ORIGINAL RESEARCH

Population assessment of *Micropogonias furnieri* on the coast of Rio de Janeiro, Brazil, using a length-based analysis

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ABSTRACT. Size structure was used as a proxy to describe the population dynamics of *Micropogonias furnieri* in a marine conservation unit in the southwest Atlantic Ocean. Length-based population assessment revealed the following estimates: asymptotic length (L_∞) = 65.86 cm, growth coefficient (K) = 0.11 year^{-1}, theoretical age of the fish (t_0) = -0.99, natural mortality (M) = 0.30 year^{-1}, instantaneous mortality (Z) = 0.35 year^{-1}, fishing mortality (F) = 0.05 year^{-1}, and exploitation rate (E_{cur}) = 0.14. The maximum (E_{max}) and optimum ($E_{50\%}$) exploitation rates were 0.61 and 0.31, respectively. Both raw data and corrected probability of capture indicated recruitment from April to June. Individuals between 20.00-44.00 cm in total length (TL) dominated the entire population. The length-based spawning potential ratio assessment model indicated that *M. furnieri* becomes vulnerable at average sizes of 50% selectivity (L_{S50}) = 21.38 cm and 95% selectivity (L_{S95}) = 31.62 cm, which is between the transition from the juvenile to the adult, and the length was similar to that of the first sexual maturity. Fishing pressure, estimated as F/M = 0.29 through the spawning potential ratio (SPR) model, and SPR values ranging between 44-68%, suggest that this portion of the *M. furnieri* population has been exploited within a safe range, considering the 50% limit of its reproductive potential. In line with this, the evaluated length structure showed similarities with regional studies, and also reflected the unique RESEXMAR-Itaipu reference points, i.e. F < M and $E_{cur} < E_{50\%}$ (the exploitation rate at which 50% of the spawning biomass is reduced). Our results suggest that length-based analysis may be a useful tool for assessing data-poor fisheries because it enables the inclusion of several years of length-frequency data and multiple gears with minimal prerequisites. Additionally, it provides an opportunity to estimate other life-history parameters used in stock assessments.

Key words: Whitemouth croaker, size composition, fish growth, mortality, life-history, fisheries management.

Evaluación de la población de *Micropogonias furnieri* en la costa de Río de Janeiro, Brasil, mediante un análisis basado en la longitud

RESUMEN. La estructura de tallas se utilizó como proxy para describir la dinámica poblacional de *Micropogonias furnieri* en una unidad de conservación marina en el Océano Atlántico Suroccidental. La evaluación poblacional basada en la talla reveló las siguientes estimaciones: talla asintótica (L_∞) = 65,86 cm, coeficiente de crecimiento (K) = 0,11 año^{-1}, edad teórica del pez (t_0) = -0,99, mortalidad natural (M) = 0,30 año^{-1}, mortalidad instantánea (Z) = 0,35 año^{-1}, mortalidad por pesca (F) = 0,05

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año^{-1} y tasa de explotación (E_{cur}) = 0,14. Las tasas de explotación máxima (E_{max}) y óptima ($E_{50\%}$) fueron 0,61 y 0,31, respectivamente. Tanto los datos brutos como la probabilidad de captura corregida indicaron un reclutamiento de abril a junio. Los individuos con un largo total (LT) de entre 20,00 y 44,00 cm dominaron toda la población. El modelo de evaluación de la tasa potencial de desove basado en la talla indicó que *M. furnieri* se vuelve vulnerable en los tamaños promedio de selectividad del 50% (L_{S50}) = 21,38 cm y del 95% (L_{S95}) = 31,62 cm, que está entre la transición del juvenil al adulto y la longitud es similar a la de primera madurez sexual. La presión por pesca, estimada como F/M = 0,29 a través del modelo de razón de potencial de desove (SPR), y los valores de SPR que oscilan entre 44-68%, sugieren que esta porción de la población de *M. furnieri* ha sido explotada dentro de un rango seguro, considerando el límite del 50% de su potencial reproductivo. En línea con esto, la estructura de longitud evaluada mostró similitudes con estudios regionales, y también reflejó los puntos de referencia únicos de RESEXMAR-Itaipú, es decir, F < M y $E_{cur} < E_{50\%}$ (la tasa de explotación en la que se reduce el 50% de la biomasa desovante). Nuestros resultados sugieren que el análisis basado en la talla puede ser una herramienta útil para evaluar pesquerías con escasez de datos, ya que permite incluir varios años de datos de frecuencia de tallas y múltiples artes de pesca con requisitos mínimos. Además, brinda la oportunidad de estimar otros parámetros del ciclo de vida utilizados en las evaluaciones de poblaciones.

