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On the biology of blackbellied angler, *Lophius budegassa* Spinola, 1807, in the north-western Mediterranean

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Abstract

In the Mediterranean Sea, the blackbellied angler, *Lophius budegassa* Spinola, 1807, represents a relevant fraction of the commercial by-catch of bottom trawling and small-scale fisheries that use passive gears (e.g., set nets, bottom longlines, etc.). Despite its importance, there are no comprehensive studies on the population dynamics of this species, and there is still scarce and scattered knowledge of its biology and ecology. Biomass, morphometric, and biological data of the blackbellied angler were collected from 1994 to 2021 by means of the Mediterranean International Bottom Trawl Survey (MEDITS) programme in the Ligurian and northern Tyrrhenian Seas, and in the EU Data Collection Framework during the period of 2006-2021. Furthermore, ageing was performed on specimens collected from 2013 to 2021 during the MEDITS programme. There were high values for the density indices and the spatial distribution of biomass in the central sector of the investigated area (the Tuscan Archipelago), mostly on the continental shelf. The length-weight relationship showed negative allometric growth when considering the sexes together, and no difference between the sexes. The size at first maturity (L_{50}) was estimated at 39.4 cm total length (TL) in females and at 29.2 cm TL in males. The obtained Von Bertalanffy growth parameters were: in females, $L_\infty = 74.50$ cm, $k = 0.10$ years^{-1}, and $t_0 = -0.40$ years; in males, $L_\infty = 61.30$ cm, $k = 0.14$ years^{-1}, and $t_0 = -0.38$ years. There were differences in growth between males and females for L_∞ ($\chi^2 = 10.04$; $p < 0.05$) and k ($\chi^2 = 6.12$; $p < 0.05$).

Keywords: *Lophius budegassa*; length-weight relationship; maturity; growth.

Introduction

The genus *Lophius* Linnaeus, 1758 includes seven species with a wide distribution in the marine waters throughout the world. Two species belonging to the genus *Lophius* are present in the Mediterranean Sea: the angler, *Lophius piscatorius* Linnaeus, 1758, and the blackbellied angler, *Lophius budegassa* Spinola, 1807 (Fischer *et al*., 1987; Sartor *et al*., 2017; Barcala *et al*., 2019). According to the available knowledge from trawl surveys and commercial fisheries monitoring in the Mediterranean Sea, the blackbellied angler is more abundant than the angler (Tsimenidis & Ondrias, 1980; Ungaro *et al*., 2002). The blackbellied angler is a demersal fish distributed in the north-eastern Atlantic, from the British Isles to Senegal, and throughout the Mediterranean Sea (Fischer *et al*., 1987; Sartor *et al*., 2017), with a wide bathymetric distribution, from coastal waters to around 800 m. It is more abundant on the continental shelf between 50 and 200 m (Ungaro *et al*., 2002; Sartor *et al*., 2017).

In the Mediterranean, the blackbellied angler is a by-catch of trawl and gillnet fisheries with a high commercial value (Maravelias & Papaconstantinou, 2003; García-Rodríguez *et al*., 2005). In general, its contribution in terms of the volume of landings is low, except in some areas such as the Gulf of Lions and the Catalan Sea (Ungaro *et al*., 2002; Colmenero *et al*., 2013). In the European Atlantic waters, the blackbellied angler investigations have included estimation of growth parameters (Dupouy *et al*., 1986; Duarte *et al*., 1997; Landa *et al*., 2001, 2008, 2014; Quincoces, 2002); characterisation of reproduction (Azevedo, 1996; Duarte *et al*., 2001; Quincoces, 2002) and diet (Crozier, 1985); and evaluation of spatial distribution (Azevedo *et al*., 2008, Barcala *et al*., 2019). However, despite the ecological and economic relevance of the blackbellied angler, in the Mediterranean there have been no comprehensive studies on its population dynamics, and the knowledge about its biology and distribution is still scarce and scattered. The understanding of the biology and ecology of this species is limited to a few studies (Tsimenidis & Ondrias, 1980; Ungaro *et al*., 2002; García-Rodríguez *et al*., 2005; Carlucci *et al*., 2009). Regarding growth aspects, Tsimenidis & Ondrias (1980), García-Rodríguez *et al*. (2005), Carlucci *et al*. (2009), and Şenbahar & Özaydin (2020) performed growth studies based on the interpretation of otoliths and/or *illicium*.

The aim of this study is to increase the knowledge on the biology, age and growth, and population dynamics of the blackbellied angler in the north-western Mediterranean, for which only a preliminary study done by García-Rodríguez *et al.* (2005) is available.

Materials and Methods

Blackbellied angler specimens were collected under the activities of the EU Data Collection Framework (Reg. EU 199/2008) carried out in the Ligurian and northern Tyrrhenian Seas (FAO-GFCM Geographic Sub-area 9) (Fig. 1). Abundance data were gathered from the Mediterranean International Bottom Trawl Survey (MEDITS) programme (Bertrand *et al*., 2002) carried out from 1994 to 2021. The biomass and density indices of the blackbellied angler were computed from each haul as biomass per swept area (kg/km^2) and the number of individuals per swept area (N/km^2), respectively (Sparre & Venema, 1992). The area swept in each haul was estimated from direct measurements of the horizontal opening of the net detected by net geometry monitoring equipment. The average biomass and density indices per year and depth stratum were also calculated. Spearman's rho coefficient was used to detect temporal trends in the density and biomass indices of *L. budegassa* in the investigated area. The spatial distribution was represented by applying the Heatmap tool of the QGIS Geographic Information System (QGIS, version 3.8.1 – Zanzibar) on the biomass indices (kg/km^2).

