Conversion factor for size structure reconstruction and growth of *Lophius gastrophysus* Miranda Ribeiro, 1915 catches in the South Atlantic Ocean

Arthur Tavares da Silva[1]*, Rafael de Almeida Tubino[2], Raquel Rennó Mascarenhas Martins[3],
Cassiano Monteiro-Neto[1] and Marcus Rodrigues da Costa[1]

[1] Universidade Federal Fluminense - Departamento de Biologia Marinha (Outeiro de São João Batista, s/n - Centro - Niterói - P.O.Box 100.644 - 24001-970 - RJ - Brazil).

[2] Universidade Federal Rural do Rio de Janeiro - Departamento de Biologia Animal (Rodovia BR 465, Km 07 - Zona Rural, Seropédica - 23890-000 - RJ - Brazil).

[3] Fundacao Instituto de Pesca do Estado do Rio de Janeiro (Praça Fonseca Ramos, s/n - Centro - Niterói - 24030-020 - RJ, Brazil).

* Corresponding author: arthurtavares@id.uff.br

ABSTRACT

Lophius gastrophysus is an exploited deep-sea demersal fishing resource in the Southeast-South region of Brazil, a capture target for the twin trawl multi-specific bottom trawling fleet. Considered a prized fish, it is commonly processed on board, retaining commercial cuts of the tail called *colas*. Thus it is difficult to recognize the original length of the specimens and, consequently, to assess the dynamics of sources and the impacts of catches. Individual length and weight data were used to generate body predictive models correlated to the monkfish *cola*. The parameters of growth, mortality and exploitation rate were also estimated from the size structure of *Lophius gastrophysus* captured by the industrial bottom trawling fleet in Southeast Brazil between May 2013 and April 2015, assessing monkfish stock based on indirect estimates of life history information. All predictive models of body size showed coefficients of determination above 0.9 (P < 0.001), indicating good data adjustments. The growth parameters were determined by the minimum residual variance methodology, being: L_∞ = 92.4 cm and k = 0.158/year. The size structure tended to increase with depth in the spring. Individuals under the age of sexual maturity contributed significantly to catches. The length of first sexual maturation was estimated at 48.6 cm and the recruitment age was between 6 and 7 years. The coefficients of total, natural, fishing and exploitation rates were estimated at: Z = 0.676; M = 0.241; F = 0.436 and E = 0.644. The fishing mortality rate was higher than the reference value (E > 0.50) indicating a state of overexploitation of the southeast most part of stock. A review of the current Brazilian legislation established for the species on the southeast coast is recommended.

Descriptors: Monkfish, Age, Growth, Mortality, Fishing.

INTRODUCTION

Baseline information on the size relationships involving length and weight variables are important predictive indices *i. e.*, weight-length ratio, length-length, fertility-length, and fertility-weight (Silva et al., 2016), with several applications in the science of fishing. Length measurements of a fish population are an important factor to investigate the ecological processes of a species, particularly due to the ease of obtaining this variable. From the size structure, it is possible to estimate the parameters of population growth and mortality and exploitation to better understand the dynamics of fish populations (Froese et al., 2018).

The monkfish, *Lophius gastrophysus* is a marine demersal teleost, distributed along the continental shelf and slope of the Atlantic Ocean between the United States and Argentina (Valentim et al., 2007). The species is found at depths down to 1000 meters and occurs with greater abundance in bottoms with unconsolidated substrates and cold waters (Vianna and Almeida, 2005; Botelho

et al., 2009). In the Southeast-South regions of Brazil, it is a relatively common component of the deep demersal ichthyofauna (Brasil, 2006), being exploited throughout the year (Perez et al., 2002a), with significant catches made by bottom trawl fleets. However, until 2002, it was also targeted for capture by deep gillnet fleets (Perez et al., 2002b).

The monkfish fishery is relatively recent, compared to other relevant species, for Brazilian fisheries harvests (Perez et al., 2002a). Until the mid-1990s, there was no demand for monkfish in the domestic market, and the fleet acted mostly upon traditional fishery resources distributed along the inner continental shelf (Botelho et al., 2009). This scenario changed from the 2000s onwards due to the combination of two factors: the foreign vessel leasing program and the displacement of the national fleet towards the outer continental shelf and slope fishing grounds (Perez et al., 2002a; Botelho et al., 2009). Thus, the deep-sea fisheries of the monkfish emerged with expectations of high yields and productivity (Perez et al., 2002b). As a result, the species experienced high exploitation rates without scientific projections of sustainable yields (Perez et al., 2002b). Subsequently, studies conducted by the Department of Fisheries and Aquaculture (DPA) of the Ministry of Agriculture, Livestock and Supply (MAPA) and the REVIZEE Project (Recursos Vivos na Zona Econômica Exclusiva) indicated the vulnerability of monkfish stocks as a consequence of the strong fishing pressures (Brasil, 2006). In the mid-2000s, the species was included in the National List of Overexploited Fish Species (Botelho et al.,2009). Despite the species' unfavourable scenario, few studies have been conducted to understand the population biology of *L. gastrophysus*.

Commercial landings by the fishing fleet are important sources of data for the development of population studies (Fonteles-Filho, 2011). Monkfish are often processed on board to obtain commercial cuts called "*colas*", which consist of the tail portion of the fish and are the main processing products of the species (Perez et al, 2002a). However, this procedure reduces the possibility of monitoring catches using length-based criteria (e.g., minimum and/or maximum catch sizes). Furthermore, it limits the estimation of relevant biological attributes for assessing stock status, which are usually based on length composition (Froese et al., 2018).