Palabras clave: Corvina negra, composición por tallas, crecimiento de los peces, mortalidad, ciclo de vida, gestión pesquera.

INTRODUCTION

The whitemouth croaker, *Micropogonias furnieri* (Desmarest, 1823), inhabits coastal and estuarine waters from the Gulf of Mexico and Antilles (20° N) to the Gulf of San Matias in Argentina (41° S) (Isaac 1988; Cergole et al. 2005). Adults are found on the continental shelf, while juveniles inhabit bays and estuaries using these sheltered waters as nurseries (Robert and Chaves 2001; Costa and Araújo 2003; Santos et al. 2015). Mature individuals move to the adjacent continental or sheltered estuarine areas to spawn (Acha et al. 1999; Jaureguizar et al. 2003; Norbis and Verocai 2005; Braverman et al. 2009; Albuquerque et al. 2012). The species is distributed across waters of neighboring countries including Argentina and Uruguay in the south (Norbis and Galli 2013) and French Guiana, Suriname, and Guyana in the north (Vaz-dos-Santos et al. 2007). In southeastern Brazil, this species is targeted by both small-scale and industrial fisheries. Small-scale fisheries (SSFs) operate in estuarine and shallow coastal waters mainly using gillnets and otter trawls/ beach seines (Costa and Araújo 2003; Santos et al. 2017). In contrast, industrial fisheries use pair, otter, and double-rig trawlers and bottom gillnets over the shelf (Cergole and Rossi-Wongtschowski 2003; Ávila-da-Silva et al. 2007). Moreover, the species supports a large industrial and artisanal fishery along the Brazilian coast, with annual catches of over 40,000 t (MPA 2012; FIPERJ 2020). Both Haimovici et al. (2021) and Dias et al. (2022) agree that this species is heavily fished and overexploited.

Near the mouth of Guanabara Bay, Rio de Janeiro (Brazil), a small and old community of artisanal fishers has developed an SSF in the coastal zone off Itaipu, where this species forms a phenotypically distinct population. Studies by Franco et al. (2023) confirmed the historical presence of this species in the region, identifying two genotypic (Macaé-North versus Itaipu-Central/ Ilha Grande-South) and three phenotypic (North, Central, and South) populations along the coast of Rio de Janeiro. These findings underscore both the ecological importance and economic value of this species, with the local fishery playing a vital socioeconomic role for coastal communities (Tubino et al. 2014). The fishing area was established under the Territorial Use Rights for Fisheries as the Itaipu Marine Extractive Reserve (RESEXMAR-Itaipu). This is a spatial type of property rights granted to individuals or groups of fishers, in which they have access privileges and fishing rights to exploit fishery resources (Christy 1982; Quynh et al. 2017). The RESEXMAR-Itaipu covers an area of 39.4 km^2. Within this area, traditional fishers may establish management strategies for stocks based on fishers' local ecological knowledge (FLEK), which is orally transmitted from one generation to another and constantly updated during day-to-day experiences of fishers as a complex adaptive system (Loto et al. 2019). Findings from our research will provide fishers and managers of RESEXMAR-Itaipu with practical tools to integrate traditional ecological knowledge with scientific data, enabling the establishment of effective management regulations for this species in the region.

Micropogonias furnieri is an important local fishery resource, with a pronounced increase in catches between the periods of 1974-1975 (270 kg) and 2001-2003 (51,309 kg) (Tubino et al. 2014). However, few attempts have been made to develop monitoring programs collecting life history information on this species captured by small-scale fisheries. Such information constitutes the basis for stock assessment and understanding the birth, growth, and death of fishes (Jennings et al. 2001; Lin and Tzeng 2010). Thus, stock assessments may shed light on the dynamics of fish populations under fishing pressure, thereby assisting in selecting the most appropriate management choices for the sustainable use of these resources (Mozo et al. 2006; Panhwar and Liu 2013).