Morphometric and biological data were collected from 2006 to 2021 from the MEDITS programme and commercial catches. Fish total length (TL) was measured to the nearest 0.5 cm (rounded down), wet weight (W) was recorded to the nearest 0.1 g, and sex and the maturity stage were determined by macroscopic observation of the gonads following the classification scale provided by Follesa & Carbonara (2019) for bony fish: 0, undetermined; 1, immature virgin; 2a, developing virgin; 2b, recovering; 2c, maturing; 3, mature-spawner; 4a, spent; and 4b, resting.

The length-weight relationship was analysed with the power equation $W = a \times TL^b$. Data exploration and analyses were carried out with R version 4.2.2 (R Core Team, 2023). The parameters a and b were estimated using the package *nlstools* (Baty *et al*., 2015). Analysis of covariance (ANCOVA) was used to test the effect of the categorical factor sex in the fish length-weight relationship. Student's t-test modified by Pauly (1984) was applied to analyse the growth allometry. The assumed significance level of 0.05 was used in all the statistical analyses.

Length at first maturity (L_{50}) was estimated by fitting a logistic function (Saila *et al*., 1988) to the proportion of mature individuals (immature: stages 1 and 2a; mature:

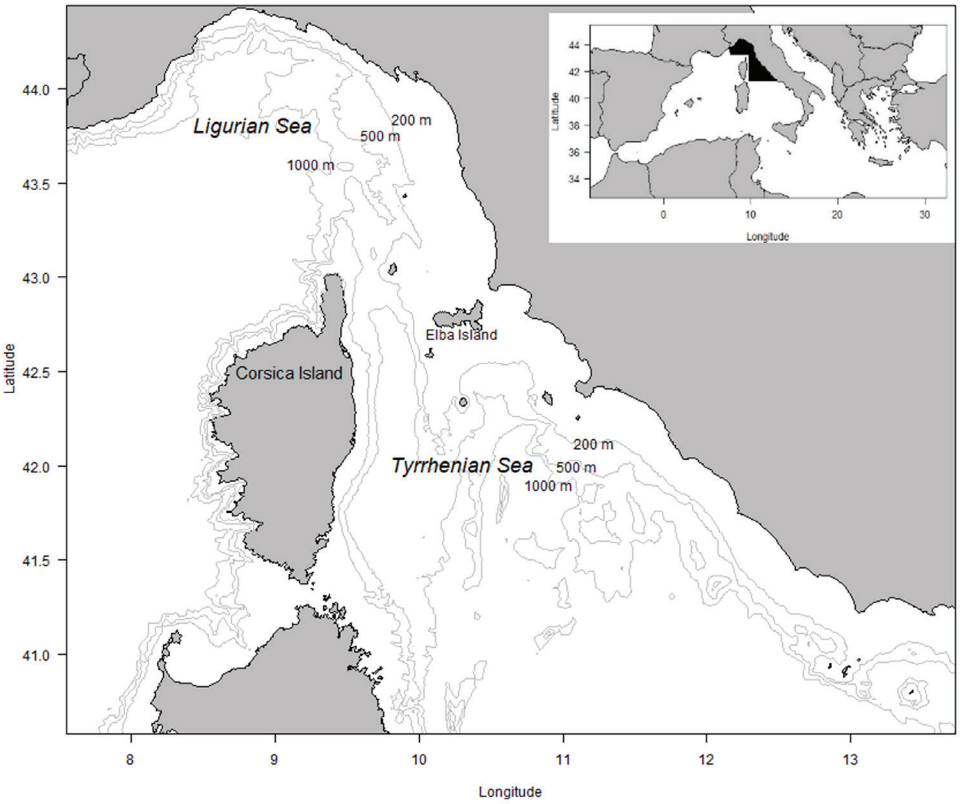

Fig. 1: Study area. The black area showed in the frame at the top-right is GSA9.

stages 2b, 2c, 3, 4a, and 4b) by size class. The function was fitted to the data by using the Levenberg-Marquardt algorithm for non-linear least squares parameter estimation (Draper & Smith, 1966). Maturity ogives, obtained for each sex, were compared with the Chen test (Chen *et al*., 1992).

Individual age was determined by counting growth rings in the transverse sections of the first dorsal fin ray (*illicium*), according to the methodology described by Carbonara & Follesa (2019) from specimens caught from 2013 to 2021 during the MEDITS programme. After removing any organic tissue, *illicia* were embedded in epoxy resin. Thin sections (500 µm) were taken from 5 mm above the peduncle up to the middle of the *illicium* using a low-speed diamond wheel saw with a micrometric knob. The age reading was performed separately by two readers with the same expertise level, using a microscope (40× and 100× magnifications) with transmitted light and connected to a digital system. Only readings in agreement were used in the growth analyses.

