua et al., 2018) suggest that fishing pressure may be the major cause for the decrease in its occurrence. Moreover, it has smaller mean length at first capture (Lc) than the optimal length at first capture (L_{c_opt}), indicating that it is suffering from growth overfishing. This can be due to the absence of mesh size restriction combined to environmental degradation observed in *P. blennoides* through pollution (Alioua et al., 2020) which might also contribute to shaping its status. In several Algerian ports, the increase in the fishing effort matched with an increasing of trawlers number that caused the stock depletion. It corresponded to 494 in 2009 and increased to 523 in 2014 (Roland, 2014) and to 688 of trawlers in 2017 (Labidi Nassima Pers. Com.). This was also observed on the landings of forkbeards both species combined (*P. phycis* and *P. blennoides*). These quantities decreased highly between 2012 and 2013 (MPRH, 2013). However, correlations of increasing fishing effort with the decrease of landings have not been highlighted with no indication on discarded fisheries in Algeria.

In this study, the small size of first catch of *P. blennoides* was lower than the size at first maturity identified in the Ionian Sea (Matarrese et al., 1998) and the Balearic Islands (Rotllant et al., 2002). In addition to discarded juvenile of *P. blennoides*, that has been observed in the Bouharoun port during our investigations suggest that the fish stock was strongly affected by fishing pressure. Also, the rate of discarded juveniles in deep fisheries reported in the Atlantic Ocean was higher than adult fish landings (Lorance, 2012), leaving only a small fraction of the adult population at sea (Fiorentino et al., 2003). The scarcity of its landings is linked to the polluted environment as it has not been spared from anthropogenic actions with variations in its heavy metal concentrations (Alioua et al., 2022). However, it is not excluded that increasing temperatures (global warming) modify the distribution of *P. blennoides* as it has been moved toward north (Valdimarsson et al., 2012). In fact, fish species near the limits of their thermal distribution would appear to be obvious candidates for range shifts with rising temperatures (Campana et al., 2020).

Length-based assessment methodologies offer a preliminary approach to estimate stock status through specific reference points (Ju et al., 2025). As the lengths frequency distribution is the only data input of the LBB, low and biased samples mainly affect the accuracy of the output results. More reliable results with narrower confidence limits were reported when the LBB was

Table 6. Length weight parameters of *P. blennoides* (FishBase). b: slope, a: intercept, S: sexes, T: total, N/A: not available, L_{min}: minimal length (cm), L_{max}: maximum length (cm), r^2: determination coefficient, N: number of individuals, SD: standard deviation, GSA: geographical sub-area according to the General Fisheries Council for the Mediterranean ("GFCM Geographical Subareas (GSAs)," 2012).

Area	b	a	S	L_{min}	L_{max}	r^2	N
North Sea, South Minch & Clyde, 1926-82 UK	0.0022	3.389	N/A	19	65	N/A	25
Gulf of Lion France	0.0019	3.238	♀	N/A	N/A	N/A	N/A
Gulf of Lion France	0.0012	3.316	♂	N/A	N/A	N/A	N/A
Cantabrico Spain	0.00137	3.543	N/A	7	21	0.96	31
Balearic Islands, 1995-96 Spain	0.0026	3.27	N/A	5.5	53.8	0.996	343
C, Aegean Sea, 1991 Greece	0.00346	3.238	T	6.4	50	0.97	505
North Aegean Sea, 2003 (March; July) Turkey	0.0017	3.55	N/A	12.3	15	0.89	12
Nazaré to St André, 1997 Portugal	0.0156	2.843	N/A	17.3	55.4	0.901	39
Gulf of Castellammare / 2004 Italy,	0.0043	3.187	N/A	6.5	27.5	0.97	301
Gulf of Cadiz, 2009-11 Spain	0.0072	3.006	T	8.6	47.8	0.97	51
North Aegean Sea, 2004-05 Greece	0.0087	2.97	N/A	15.8	45	0.94	333
Ligurian and North Tyrrhenian Sea (GSA 09) Spain	0.00381	3.21	♀	N/A	N/A	N/A	N/A
Ligurian and North Tyrrhenian Sea (GSA 09) Spain	0.00299	3.29	♂	N/A	N/A	N/A	N/A
Tunisia	0.00191	3.46	♂	16	47.7	0.929	N/A
Northeast Atlantic	$0.010±0.001^{SD}$	$2.946±0.028^{SD}$	N/A	N/A	N/A	N/A	N/A
Present study	0.00399	3.132–3.188	T	5.7	62.7	0.9792	1050