The regulation of the monkfish fishery was instituted by Interministerial Normative Instruction MPA/MMA 3rd, of September 4, 2009 (Brazil, 2009), which defines fisheries management criteria and procedures. Among them, there is the need for a fishing permit issued by the government fisheries authority, definition of fishing exclusion areas, limitation of the fleet to nine Brazilian vessels, with a mandatory on-board observer, an annual catch quota of 1,500 tons, minimum depth of action of 250 meters and use of a fixed bottom stationary net only. Finally, the regulation states that renewal of the fishing permit is conditional on determination of technical feasibility given the state of exploitation of the stock (Brasil, 2009).

In this sense, studies on the population structure in terms of size, age and growth and mortality rates of species subject to exploitation are the technical framework that supports the management of fishing activities (Dias-Neto, 2010; Fonteles-Filho, 2011). This set of information is important because it allows understanding the behavior of stocks against fishing pressure and the monitoring of attributes that influence the size of populations and, consequently, the abundance of resources (Dias-Neto, 2010; Prince et al., 2020). The present work aims to reconstruct the catch size structure of *L. gastrophisus* from *colas* landing data to determine its growth parameters, mortality rates and level of exploitation. Such information may help further understanding of species life history in Southwestern Atlantic-Brazil and contribute to decision-making in resource management.

METHODS

Sample collection and procedure

The study area comprises the continental shelf region between latitudes 21°56'S (Rio de Janeiro) and 24°45'S (São Paulo) (Figure 1), within the Southeastern-Eastern Brazil Marine Ecoregions (Spalding et al., 2007). The Brazil Current (BC) is formed by two surface waters and two water masses: (i) Coastal Water - CW; (ii) Tropical Water - TW. The South Atlantic Central Water (SACW) joins the BC at 20°S, between 400 and 500 m deep to the southwest-south. On the continental slope, between 1000 and 2000 meters deep, close to the parallel 25°S, flows the Intermediate Contour Current - ICC, with the Intermediary Antarctic Water mass - IAW; and further down,
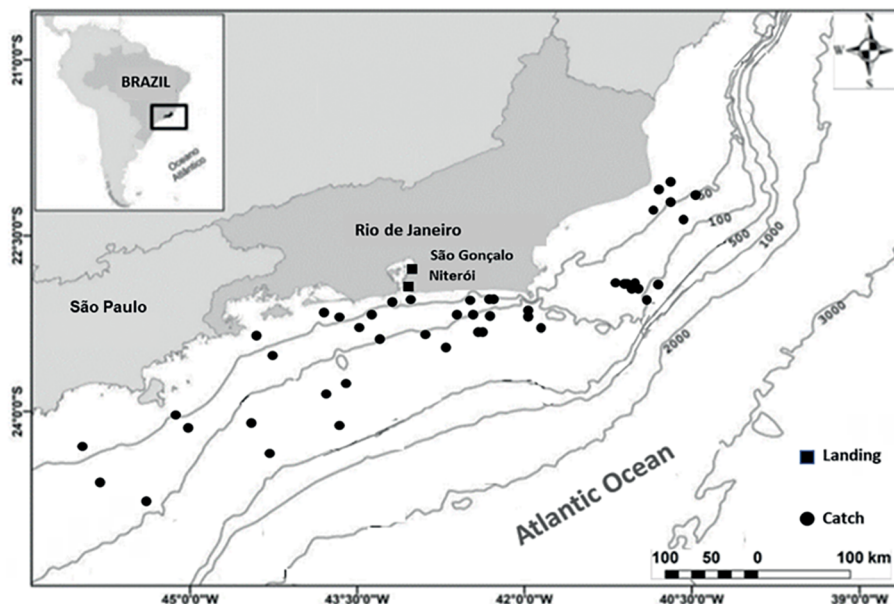
Figure 1. Area of operation of the double-bottom trawling fleet based in Rio de Janeiro. Capture points (circles) and landing ports (squares).

at approximately 3000 meters deep, the Deep Contour Current - DCC, carrying the North Atlantic Deep Water- NADW, also moving South. The most striking oceanographic feature in this region is the summer presence of the SACW on the inner continental shelf (around the municipality of Cabo Frio) separated by a strong thermocline from the surface layer of AT mixture. The inflection of the coastline associated with bathymetric changes (narrowing of the Cabo Frio platform towards the northeast) and the greater intensity of the northeast winds (NE) favors the coastal outcrop of cold waters (SACW) rich in nutrients, leading to increased local biological productivity (Albuquerque et al., 2012). During the winter, SACW retracts and the water column on the inner and middle shelf acquires almost homogeneous characteristics, with the disappearance of the thermocline. The region is characterized by the predominance of sand, mud and clay bottoms (Albuquerque et al., 2012).

The data used in the present study came from a sampling effort conducted at the landing docks of the municipalities of Niterói and São Gonçalo (Rio de Janerio State), monitoring the landings of the twin trawl bottom trawling fleet. In all, 34 vessels were monitored, with operating areas between 30 and 150m deep on the continental shelf of Southeast Brazil. The data matrix was composed of two sets of

information: the first consisted of a biometric database with information on *cola* length and weight, designated as *Cola* length (CL) and *Cola* weight (CW), of 5,879 captured specimens between November/2013 and June/2015 at depths of 30 to 150 m. *Cola* length was measured from the insertion of the first and third post-cephalic spines of the dorsal fin to the end of the caudal fin (Figure 2). This on-board processing practice aims to maximize the yields, with *cola* being the marketable body portion of the monkfish, thus the main component landed in this fishery. The second dataset came from whole individuals of *L. gastrophysus* obtained monthly from landings, as part of a monitoring program by the state fisheries authority, FIPERJ (Fundação Instituto de Pesca do Rio de Janeiro) with the participation of boat skippers and fishermen. The catches took place from May/2013 to April/2015 at depths of 30 to 120 m. The specimens were collected randomly at the time of unloading in order to allow all strata of size to be represented. A total of 372 specimens were collected, from which measures of total length (TL) in cm and total weight (TW) in grams were taken. Subsequently, *cola* cuts were obtained from 292 whole individuals, which were measured (cm) and weighed (g) to obtain the *cola* length (CL) and *cola* weight (CW).