The theoretical birth date was defined as 1 January (Carbonara *et al.*, 2019), according to the spawning period of the species reported in the Mediterranean (Maravelias & Papaconstantinou, 2003; Carbonara *et al*., 2005). The age was assigned by considering the scheme proposed by Carbonara *et al*. (2019). The growth of *L. budegassa* was estimated by using the von Bertalanffy growth formula (VBGF): $L_t = L_\infty \times (1 - e\ (-k \times (t - t_0))$, where L_t is the mean total length at age t (cm), L_∞ is the theoretical asymptotic length (cm), k is the instantaneous growth coefficient (years^{-1}), t is age (years), and t_0 is the theoretical age at length zero (years). The parameters of the VBGF were calculated by sex by using the R package *FSA* (Ogle, 2016). The extra-sums-of-squares test (Ritz & Streibig, 2008) was used to identify significant differences between the sexes. Coefficient of Variation (CV; Chang, 1982) and Average Percent Error (APE; Beamish & Fournier, 1981) were calculated to assess the precision of the age determination.

The growth performance index, $\Phi' = \log k + 2 \log_{L\infty}$ (Pauly & Munro, 1984), was calculated to compare the results of the present study with results obtained in different areas of Mediterranean Sea and in the Atlantic Ocean.

Results

Abundance trends from the MEDITS programme

The time series of biomass and density indices of the blackbellied angler in the Ligurian and northern Tyrrhenian Seas are shown in Figure 2. During the period investigated by the MEDITS programme (1994-2021), the abundance indices showed a fluctuating trend, with a strong decrease since 2018 in terms of both biomass and density. The lowest biomass index value (1.6 ± 0.3 kg/km^2) was recorded in 2021, the last year of the time series, while the highest value (11.1 ± 4.1 kg/km^2) was recorded in 2018, with an average over the entire period of 5.6 ± 1.3 kg/km^2. The density index values ranged from 4.9 ± 1.0 N/km^2 in 2001 to 17.5 ± 5.9 N/km^2 in 2018, with an average of 8.7 ± 1.8 N/km^2. Although the time series are characterised by large fluctuations, Spearman's rho coefficient analysis did not show a significant trend in the density and biomass time series. The spatial distribution of the biomass index by haul and year (Fig. 3) shows the highest values in the central sector of the investigated area, corresponding to the Tuscan Archipelago (eastern Ligurian and northern Tyrrhenian Seas). Furthermore, the blackbellied angler was more abundant on the continental shelf (up to a depth of 200 m) than on the slope, with average biomass index values of 8.2 ± 2.4 kg/km^2 and 2.5 ± 0.9 kg/km^2, respectively. The density index values showed the same pattern: 13.2 ± 3.4 N/km^2 on the shelf, and 3.4 ± 1.0 N/km^2 on the slope.

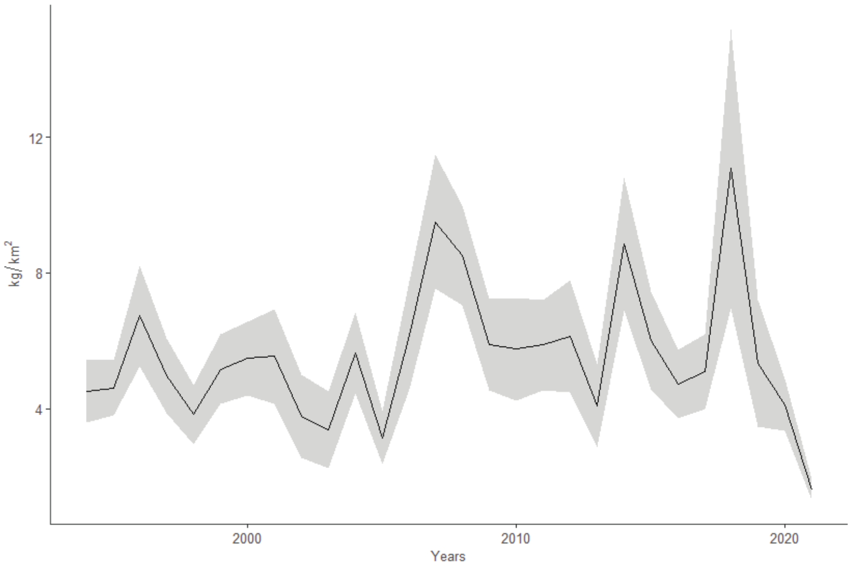

Fig. 2: Temporal evolution of biomass and density indices from MEDITS survey data (1994 2021). Shaded areas are standard deviations.