applied to 16 stocks from 4 Indonesian Fisheries Management Areas showed (Dimarchopoulou et al., 2021). According to these authors, narrower confidence ranges highlight the importance of using fishery-specific information when applying generalized stock assessment methods. In contrast, the LBB method is not accurate enough in resource assessment because it just inputs length and frequency data (Wang et al., 2020b). For example, most Indonesian catches had few immature fish, half of their assessed stocks were consistently shown to have low biomass, indicating high risk of overfishing (Dimarchopoulou et al., 2021). In Mauritanian coast, the LBB method produced results that were very pessimistic about stock status but whose reliability was affected by non-constant recruitment (Meissa et al., 2021). However, the results of this study align with scarcity of landings observed during our investigation. Several factors were identified such as intense fishing pressure, as evidenced by the increasing number of trawlers along the Algerian coast and environmental stressors (Alioua et al., 2020; Alioua et al., 2022). These combined pressures have resulted in a significant reduction in catches and the overall stock status of *Phycis blennoides* in Algerian waters.

Representative length frequency samples from the main gear used in the fishery or from the main landing site may suffice to get a preliminary impression of stock size relative to levels that can produce MSY (Froese et al., 2018). In order to validate the maximum representation of length frequency distribution and least data error, it is best to use the survey data for LBB analysis to ensure the maximum representation of length frequency samples and minimum data errors (Barman et al., 2021). According to these authors, the most challenging concern for both commercial and artisanal fishing were the fishing effort, hauling time, fishing ground and the mesh size of nets. The fishing vessel may not maintain the same effort and hauling time and may also operates in specific fishing ground areas instead of random operation for sampling. Therefore, the misinterpretation of length frequency data due to the data accuracy and result can be affected (Barman et al., 2021). Our study’s results are based on extensive sampling, with length frequency data mainly derived from scientific surveys conducted over several years to ensure the most representative and reliable data possible.

Applying the LBB method enabled a comprehensive assessment of *P. blennoides* stock status in Algerian waters. The findings demonstrate urgent need for management actions such as increasing mesh size and preventing juvenile harvest. Additional studies are required to monitor distributional changes potentially linked to climate warming and anthropogenic impacts. These reference points serve as essential tools for future sustainable exploitation and decision-making in Mediterranean fisheries management.

Conclusion

In this study, we applied the LBB method to evaluate the stock status of *P. blennoides* in Algerian waters using total length measurements, defined as collapsed stock. This approach addresses the challenge of assessing fish stocks in Algeria, where fisheries data are largely unavailable. Our findings highlight an urgent need for management measures, particularly by increasing mesh size and preventing the harvest of juveniles smaller than the size at first maturity, in order to ensure stock renewal and enhance both species catch and biomass. Future studies should investigate potential distributional shifts driven by climate warming and other anthropogenic pressures using abundance-based data to better predict changes in stock dynamics and quantify the magnitude or orientation of the shift. Research on discarded catches is also required for a better understanding of fisheries impacts. As a baseline assessment, our estimates provide essential reference points for the management of deep-sea fish stocks in Algeria suggesting urgent management actions. These results offer valuable tools to design sustainable exploitation strategies for *P. blennoides* and can serve as priors for other stock assessment models in the Mediterranean.

Ethical Statement

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Author Contribution

A.Z., Conceptualization, Investigation, Data curation, Formal analysis, Visualization, Writing original draft, Writing review & editing. **A.S,** Conceptualization, Investigation, Data curation. **K.G.E.Y.,** Visualization, Data curation. **M.M.,** Data curation, Visualization. **Z.- K. F.,** Supervision, Project administration.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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