Traditional methods of studying the dynamics of exploited fish stocks are primarily based on age-structured data (Lepak et al. 2012; Volpedo and Vaz-dos-Santos 2015; Pacheco et al. 2021). However, estimating the age of tropical fish is challenging because of overlapping age rings, particularly in older fish. Stock assessment methods based on length, frequency, and catch per unit effort data have become the preferred choice when age-structured fishery data are limited (Velasco et al. 2007). The use of computers and theoretical advantages of analytical methods based on length-frequency analysis (LFA) have led to the development of new techniques for handling poor data (Pauly and Morgan 1987; Pauly 1990; Castro et al. 2002). Stock assessment methods based on length, rather than age, have become increasingly common in fisheries studies (Jones 1984; Pauly and Morgan 1987; Velasco et al. 2007; Amin et al. 2008; Bentes et al. 2016; Raza et al. 2022). The von Bertalanffy growth model (von Bertalanffy 1938) is the most widely applied due to its mathematical simplicity. More accurate methods have been developed, such as bootstrapped LFA (bootLFA) and bootstrapped Electronic LEngth Frequency ANalysis with genetic algorithm (ELEFAN_GA), which enable the evaluation of uncertainties around estimated parameters (Mateus and Penha 2007; Silva et al. 2014; Sá-Oliveira et al. 2015; Mildenberger et al. 2017b). Among length-based approaches, the ELEFAN_GA method is a popular technique for estimating growth parameters. This method, based on the ELEFAN I framework introduced by Pauly and David (1981), incorporates a genetic algorithm (GA) implemented by Scrucca (2013) in the R package GA. Mildenberger et al. (2017b) further refined this integration making the ELEFAN_GA method a reliable tool for estimating L_∞ and K from time series of length-frequency data. When specific recommendations and criteria are followed, LFA proves to be a reliable tool for assessing growth parameters essential for fishery stock assessment and management (Schwamborn et al. 2023).

Despite its economic relevance, there is little information on the stock assessment of *M. furnieri* captured by SSFs. This study aimed to determine some of the main life history parameters (growth, mortality, recruitment pattern, and spawning potential) of *M. furnieri* captured with beach trawls and gillnets in RESEXMAR-Itaipu, and compare them with data from other areas. By examining these biological benchmarks within a spatially managed artisanal fishery, our study provides critical insights for testing the hypothesis of a locally adapted *M. furnieri* population, an issue of ecological significance and management relevance, given the species' phenotypic differentiation and the unique socio-ecological context of the conservation unit.

MATERIALS AND METHODS

Study area

The RESEXMAR-Itaipu covers an area of 39.43 km^2. The area is located east of the mouth of Guanabara Bay and creates a semi-sheltered cove protected by three coastal islands. It harbors an intensive small-scale fishery established in the 18th century (Loto et al. 2018, 2019). Most fishing occurs within the limits of RESEXMAR-Itaipu, but gill netters may extend these limits to a larger area (Figure 1). Over the past four decades, the Itaipu Small-Scale Fishery System has undergone significant changes due to factors such as gentrification, economic pressures, and technological advances. Loto et al. (2018) assessed these temporal changes, including variations in fishing gear. For instance, the beach seine, which was 120 m long in the 1970s, increased to 200 m between 2001 and 2003, and reached 250 m between 2013 and 2016. Mesh sizes also fluctuated during these periods, ranging from 40-45 mm to 18-32 mm, and currently to 18-45 mm. A similar trend was observed in 'corvineira' gillnets, which showed variations in both length and mesh size. In the 1970s, nets were 330 m long with mesh sizes of 45-60 mm, later increasing to 1,031 m with mesh sizes ranging from 45-70 mm. In the most recent period, net lengths range from 500 to 1,600 m, with mesh sizes still between 45-70 mm. These shifts emphasize the adaptability of the fishery, which has evolved in response to environmental, economic and social changes, including seasonal variations in fishing activity and catch composition.