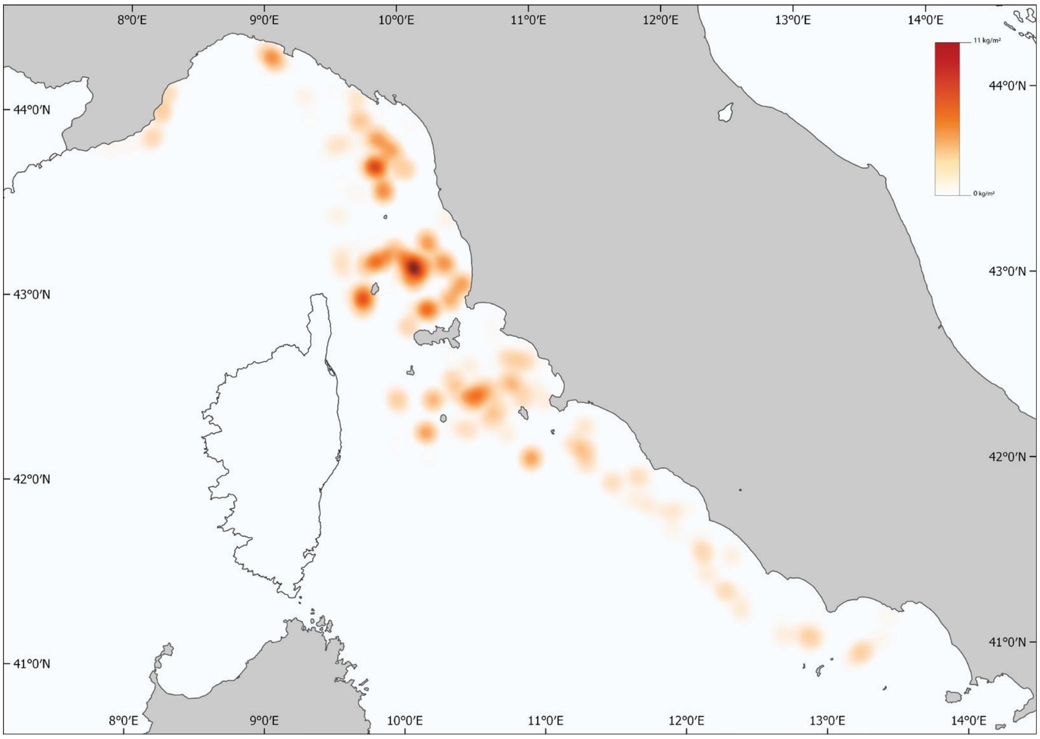

Fig. 3: Heatmap representing the spatial distribution of blackbellied angler in terms of biomass per spatial unit, obtained from MEDITS survey data (1994-2021).

Biological parameters

The morphometric and biological aspects of 232 specimens (99 females, 128 males, and 5 undetermined) were analysed (Table 1).

Length-weight relationship

Figure 4 and Table 2 show the results for the entire sample and separately by sex. ANCOVA did not show significant differences between sexes. The parameter b was less than 3 in all the cases, indicating a negative allometric relationship.

Length at first maturity (L_{50})

The smallest mature female measured 32.5 cm TL, while the smallest mature male was 21.0 cm TL. L_{50} was estimated at 39.4 cm TL in females and 29.2 in males (Fig. 5, Table 3). The size at which all individuals were mature was 49.5 cm TL in females and 36.0 cm TL in males. There was a significant difference in L_{50} between the sexes ($t = 0.61$, $p < 0.05$).

Age and growth

A total of 275 *illicia* was collected and analysed (Fig. 6). However, age could only be determined from 257 of the 275 *illicia* because some were damaged or unreadable. Out of the 257 readable *illicia*, there were 114 females ranging from 14.0 to 72.5 cm TL, 138 males ranging from 11.0 to 62.0 cm TL, and 5 immature individuals ranging from 9.5 to 12.5 cm TL. The estimated age range for males and females varied from 0 to 16 years. The Von Bertalanffy growth curves are shown in Figure 7, while Table 4 summarises the estimated growth parameters and the growth performance values. The extra-sums-of-squares test carried out on the von Bertalanffy parameters showed significant differences between males and

Table 1. Sample composition with number of specimens (n), size range, mean TL with standard deviation (SD) and weight range, mean W with standard deviation (SD) for females (F), males (M), and undetermined (N).

Sex	n	TL (cm)		W (g)	
		Range	Mean ± SD	Range	Mean ± SD
F	99	14.0 - 72.5	37.4 ± 11.6	36.6 - 4900.0	896.6 ± 832.2
M	128	11.0 - 81.5	31.9 ± 8.4	20.0 - 6000.0	552.0 ± 636.6
N	5	9.5 - 12.5	10.6 ± 1.3	10.3 - 117.9	36.5 ± 45.7