Figure 2. Cutting cola of *Lophius gastrophysus* resulting from processing ready to take measurements of length (cm) and weight (g).

DATA ANALYSIS

Power regressions were constructed from CL and CW data obtained in laboratory from whole individuals, having TL and TW from the same individuals as dependent variables to generate reliable predictive equations. For this purpose, the following regressions were elaborated: TL = a x CL^b, TL = a x CW^b, TW = a x CL^b, TW = a x CW^b, where a = linear coefficient a nd b = slope. The fit of the data to the models was measured using the determination coefficient(R^2). The equations that provided the best adjustments for the CL and CW data from the biometric database for conversion to TL and TW were chosen. From the converted values and data from whole individuals, the weight-length relationship was estimated according to the Huxley equation (1924): TW = a x TL^b. where a = linear coeficient and b = slope coefficient (allometry c officient). To verify whether the increments in weight

are isometric (b = 3) or allometric (b ‹3 ‹b), the value of the slope was tested using the Student t-test $\left(t = \frac{(b-3)}{\text{SD}} \right)$, using a of 5% (Zar, 1999).

From the TL values measured and estimated by the regression, the individuals were grouped into 1.0 cm length classes for analysis of the length frequency distributions. Possible differences in fish size depending on depth (class: 0-50 m, 51-100 m, 101-150 m) and austral seasons (summer: January-March; autumn: April-June; winter: July-September and spring: October-December) were investigated using the Kruskal-Wallis test. The biomass (kg) of the catch landed was estimated (regression equations) by depth class, season and the estimated age of the individuals (interval of 1 year). The growth parameters of von Bertalanffy (1938) were estimated using an iterative routine to minimize variances according to Gonçalves and Fontoura (1999). The starting point is to obtain the average lengths of the age groups/cohorts, obtained from the analysis of the frequency distribution of the length data, grouped monthly. To this end, the Battacharya's method provided by the FISAT II FAO-ICLARM package was applied to identify the number of cohorts and estimate the respective average lengths. These average length values were used as seed input values to estimate growth parameters using the method of minimum residual variance (MINIVAR). This method allows quantification of the asymptotic length (L∞) and the instantaneous growth rate (k) with less variance from an estimated value of L∞ (Pauly empirical equation, 1983) and the assumed age of the first age group. To define the age of the first group, it was necessary to determine the interval of months between the reproductive/recruitment period and the appearance of the first age group in the samples and then divide this value by 12 (number of months in the annual cycle). From this data, the algorithm returns values of L∞ and k within biologically acceptable limits which are refined by the operator according to the biological characteristics of the species. Ages were assumed at 1 year intervals, taking into account the formation of an annual age ring observed in the species (Lopes, 2005). The selection of the best set of values is made based on the lowest residual variance (RV) obtained. As a reference, RV values below 0.5% were considered acceptable. The k parameter was estimated by the equation $k = \sum \left[-ln \left\{ 1 - \left(\frac{Lt}{L\infty} \right) \right\} \div t \right] \div n$, where Lt:

average length (cm) of the age group with assumed age t (years); L∞: asymptotic length (cm); and n: number of age-length pairs. The residual variance was given by the equation: $S^2 = \sum\left[\left\{L\infty \times \left(1-e^{k \times t}\right) - Lt\right\}^2 \div (n-1)\right]$. To verify the fit between parameters k and L∞ as well as consistency with the other estimates made for similar species, the growth performance index (φ) was estimated according to Pauly and Munro (1984): $\varnothing = \log k + 2 \times \log L\infty$. Longevity ($A_{0.95}$), defined as the time required to reach 95% of the asymptotic length, was estimated by the Taylor equation (1960): $A_{0.95} = t_0 + (2.996 \div k)$. To calculate the theoretical age at zero length (t_0), a parameter of the von Bertalanffy growth equation, the Pauly formula (1979) was used: $\log - t_0 = -0.392 - 0.275 \times \log L\infty - 1.038 \times \log k$.

The total mortality coeficient (Z) was estimated through the linearized length capture curve according to the model presented by Sparre and Venema (1992). The natural mortality coeficient (M) was obtained by the empirical equation of Rikhter and Efanov (1976): $M = 1.521 \div \left(T_{m50\%} \times 0.720\right) - 0.155$, where: $T_{m50\%}$ = age of first sexual maturation (corresponding to the length in which 50% of individuals reached sexual maturity). The $T_{m50\%}$ value was obtained using the von Bertalanffy (1938) (I) inverse equation using the 48.6 cm length of first sexual maturation ($L_{50\%}$) estimated by the empirical equation of Froese and Binohlan (2000) (II): (I) $t_{m50\%} = t_0 - \left(\frac{1}{k}\right) \times ln\left[1 - \left(\frac{L}{L\infty}\right)\right]$; (II) $\log L_{50\%} = 0.8979 \times \log L\infty - 0.0782$.

The fishing mortality coeficient (F) was determined by the difference between Z and M (I) whereas the exploitation rate (E) was estimated by the quotient between F and Z (II): (I) F = Z - M; (II) $E = \frac{F}{Z}$.