Sample collection

Length data for *M. furnieri* were collected from catches of small-scale beach seine and gill-

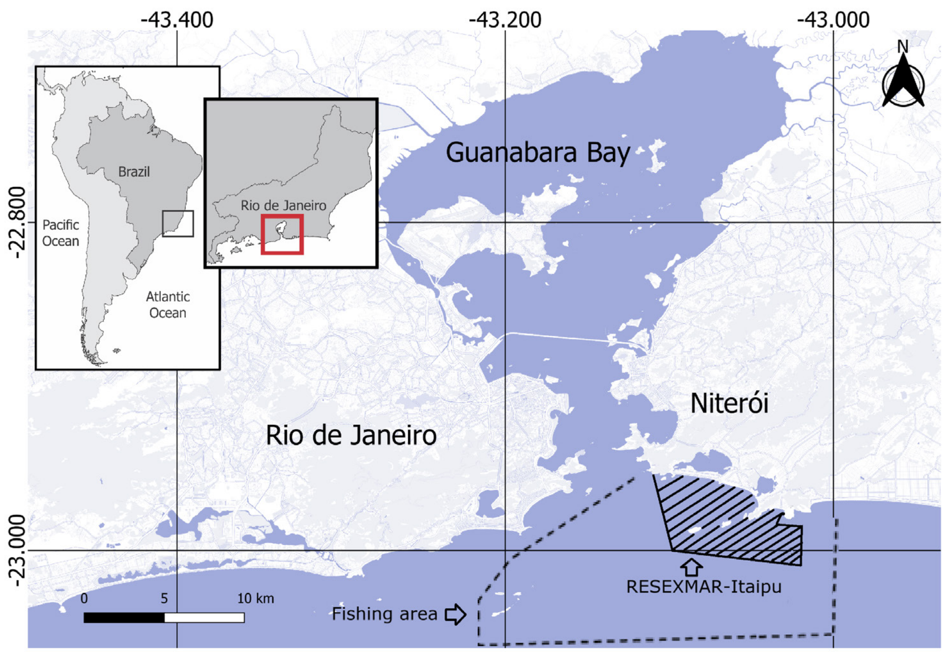

Figure 1. Geographical location of the State of Rio de Janeiro and detail of the coastal region showing the RESEXMAR-Itaipu area (Marine Extractive Reserve, hatched area), which is a protected area dedicated to sustainable fishing practices, and the fishing area used by local fishermen (dotted line).

net fisheries within RESEXMAR-Itaipu during a 48-month sampling period from January 2001 to December 2004. All hauls occurred over a 200-m beach stretch. Boats were monitored by teams of 2-3 observers at the landing site on the sampling day. Total length (TL, in cm) and total weight (TW, in g) of fish were taken whenever possible. Once a month, one full beach seine haul was conducted to collect scientific information, including the TL and TW of *M. furnieri*.

Data analysis

Stock assessment was conducted using individual TLs and the TropFishR package (Mildenberger et al. 2017a) to calculate population growth parameters. The TropFishR includes enhanced versions of all functions of the FAO-ICLARM Stock Assessment Tool II (FISAT II) (Gayanilo et al. 2005). We applied an optimized bootstrapped ELEFAN_GA (Mildenberger et al. 2017b; Schwamborn et al. 2019) to the length-frequency distributions (LFD) to assess uncertainties around growth estimates. The length data were grouped into 2-cm size classes to obtain approximately 20-25 length classes, as suggested by Gayanilo et al. (2002). Data from corresponding months across different years (e.g. January 2001, January 2002, January 2003, and January 2004) were merged monthly and treated as a single theoretical year to minimize adjustment errors in population parameters. The selectivity curve was used to correct the length-frequency data for gear selection in small fish (Sparre and Venema 1997). The Bhattacharya method is a statistical approach used to separate length-frequency distributions into distinct cohorts by decomposing data into overlapping normal distributions, each representing a group of individuals of similar size and age.