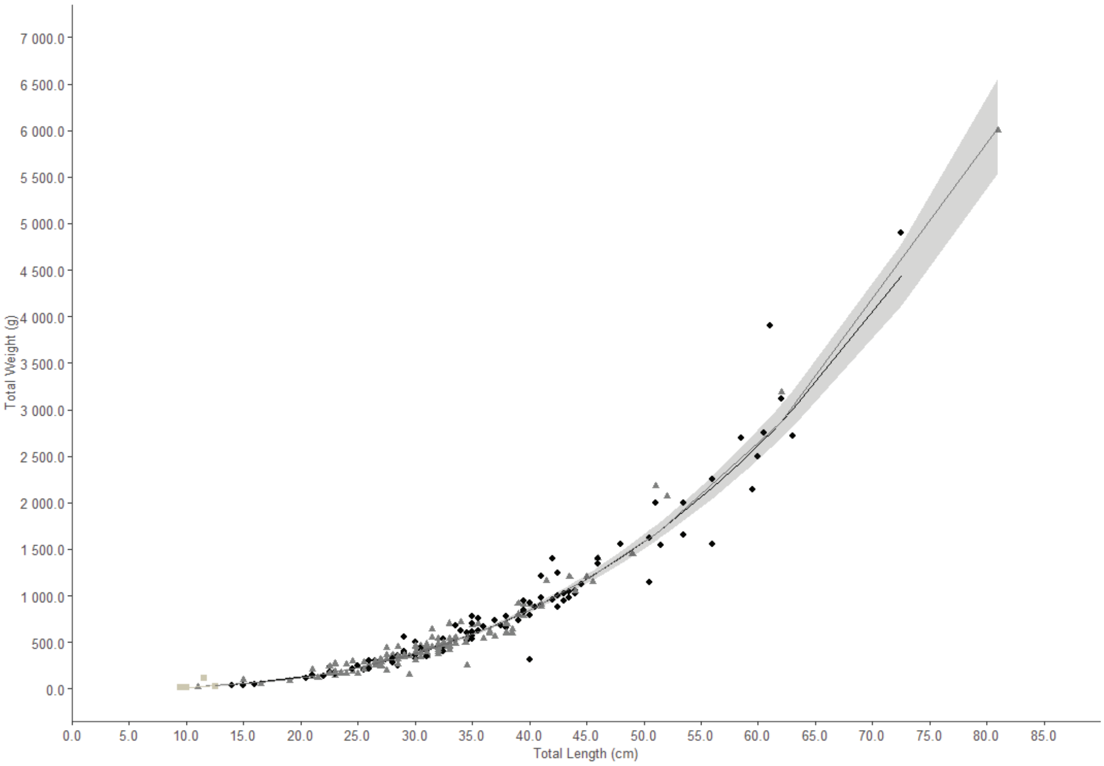

Fig. 4: Length-weight relationship of *L. budegassa* for males (black dots), females (dark grey triangle) and undetermined (light grey square) specimens.

Table 2. Length-weight relationships' parameters for total population, females and males of *L. budegassa*; a and b = parameters of the power curve; SE = standard error; p: significance level of Student's *t*-test (null hypothesis: $\beta = 3$); R^2 = coefficient of determination.

	a	**SE(a)**	**b**	**SE(b)**	**p**	**R2**
Total	0.030	0.060	2.775	0.043	<0.05	0.946
M	0.030	0.106	2.769	0.070	<0.05	0.923
F	0.025	0.090	2.824	0.058	<0.05	0.961

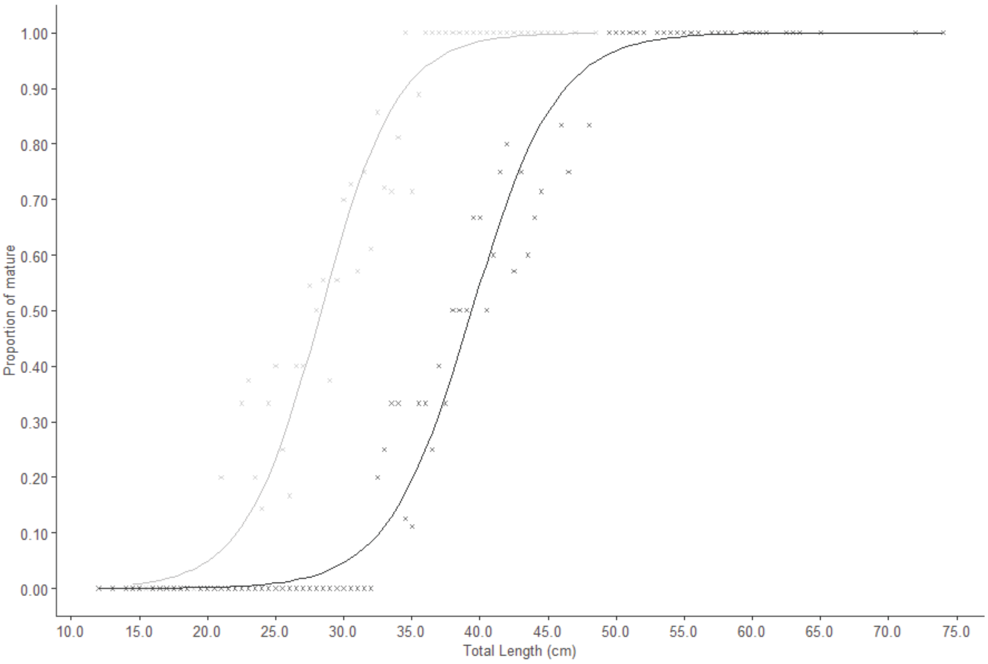

Fig. 5: Maturity ogives for females (dark grey) and males (light grey) of *L. budegassa.*

Table 3. Estimated values of size at first maturity (L_{50}, cm) and maturity range (MR) (with relative standard error, SE) in females and males of *L. budegassa*.