RESULTS

The power regressions to estimate TL and TW from the CL and CW data showed good adjustments for the conversion of biometric data (Table 1). Among all regressions, the following equations were selected: TL = 2.6282 x CL$^{0.8488}$, n = 254, R^2 = 0.964 and TW = 5.6032 x CW$^{0.9254}$, n = 260, R^2 = 0.956 (Fig. 3A and B).

The 372 whole individuals presented TL between 22.0 and 75.8 cm, mean ± standard error of 46.8 ± 0.49 cm and mode of 45.0 cm. The samples from the *cola* biometrics totaled 5,879 specimens, converted based on the regression TL = 2.6282 x CL$^{0.8488}$, which generated a distribution of total lengths that ranged from 18.0 to 84.6 cm, mean 49.8 ± 0 , 21 cm and modes between 47.0 and 49.0 cm. The frequency distribution by TL class

Table 1. Power regressions to estimate the total weight (TW) and total length (TL) from the *cola* weight (CW) and the *cola* length (CL). n = sample size, R^2 = coefficient of determination.

Predictor variable	Dependent variable	n	R^2
CW	TW	260	0,956
CL	TW	256	0,920
CW	TL	252	0,910
CL	TL	254	0,964
Conversion Factors			
TL = 2.6282 x CL$^{0.8488}$			
TW = 5.6032 x CW$^{0.9254}$			

(Fig. 4) for all individuals (*i. e.* whole and *cola*) indicated a predominance of specimens with total length between 45.0 and 51.0 cm and modes between 47.0 and 49.0 cm. Individuals smaller than 25.0 cm and larger than 70.0 cm were not abundant. The size structure showed significant variation between the seasons (Kruskal-Wallis, H = 885, p <0.05) with higher TL values in the spring months, both in 2013 and 2014. Significant differences were also found between the depth classes (Kruskal-Wallis, H = 50.27, p <0.05) with a clear tendency to increase the TL according to the depth increase, notably in the 101-150m depth range.

The weight-length relationship for grouped sexes was determined from weight and length data of 5,905 individuals, from whole specimens and converted "*cola*s", being estimated at: TW = 0.0136 x TL$^{3.0156}$, n = 5,905, R^2 = 0.953. The Student *t*-test did not indicate a significant difference for the coefficient *b* (*t* = - 0.21825, *p*> 0.05) characterizing growth of the isometric type (*b* = 3) (Fig 5).

The total monitored biomass landed was 12,379 kg. In 2013, 2,207 kg were landed during six months; in 2014, a total of 7,331 kg were landed in 11 months; and in 2015, 2,841 kg were landed in six months of sampling in the monitored ports. The estimated biomass values varied by depth classes, with more expressive values in the intermediate classes of 51-100 m and 101-150 m, with yields of 7,541 and 3,909 kg respectively, followed by the other classes of 0-50 and 151-200m with respectively 706 and 223 kg. Seasonally, there was an interannual pattern of higher yields in the spring/summer period followed by a decrease in autumn/winter (Table 2).
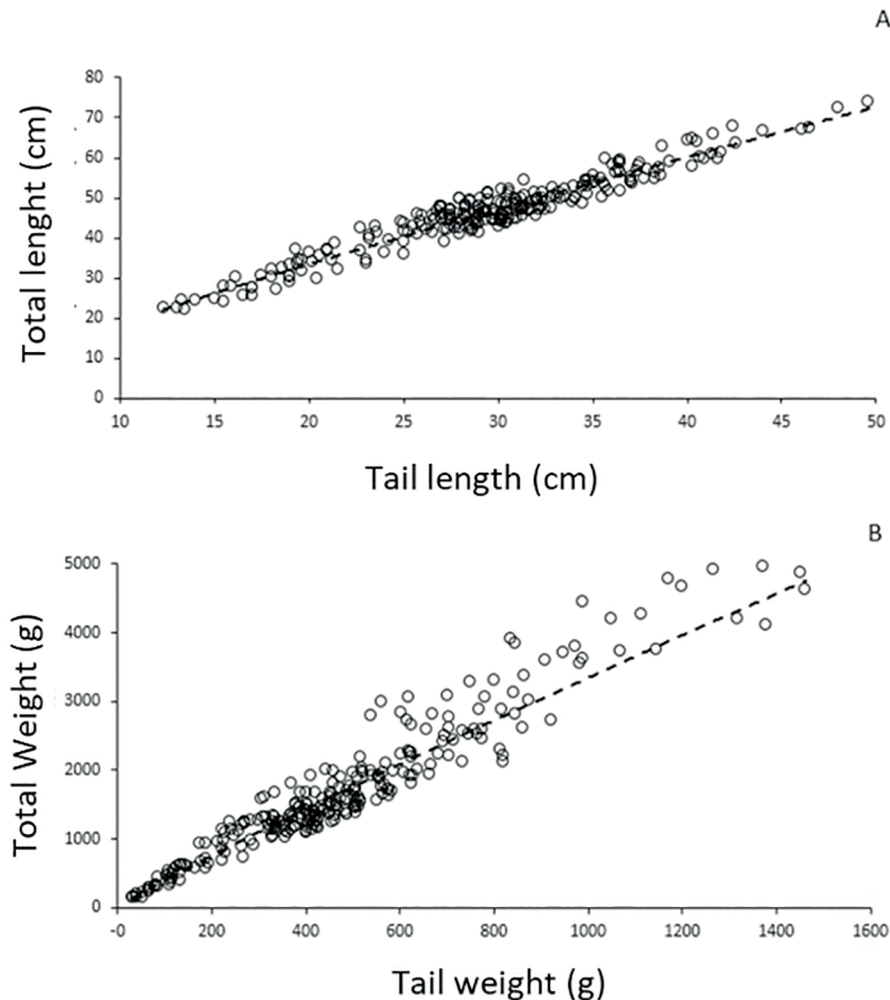
A

B

Figure 3. Power regressions between the *cola* length and the total length (A) and between the *cola* weight and the total weight (B).