The relative growth-weight/length relationship was calculated using the equation $W = a.L^b$ (Pauly and Munro 1984), and logarithmically transformed into $\log W = \log a + b \log L$, where W is the weight (g), L is the total length (cm) of the fish, a is the intercept of the regression curve (related to fish body form), and b is the regression coefficient (exponent indicating growth) (Froese 2006). This coefficient was compared with and tested against the value of 3 (t test, Zar 1984) to determine deviation from isometric growth. Growth parameters were investigated by fitting a seasonally oscillating von Bertalanffy growth function (VBGF) (Somers 1988):

$$L_t = L_\infty \left(1 - \exp^{-(k(t-t_0)-\left(\frac{CK}{2\pi}\right)\sin 2\pi + \left(\frac{CK}{2\pi}\right)\sin 2\pi\,(t_0-t_s)}\right)$$

where L_∞ is the asymptotic length, K is the von Bertalanffy growth coefficient, L_t is the length at age t, C is the amplitude of growth oscillations (typically between 0-1; values > 1 imply rare periods of length shrinkage), t_0 is the theoretical age of the fish when L_t is equal to zero, and t_s is the fraction of a year (relative to the age of recruitment, $t = 0$) where the sine wave oscillation begins (i.e. turns positive). One additional output of ELEFAN_GA run in TropFishR is the parameter t_{anchor}, which represents the fraction of the year in which yearly repeating growth curves cross the length equal to zero.

The VBGF parameters were adjusted using the TropFishR ELEFAN_GA function. The genetic algorithm uses the idea of natural selection to find the best-scoring parameter combinations. These parameters were treated as genes carried by individuals in the population. Individuals with the highest fitness (i.e. Rn score) reproduced and recombined their parameter values in subsequent generations. Over time, the population becomes dominated by individuals with an ever-increasing fitness. The growth parameter seed values were obtained from FISAT II routines (Maximum Length Estimation and K-Scan) (Gayanilo et al. 2005) and applied to the LFDs. For the more complex genetic algorithm (ELEFAN_GA), some key settings were fine-tuned for precision, allowing for assessment of uncertainties around the growth estimates (Mildenberger et al. 2017b; Schwamborn et al. 2019). The ELEFAN_GA settings were fine-tuned for precision as follows: MA = 5, maxiter = 50, run = 10, pmutation

= 0.2, and considering a dataset with popSize = 100. The progression of modal groups in monthly length-frequency distributions was analyzed using Bhattacharya's method implemented in FISAT II. The dataset was divided into 2.00-cm size-class intervals. This method identifies cohorts based on the mean length of each modal group (Sparre et al. 1989; Gayanilo et al. 1994). The growth performance index (Φ) was estimated based on the equation: $\Phi = \log K + 2 \log L_\infty$ (Pauly and Munro 1984).

The recruitment pattern was obtained by back-projecting onto the time axis using a single set of growth parameters (Pauly 1982), a time series of length-frequency data, and reconstructing the predominant recruitment pulse. Input parameters were L_∞, K, and t_0.

The length-converted catch curve (Gayanilo et al. 2002) was used to estimate the total instantaneous mortality (Z). Based on the mean annual environmental temperature of 21.8 °C recorded during the sampling period, an independent estimate of natural mortality (M) was obtain using the equation of Pauly (1980). The fishing mortality (F) was derived from the difference between Z and M. Mortality estimates (F and Z) were used to determine the exploitation rate (E_{cur}), calculated as $E_{cur} = F/Z$. The estimated longevity (T_{max}) represents a theoretical maximum age, used in stock assessment models and in comparisons between species (Taylor 1958 $-T_{max} = 3/k$). Resource status was evaluated by comparing estimates of the fishing mortality rate with the target (F_{opt}) and limit (F_{limit}) biological reference points which were defined as: $F_{opt} = 0.5$ M and $F_{limit} = 2/3$ M (Patterson 1992). The size at first maturation (L_{50}), defined as the length at which 50% of individuals reach sexual maturity, was estimated based on values for females reported in Santos et al. (2015) ($L_{50} = 34.1$) and applied to the pooled data (both sexes). The length at 95% selectivity (L_{95}) was calculated as $L_{95} = 1.1 \times L_{50}$, according to Prince et al. (2015).