	Females	**Males**
L_{50}	39.4	29.2
SE	1.0	1.0
MR	3.4	3.1
SE	0.7	1.0

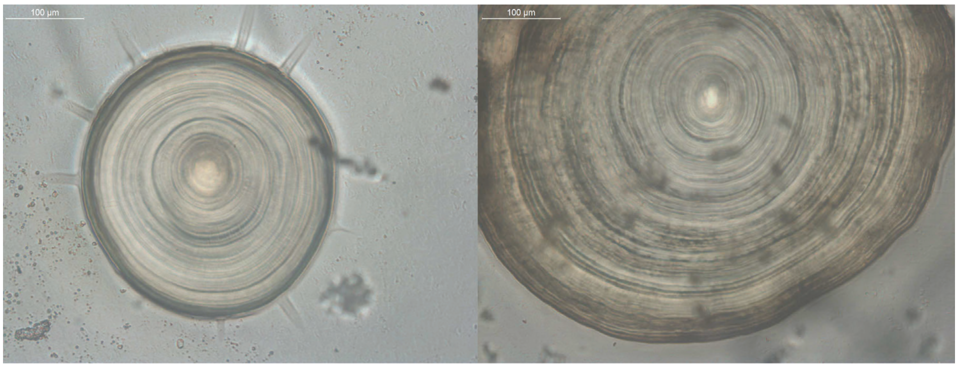

Fig. 6: Sections of *illicia* of *L. budegassa* (magnification 100x). Left: Female, 28.0 cm TL; Right: Female, 42.5 cm TL.

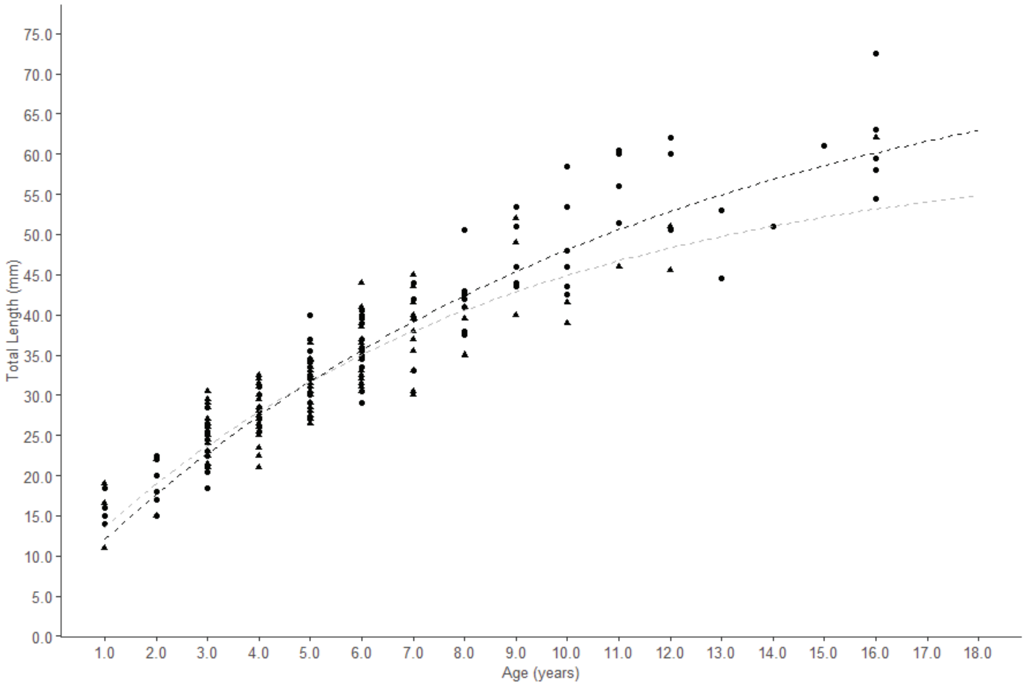

Fig. 7**:** Von Bertalanffy growth curves (dashed lines) for females (black) and males (grey) of *L. budegassa* in the study area. Dots and triangles represent observations for females and males, respectively.

Table 4. Growth parameters (with SE standard error, t value and significance) and performance growth index of *Lophius budegassa*. L_∞= asymptotic length; k = growth coefficient; t_0 = hypothetical age at zero length; t-value = Student's t-test value; p = p-value associated to the Student's t-test.

		Estimate	**SE**	**t value**	**p**
Females	L_∞ (cm)	74.50	3.95	18.86	< 0.05
	k (years^{-1})	0.10	0.01	10.01	< 0.05
	t_0 (years)	-0.40	-1.40	-2.84	< 0.05
Males	L_∞ (cm)	61.30	3.07	19.97	< 0.05
	k (years^{-1})	0.14	0.01	10.65	< 0.05
	t_0 (years)	-0.38	0.11	-3.39	< 0.05

females in terms of L_∞ ($\chi^2 = 10.04$; $p < 0.05$) and k ($\chi^2 = 6.12$; $p < 0.05$). The percentage of agreement between the readers was 60.4%, while APE and CV were 6.2% and 8.7%, respectively. The age bias plots (Fig. 8) highlight an increase in discrepancies between the two readers proportional to the estimated age.