From the length frequency distribution data, it was possible to estimate the growth parameters and identify the number of age groups (cohorts) present in the global sample. Modal decomposition using Battacharya's method identified five cohorts and their respective average lengths. Biological data of the species available in the literature were used to refine the results. The routine of minimum residual variance (VR) adjusted to von Bertalanffy's growth function returned 10 pairs of values (L∞ and k), with asymptotic lengths ranging from 92.0 to 92.9 cm and the instantaneous growth rate from 0.1587 to 0.1561 year^{-1}. The pair that provided the lowest RV value (0.0623) was L∞ = 92.4 and k = 0.1576 year^{-1} (Fig. 6).

Longevity was estimated at 17.20 years, the theoretical age t_0 at 1.765 and the growth performance index (φ) at 3.13. Table 3 summarizes the values of the growth parameters and performance indexes obtained in this work and those recorded in the literature for similar species.

The estimated von Bertalanffy growth equation was: $L = 92.4 \times \left[1 - e^{-0.158(t-1.765)} \right]$ (Fig. 7A). From the growth parameters, the capture curve converted into linearized length was constructed using the entire structure in sample size considering a theoretical year (May to April) (Fig. 7B). The age of recruitment to fishing was approximately 6 years, which corresponded to 31% of the catches in the study area (Fig. 7B); catches under the age of 6 years totaled 29% whereas catches over 6 years totaled 40%. In terms of biomass, production at the age of 6 was 3,185.6 kg, equivalent to 25.7% of the total. The estimated biomass for ages under 6 years was 1,523 kg (12.3% of the
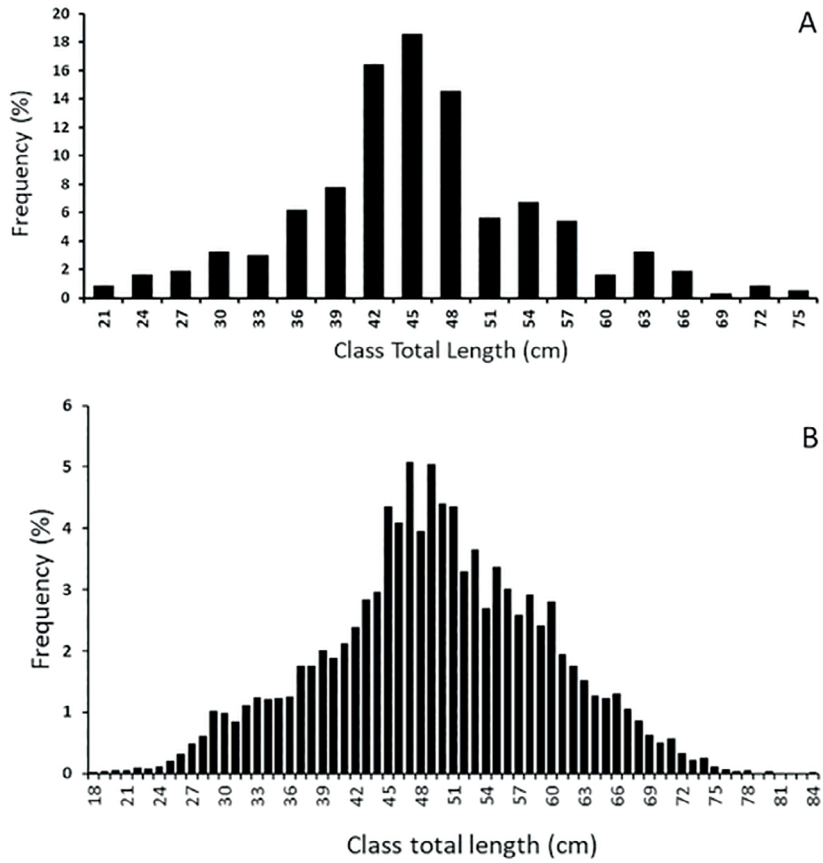
Figure 4. A = Total length frequency distributions of *L. gastrophysus* obtained directly from the sampling. B = Total length frequency distributions of *L. gastrophysus* resulting from the application of the conversion factors to the "colas" size structure.
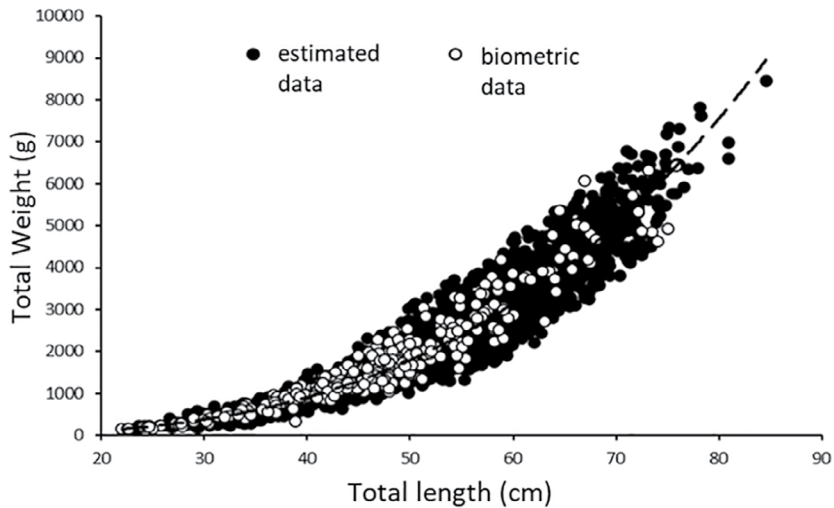

Figure 5. Weight/Length relationship of the monkfish *Lophius gastrophysus* in southeastern Brazil. Dark circles (estimated data) and light circles (biometric data).