The minimum catch size was determined using the length-converted catch curve, which estimated the probability of capture by backward extrapolation of the catch curve and by comparison of the numbers actually caught with those that ought to have been caught. Total and natural mortalities were required to extrapolate the probability of capture from the length-converted catch curve (Gayanilo et al. 2005).

The spawning potential was estimated using the length-based spawning potential ratio (LBSPR) method, which compares a modeled length composition of a stock without fishing mortality with the current length composition observed from the catches. This method has been developed for data-limited fisheries, where little data are available other than a representative sample of the size structure of the vulnerable portion of the population (i.e. catch).

The LBSPR assessment technique requires length-catch composition data and life history parameters including the M/K ratio, L_∞, and the size at which 50% (L_{50}) and 95% (L_{95}) of the population matures. These models estimate the length at 50% (L_{S50}) and 95% (L_{S95}) selectivity and the F/M ratio, which were then used to calculate the spawning potential ratio (SPR) (Hordyk et al. 2015a, 2015b). This can be used as an indicator of the stock unit status for fishery management. All simulation modelling was performed using the open-source statistical software R (R Core Team 2016).

RESULTS

A total of 1,148 *M. furnieri* individuals were caught by the Itaipu fishery between 2001 and 2004. Individuals ranging from 8.00 to 60.00 cm TL were caught by beach seine, and those ranging from 30.00 to 60.50 cm TL were caught by gillnets (Figure 2 A). The population was characterized by five modal size groups, with total lengths ranging from 8.00 to 60.50 cm (Figure 2 B). Among the five well-defined size groups identified by the Bhattacharya method, the presence of addition-

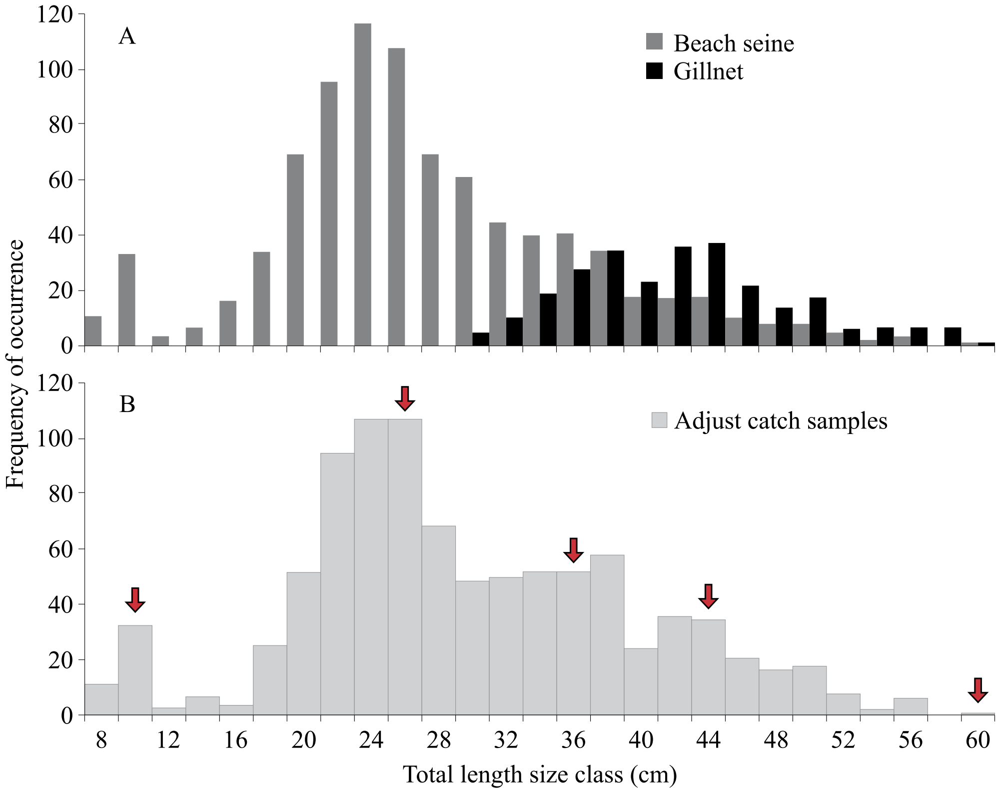

Figure 2. A) Length frequencies distribution of *Micropogonias furnieri* in RESEXMAR-Itaipu cove as collected by beach seine and gillnet between 2001-2004. B) Pooled length frequency data for one theoretical year, after correction for selective patterns. Red arrows indicate size groups.