Discussion

The present study provides the first information on the biology and population dynamics of the blackbellied angler, *L. budegassa*, in the Ligurian and northern Tyrrhenian Seas (north-western Mediterranean Sea). According to our observations, the blackbellied angler showed the highest abundance on the continental shelf, in particular on the shelf break, at a depth of 100-200 m. This pattern agrees with findings from other areas, both in the north-western Mediterranean, such as the Gulf of Lions, and the eastern Mediterranean (e.g., the Aegean Sea; Ungaro *et al*., 2002). In contrast, the congeneric species *L. piscatorius* is more abundant on the slope due to its ontogenetic migration along the bathymetric gradient (predominance of juveniles on the shelf and large individuals on the slope; Macpherson & Duarte, 1991; Ungaro *et al*., 2002). In terms of geographical distribution, *L. budegassa* shows the highest abundance in the central sector of the investigated area (i.e., eastern Ligurian and northern Tyrrhenian Seas). This can be linked to the wide extension of the continental shelf in those two basins compared with the very narrow shelf in the western Ligurian Sea. Despite the wide continental shelf, there was low abundance in the central Tyrrhenian Sea (the southern part of the investigated area). Ungaro *et al*. (2002) and Barcala *et al*. (2019) also reported low abundance of the blackbellied angler in the central Mediterranean (central and southern Tyrrhenian Sea and the Strait of Sicily). These aspects could be due to environmental conditions other than depth (e.g., the type of sediment, etc.) that are not suitable for the species, or to the high fishing pressure on the stock exerted in those areas, because one of the most important Italian trawling fleets operate in these areas (Cataudella & Spagnolo, 2011; Sabatella *et al*., 2017)

With respect to the length-weight relationship, the negative allometric growth found in the present study has also been reported by others authors for *L. budegassa* in Mediterranean areas (Tsimenidis & Ondrias, 1980; García-Rodríguez *et al*., 2005). A growth pattern with length that is proportionally greater than weight can be explained by the substantial asymmetry between the head and the rest of the body, typical in the genus *Lophius* (García-Rodríguez *et al*., 2005). However, La Mesa & De Rossi (2008) reported isometric growth of the blackbellied angler in the Pomo Pit area of the Central Adriatic Sea.

L_{50} was estimated at 39.4 cm TL in females and 29.2 cm TL in males. Environmental and anthropogenic factors may affect maturity processes (Trippel, 1995) and can determine variations in L_{50}. These factors can explain the differences in L_{50} observed between the Mediterranean and Atlantic populations. In fact, L_{50} appears to always be greater for the Atlantic populations than the Mediterranean populations: 56.2 cm TL in Portuguese waters (Azevedo, 1996), 53.0 cm TL in Atlantic Iberian waters (Duarte *et al*., 2001; Landa *et al*., 2014), 58.7 cm TL in the Bay of Biscay (Quincoces, 2002), and 70.4 cm TL in Scottish waters (Laurenson *et al*., 2008). Considering the Mediterranean Sea, Tsimenidis (1984) estimated an L_{50} at 34.0 cm T in females and 24.0 cm TL in males of *L. budegassa* in the Aegean Sea, while Colmenero *et al* (2013) found 48.2 cm TL for females and 33.0 cm TL for males in the north-western Mediterranean. The present findings are in line with those results, but they differ from

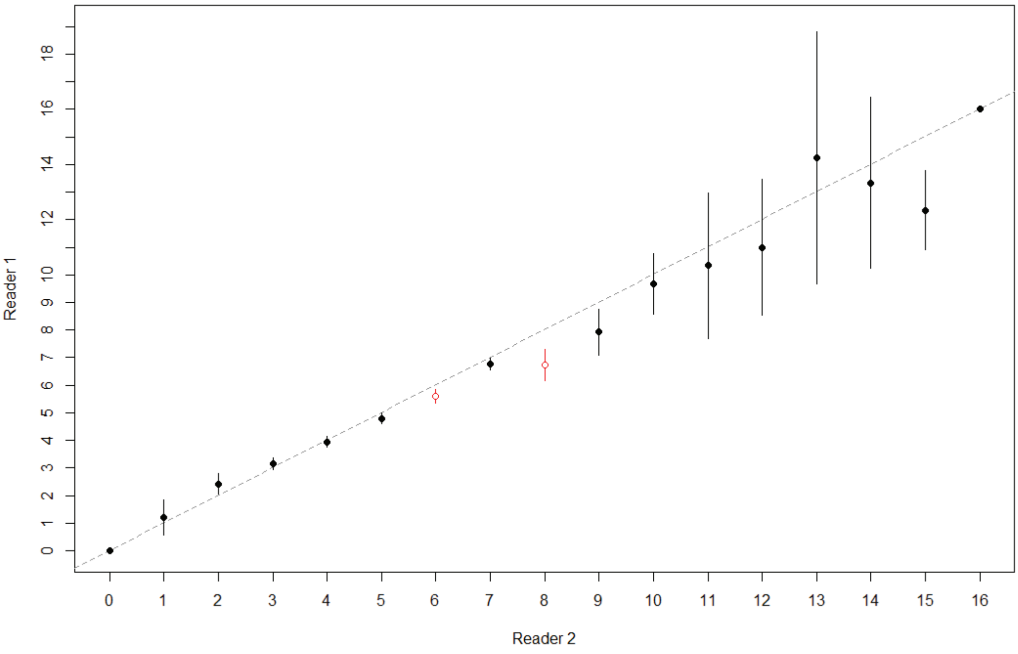

Fig. 8: Age bias plots between two readers with the mean age recorded (black points) and 95% confidence intervals (bars). Red points represent mean age estimates that differ significantly between readers.

those reported by Ungaro *et al*. (2002), who estimated an L_{50} of 66.2 cm TL in females. However, this value was calculated using data from different areas of the Mediterranean and a different maturity scale compared with the one that is currently (since 2004) in use at international level in the Mediterranean basin (please see the MEDITS Handbook version 9 available at https://www.sibm.it/MEDITS%202011/docs/Medits_Handbook_2017_version_9_5-60417r.pdf).