Table 2. Estimates of biomass (kg) by season and depth class (m).

Season	Biomass (kg)
Autumn/2013	14.35
Winter/2013	573.13
Spring/2013	1,620.14
Summer/2014	1,555.31
Autumn/2014	1,118.76
Winter/2014	2,022.98
Spring/2014	2,634.55
Summer/2015	2,153.40
Autumn/2015	596.99
Winter/2015	89.75
Total	12,379.0
Depth (m)	Biomass (kg)
0-50	700.0
51-100	7,541.0
101-150	3,909.0
151-200	223.0
Total	12,373.0

by the method of Rikhter and Efanov (1976) was 0.241 year[1]. Fishing mortality (F) was 0.436 and the exploitation rate (E) equal to 0.644. Fishing mortality (F) was relatively higher than the natural mortality rate being the main vector of population mortality. Furthermore, the value of the exploitation rate suggests a state of overexploration of the stock.

DISCUSSION

In recent decades, fisheries scientists have used population size structure as a qualitative indicator of a species' development, which can be understood as the relationships between body measurements (total weight - TW vs. total length - TL) or between age and length (Schwamborn et al., 2019). Fish growth tends to be continuous throughout life, even after reaching sexual maturity. Thus, it is expected that random sampling of fish reflects the variations in size distribution of fish in the total stock, or part of the stock available in the catch area (King, 2007). Based on this information, it is possible to quantify the impacts of
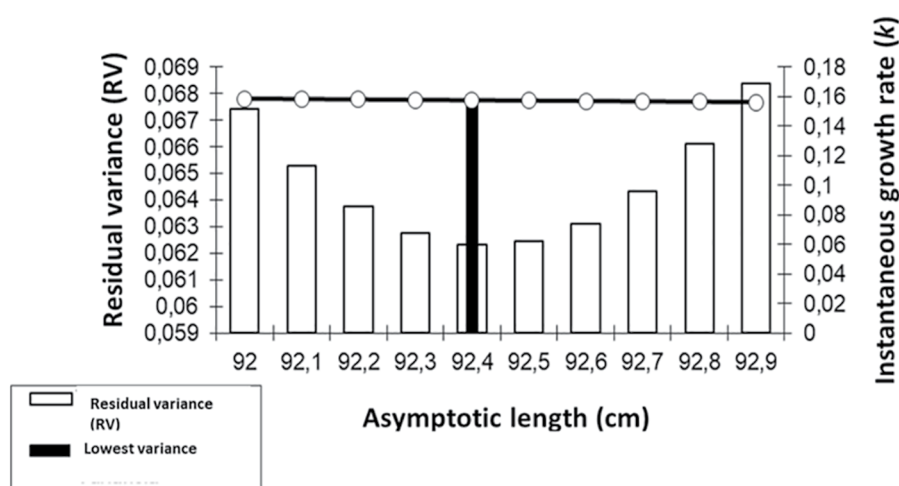

Figure 6. Minivar plots to estimate growth parameters of the von Bertalanffy growth function for the monkfish *Lophius gastrophysus* in southeastern Brazil. ◇ k

total), while over 6 years was 7,670.7 kg (62.0%). Thus, specimens under the age of sexual maturity (i_{50} = 6 years) contributed considerably to the catches in numbers, however in biomass they contributed less proportionally.

The instantaneous total mortality rate (Z) for the period 2013-2015 was estimated at 0.676 year[1]. The natural mortality rate (M) estimated

fishing on fish stocks, ensuring the safe exploitation of resources. Obtaining biological information about stocks is commonly challenging and ends up making stock monitoring dificult. However, size structure data are relatively easy to collect and serve as a starting point for population investigations. Thus, our results are in line with the principles of fisheries management by using simple

Table 3. Compilation of estimated growth parameter values for *Lophius* genus. Asymptotic length (L∞), growth constant (*k*), longevity, growth performance index (φ), sex and source of information. Data compiled at literature using only species with growth data available.

Species	L∞ (cm)	k (year⁻¹)	Longevity	φ	Sex	Source
L. gastrophysus	**92.4**	**0.158**	**17.20†**	**3,13**	**Grouped**	**This work**
L. gastrophysus	95.4	0.125	23.96†	-	Female	Lopes (2005)
L. gastrophysus	55.2	0.299	10.02†	-	Male	Lopes (2005)
L. gastrophysus	187.4	0.06	18‡	3.32	Grouped	Camilo and Schwingel (2019)
L. gastrophysus	89.1	0.110	27.23†	2.94	Grouped	Costa et al. (2019)
L. piscatorius	106.0	0.180	16.64†	3.31	Grouped	Crozier (1989)
L. piscatorius	122.0	0.100	29.96†	3.17	Grouped	Duarte et al. (1994)
L. piscatorius	140.0	0.110	27.23†	3.33	Grouped	Landa et al. (2008)
L. budegassa	97.0	0.178	16.83†	3.22	Grouped	Landa and Barcala (2017)
L. budegassa	103.0	0.150	19.97	3.20	Grouped	STECF (2013)

†$A_{0,95}$(year); ‡observed (direct method-Illicium).

and easily visualized data (size and weight of fish) to build a predictive model for monitoring the fishery.