al cohorts was observed along the size gradient. This structure suggests that recruitment occurs in relatively distinct events, with partial overlap between cohorts and possible variations in growth and survival rates among age groups. Linear regression analysis of the weight-length relationship for pooled data yielded the following parameters: $a = 0.0073$, $b = 3.11$, and $r^2 = 0.97$. The estimated parameter *b* was significantly different from the isometric growth value ($t = 6.16$, $P < 0.01$).

The monthly distribution of TL classes revealed the presence of different cohorts throughout the year (Figure 3). Smaller individuals (10-20 cm TL) were mainly recorded in April and November, indicating more intense recruitment periods during these months. Intermediate-sized individuals (20-40 cm TL) were observed more consistently, with higher concentrations from March to May and again in October and November, reflecting the growth of previously recruited cohorts. Larger individuals (> 40 cm TL) were less frequent, occurring primarily in April and May, suggesting the presence of older fish or remnants of previous cycles.

The VBGF was applied to *M. furnieri* length data and yielded the following results: $L_\infty = 65.86$ cm, $K = 0.11$ year^{-1}, $t_{anchor} = 0.34$, $C = 0.61$, and $t_s = 0.76$ (Figure 4). From the growth parameter estimates, we obtained $t_0 = -0.99$ and $A_{0.95} = 27.2$ years. Growth performance (Φ) was estimated to be 2.68. Results from this study were compared with those reported from different locations within the geographical distribution range of the species (Table 1).

The recruitment pattern of *M. furnieri* obtained by backward-projection was continuous through-

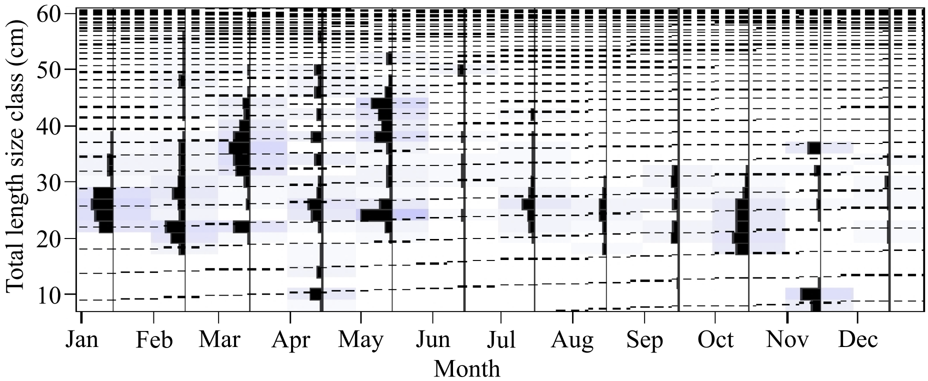

Figure 3. Growth curves for cohorts estimated from the size structure of *Micropogonias furnieri* in RESEXMAR-Itaipu (2001-2004 pooled data), drawn using a seasonally oscillating von Bertalanffy growth function by ELEFAN_GA. Observed length frequencies are shown as black bars, while darker and more intense purple shading indicates greater numbers of individuals recorded in each size class and month.

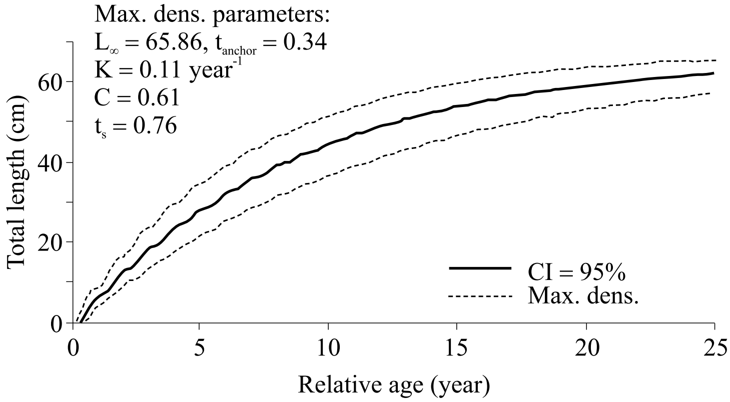

Figure 4. Growth curve (thick black line) for *Micropogonias furnieri*, based on the kernel density distribution derived from full bootstrap resampling (Nruns = 1,000). Dashed lines indicate the 95% confidence contours.