The growth of *L. budegassa* based on the ageing of hard structures has been investigated in European Atlantic waters using transversal sections of the first dorsal fin ray (*illicium*; Dupouy *et al*., 1986; Duarte *et al*., 1997; Landa *et al*., 2001). The ageing technique based on *illicium* has been standardised for both angler species, *L. piscatorius* and *L. budegassa*, from the European North Atlantic based on specific workshops (Anon, 1991, 1997, 1999; Landa *et al*., 2002). Studies and workshops comparing otolith and *illicium* readings showed that age estimates based on *illicium* readings provide greater agreement in terms of precision between readers (Dupouy *et al*., 1986).

Regarding the ageing procedures, ring identification has proved to be difficult due to unclear growth pattern (the presence of false rings) related mainly to the characteristics of the calcified structure, but also to preparation technique issues. In fact, a cut of *illicium* that is not perfectly perpendicular may lead to the observation of rings belonging to different planes. Therefore, the implementation of standardised procedures for the preparation of calcified structures and reading, as done in this study, is fundamental to improve the accuracy and reliability of ageing and to reduce the effects of bias (Vitale *et al.*, 2019; Carbonara & Follesa, 2019). Differences in growth parameters reported for Mediterranean and Atlantic populations, in terms of asymptotic length, can be related to different range sizes analysed and environmental variability that characterises these geographic regions, in particular, differences in temperature and productivity (Atkinson & Silby, 1997; Garcia-Rodriguez *et al*., 2005). It should also be noted that the calcified structures used for age determination (otoliths or *illicia*) usually lead to differences in ageing results (Landa & Pereda, 1997; La Mesa & De Rossi, 2008).

Various factors can determine a certain variability in age/growth data. In some cases, it may be related to technical factors such as the hard structure chosen to study the age/growth in a given species, the size range (Coggins *et al*., 2013), the preparation methods (Smith *et al*., 2016; Carbonara *et al.*, 2020), the age criteria used (Hüssy *et al*., 2016; Carbonara & Follesa, 2019), and/or the experience of the readers (Carbonara *et al*., 2019). Moreover, the geographical differences of the environmental

Table 5. Von Bertalanffy growth parameters (L_∞, k and t_0) and growth performance index (Φ') obtained for *L. budegassa* estimated by different authors. (Methodology: Illicium = direct reading; LFD = Length Frequency Distribution; MPA = Modal Progression Analysis).

Area	Region	Sex	Methodology	L_∞ (cm)	k (years^{-1})	t_0 (years)	Φ'	Authors
Mediterranean	Ligurian and northern Tyrrhenian Sea	F	illicium	74.5	0.10	-0.40	2.74	Present Study
		M		61.3	0.14	-0.38	2.72	
	NW Ionian Sea	C	illicium	68.4	0.10	-1.43	2.67	Carlucci *et al*. (2009)
		F		68.5	0.112	-1.18	2.72	
		M		60.3	0.109	-1.56	2.59	
	Spanish waters	C	illicium	90.0	0.08	-0.10	2.81	García-Rodríguez *et al*. (2005)
			LFD	102.0	0.15	-0.05	3.19	
	Spanish waters	C	LFD	96.7	0.178	-0.08	3.22	Landa and Barcala (2017)
		C	LFD	109.6	0.139	-0.05	3.22	
		C	MPA	105.4	0.144	-0.21	3.20	
	Aegean Sea	C	illicium	74.8	0.18	-0.34	3.00	Şenbahar and Özaydin (2020)
		F		73.5	0.186	-0.15	3.00	
		M		68.5	0.223	-0.17	3.01	
Atlantic	ICES Divisions VII and VIII	F	illicium	111.2	0.08	0.50	2.99	Dupouy *et al*. (1986)
		M		84.8	0.096	0.56	2.84	
	ICES Divisions VIIIc and IXa	C	illicium	101.7	0.08	-0.20	2.92	Duarte *et al*. (1997)
	ICES Divisions VIIIc and IXa	C	illicium	132.4	0.056	0.04	2.99	Landa *et al*. (1998)
	ICES Divisions VIIIc and IXa	C	illicium	93.5	0.101	0.38	2.95	Landa *et al*. (2001)
		M		71.5	0.13	0.05	2.82	
		F		93.5	0.101	0.50	2.94	

conditions (Bellodi *et al*., 2022), together with different degrees of fishing pressure (Schindler *et al.*, 2000; Carbonara *et al*., 2022), commonly represent an additional source of variation in growth characteristics.

In general, the growth parameters and growth performance index obtained in this study are comparable with those obtained in other areas of the Mediterranean (Table 5) and Atlantic. All of these studies have reported different growth patterns in females and males, with females showing slower growth rates, but reaching larger sizes than males. The different growth pattern between females and males should be considered while performing stock assessment, which relies on the availability of robust information on the biology and population dynamics of a stock. To this end, the results of the present study provide new insights on the biology of the blackbellied angler in the north-western Mediterranean, and are expected to contribute to future quantitative stock assessment.

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All authors have read and agreed to the published version of the manuscript.

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