In the Southwestern Atlantic, the main forms of commercialization of landed monkfish are either gutted individuals or only the *cola*. In cases like this, it is common to use conversion equations for biometric measurements to estimate the actual size and weight of the fish caught. This approach is common for the genus *Lophius*, as can be seen in Almeida et al. (1995). For *L. gastrophysus*, these conversions were applied by Perez et al. (2002a) to convert *cola* weight into total weight and subsequently derive estimates of yield and production. In this work, we used the size structure to estimate the parameters of growth and mortality. Our estimates showed good adjustments demonstrating the effectiveness of these predictive equations, in agreement with the findings of Perez et al. (2002a). Therefore, the estimates of the structure in size (*cola*) from the landings of the fishing fleet could be used in determining parameters of the life history of this resource.

The estimated weight-length ratio showed values of the coefficients *a* and *b* similar to those reported in the literature for the species and its cogenerics (Froese and Pauly, 2020), showing isometric growth. The differences observed in this and other studies can be attributed to a combination of factors such as: number of specimens evaluated, size structure, sex, gonadal maturity in addition to the preservation techniques used (Hossain et al, 2014). Morphometric relationships,

mainly of fishery resources, are necessary to estimate unknown measures from known measures. In addition to these, it is also possible to estimate the condition of individuals from the linear coefficient related to the body shape (Froese, 2006). In fish population dynamics, the most commonly used measures are length and weight. In this way, the parameters estimated here should be applied only within the specified length ranges, allowing good estimates of both total length and total individual weight/biomass landed from the monkfish colas.

Population parameters of the monkfish, including growth parameters, estimated from the reconstructed size structure, were similar to those presented by Lopes (2005) and Costa et al. (2019) for the Southwestern Atlantic . Our results were also consistent with growth parameters from cogeneric species with similar theoretical maximum lengths, available on the Fishbase platform (Froese and Pauly, 2020), as well as their performance index values (Tab. 3). Some differences observed may be associated with the inverse relationship between k and L∞, *i.e*. if a fish grows rapidly, it will take less time to reach its maximum length, which will have a lower value than if it had grown slowly and reached a larger size (Fonteles-Filho, 2011). However, we cannot rule out other factors acting on growth, which were not measured here. The selectivity of the fishing gear and the different catch/fishing areas can determine variations in the population structure in terms of size and other vital processes of the species, regardless of the growth rate, which
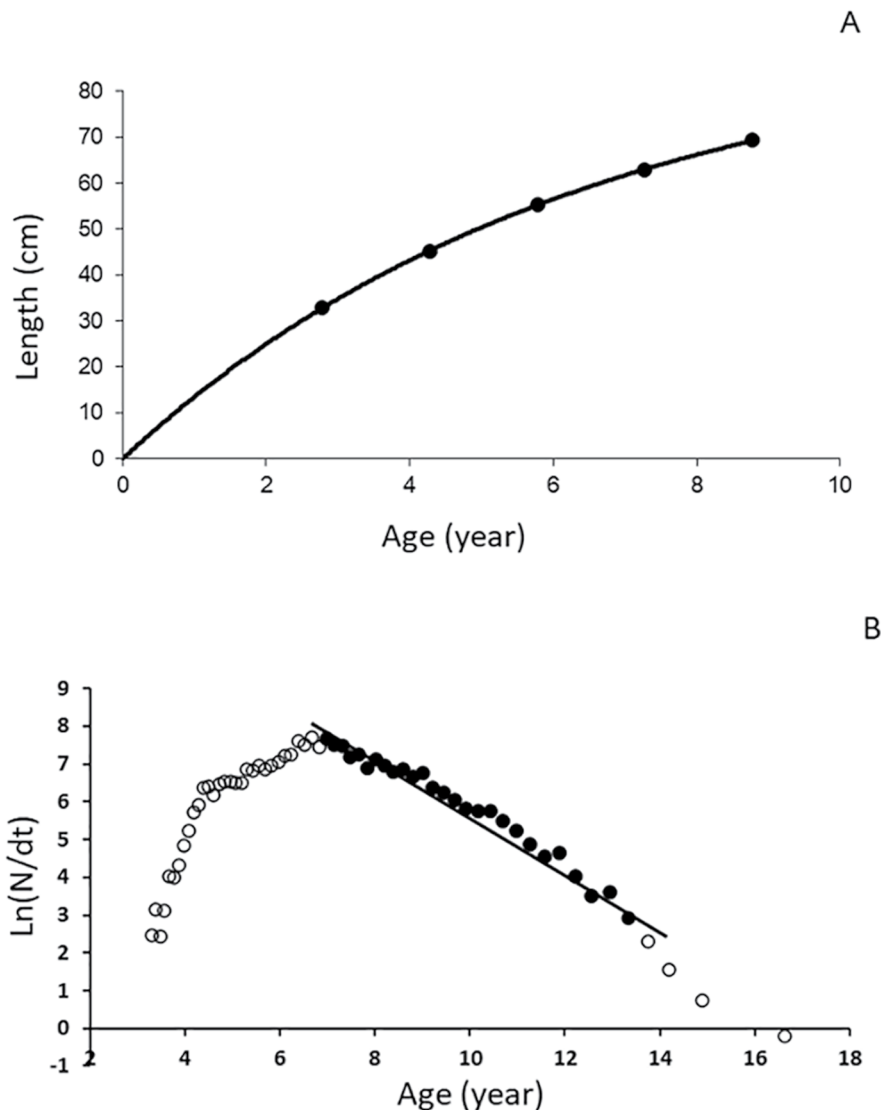
Figure 7. A - Estimated von Bertalanffy growth curves with minimal residual variance for the monkfish *L. gastrophysus* in southeastern Brazil. B - Length converted catch curves applied to length frequencies data. The slope of the right descending arm (black dots) of the curve allows the estimation of total mortality (Z; R^2 = 0,974). White dots (empirical data) the numbers of fish actually sampled (observed).

is genetically/physiologically determined for each species (Beverton and Holt, 1957; King, 2007). Other estimates of the population dynamics of the species have also been determined and are closely linked to growth. They are the rates of mortality, longevity and exploitation. The estimated growth coefficient has a physiological interpretation associated with the availability of food and the space occupied by the species, suggesting that it has to adapt to different realities, with the consequence of specific population parameters for each population or strata (Lowe-McConnell, 1999). Our indirect

estimates pointed to a relative age of 8.8 years, close to the findings of Camilo and Schwingel (2019) who used the illicium to determine age, with the highest frequency between 6 and 11 years (30-75 cm TL). The study by Sherwood et al. (2013) with the cogeneric species *L. americanus*, using the illicium, also observed ages between 8 and 10 years, indicating that this structure is an age predictor for this species. Several authors agree that lofiiform fishes are sit-and-wait predators, attracting their prey by moving the illicium (Valentim et. al, 2007). Even though a similar age pattern is

observed at different latitudes, such feeding behavior (variable between sexes, size and type of habitat) (Sherwood and Grabowski, 2006) could explain the variable nature of the presence of age rings in different locations.

The obtained longevity of 17.2 years is directly associated with the high value of t_0 and k, indicating that it is within the expected for the species, since Camilo and Schwingel (2019) registered monkfish individuals up to 18 years of age. Other authors assessing the growth of cogeneric species through vertebrae (Armstrong et al., 1992), illicium (Sherwood et al., 2013) and otoliths Sun et al., (2020) also observed longevities equivalent to our findings. Comparing the estimated values of mortality M and F, we can see that fishing was the most important factor (F>M) for the southeast stock. Although a fishery targeting monkfish is relatively recent, it is known that one species is the target of accidental capture in shrimp fisheries (Vianna and Almeida, 2005). Thus, it is possible that the high value of F is due not only to the targeted fishing but also to accidental captures. The estimated exploitation rate compared to the reference value equal to 0.5 (Gulland, 1983) indicates that this stock is under pressure for fishing above the sustainable limit for the region, corroborating the state of overexploitation observed in past studies (Perez, 2006). Thangstad et al. (2006) conducted studies with *L. budegassa* and *L. piscatorius* stocks with a similar size structure to that reported in the present study and obtained the following mortality estimates: M = 0.15, F varying from 0.42 - 0.76 and Z varying from 0.57 - 0.91 for age groups between 4 and 11 years old. Comparing the estimated values for M and F in both regions, we can see that the fishing gear is decisive for estimating the exploitation rate by placing stocks close to or above the sustainable limits of exploitation. In this sense, we agree with Thangstad et al. (2006) who reported the need for more research to improve and standardize such estimates to obtain more accurate data on the total permitted catch size.

Tradicional trawler fishing grounds on the Rio de Janeiro coast are concentrated in the shallower area of total distribuition of monkfish (30-150m) during all seasons, especially due to the limited tecnology of the fishing vessels (Martins, 2017). The monkfish catches are higher in spring and summer, due to the reproductive cicle of the specie and SACW sincronization which promotes increased local biological productivity and, consequently, greater availability of food. In addition, it is recognized that the monkfish responds quickly to changes in ambient temperature, following the SACW intrusion on the continental shelf (Soares-Gomes and Fernandes, 2005). This process increases the occurrence of juveniles in the region where the fishing fleet operates, as described by Valentim et al. (2007), and observed in the present study 10 years later. Catches of fishes under the age of 6 years, the estimated age of monkfish recruitment, totaled 29.0% of total removed biomass, while the size structure showed that 45.9% of landings in RJ correspond to juvenile fish, in number of individuals, (TL < $L_{50\%}$ = 48.6 cm). The high capture of juvenile individuals by the twin trawl bottom trawling fleet has already been documented and appears to be the result of the concentration of the fleet's capture power in specimens smaller than 50.0 cm (Perez et al., 2002b). This pattern was observed initially by Schwingel and Andrade (2002) and later by Perez et al. (2002b) on the Southeast-South coast of Brazil. On the coast of Rio de Janeiro, similar observations were made by Valentim et al., (2007) and confirmed in this work. This pattern suggests a future loss of revenue and ecossytem health, due to the capture of a large number of low-value individuals which did not contribute to stock recomposition yet, decreasing the sustainability of these fishing practice and the monkfish as a fishery resource.

CONCLUSION

From the results raised here, we can conclude that: i) the conversion equations for body measurements are good predictors for the reconstruction of the species' life history parameters and ii) the trawling fleet acting on the monkfish stock, even if considering it an accessory species, needs accurate management measures, which involve status and integrity monitoring of this stock since some parameters of its population dynamics already indicate a state of overexploitation of the catches made off the southeast coast. We recommend the development of an adequate management strategy for this fishery in view of minimizing the high catches of juveniles landed, maximizing the benefits of this fishery for food supply security.

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AUTHOR CONTRIBUTIONS

A. T. S.: Conceptualization; Formal analysis; Writing - original draft; Writing - review & editing;

R. A. T.: Data curation; Conceptualization; Metodology, Writing - review & editing;

R. R. M. M.: Writing - review & editing; Resources;

C. M. N.: Resources; Funding acquisition; Writing - review & editing;

M. R. C.: Software; Validation; Methodology; Writing - review & editing.

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