out the year, with two major peaks and no recruitment in December. The first peak occurred in April (18.64), while the second peak was observed in September (9.47%) (Figure 5).

The total instantaneous mortality rate (Z), estimated from length-converted catch curves based on growth parameters was 0.35 year^{-1} ($r^2 = 0.96$). The annual natural mortality rate (M) from the empirical formula of Pauly was 0.30 year^{-1}, the instantaneous fishing mortality rate (F) was 0.05 year^{-1}, and the current exploitation rate (E_{cur}) was 0.14.

This particular stock unit was assessed from a representative sample of the catch length structure (L_∞ and M/K ratio calculated) associated with the available regional data of size at maturity. Using these input parameters, we obtained the following estimates (95% confidence intervals): LBSPR = 0.56 (0.44-0.68), L_{S50} = 21.57 (20.35-22.79 cm), L_{S95} = 31.62 (29.58-33.66 cm) and F/M = 0.29 (0.17-0.41). A length-frequency histogram was plotted using the collected data and compared with the expected size composition for SPR equal to 1, or 100% of the population's potential (Figure 6 A). The estimated M/K ratio was 2.72, and the SPR was 56%, ranging from 44% to 68% when accounting for uncertainties in the life history pa-

Table 1. Growth parameters of *Micropogonias furnieri* within the species geographical distribution range for grouped sexes. BR = Brasil, MAC = Macaé, SIG = Santos-Iha Grande, SC = Santa Catarina, RS = Rio Grande do Sul and RJ = Rio de Janeiro. LFA = length-frequency analysis; LAA = length-at-age; VPA = virtual population analysis. T_{max} = maximum theoretical age.

L_∞	K	t_0	Φ (Phi)	T_{max}	Method	Region (type of fishery)	Source
38.60	0.50	-0.28	2.87	6.0	LFA	Caribbean Sea (scientific cruises)	García and Duarte (2006)
74.10	0.15	-0.15	2.92	20.0	VPA	Caribbean Sea (artisanal)	Soomai et al. (2000)
34.00	0.44	0.36	2.71	6.8	LFA	Caribbean Sea (artisanal)	Mozo et al. (2006)
53.15	0.05	-8.84	2.15	60.0	LAA	BR southeast (artisanal)	Santos et al. (2017)
96.15	0.08	-0.99	2.87	37.5	LFA	BR southeast (industrial)	Carneiro (2007)
60.83	0.27	-0.54	3.00	11.1	LAA	BR-MAC southeast (scientific cruises)	Haimovici et al. (2016)
51.99	0.17	-2.45	2.66	17.6	LAA	BR-SIG southeast	
52.03	0.23	-1.69	2.79	13.0	LAA	BR-SC south	
62.04	0.21	-1.72	2.91	14.3	LAA	BR-RS south	
50.70	0.25	0.14	2.81	12.0	LAA	BR south	Vazzoler (1962)
57.49	0.27	0.28	2.95	11.1	LAA	BR south (industrial)	Haimovici and Umpierre (1996)
52.78	0.18	-2.81	2.70	16.7	LAA	BR south (industrial)	Haimovici et al. (2021)
58.58	0.22	-1.09	2.88	13.6	LAA		
67.73	0.23	-0.16	3.02	13.0	LAA		
64.34	0.32	-0.02	3.12	9.4	LAA		
67.39	0.24	-0.42	3.04	12.5	LAA		
30.20	0.19	-2.12	2.24	15.8	LAA	Uruguay (scientific samples)	Borthagaray et al. (2011)
65.86	0.11	-0.99	2.68	27.2	LFA	BR-RJ- Southeast (artisanal)	In this study

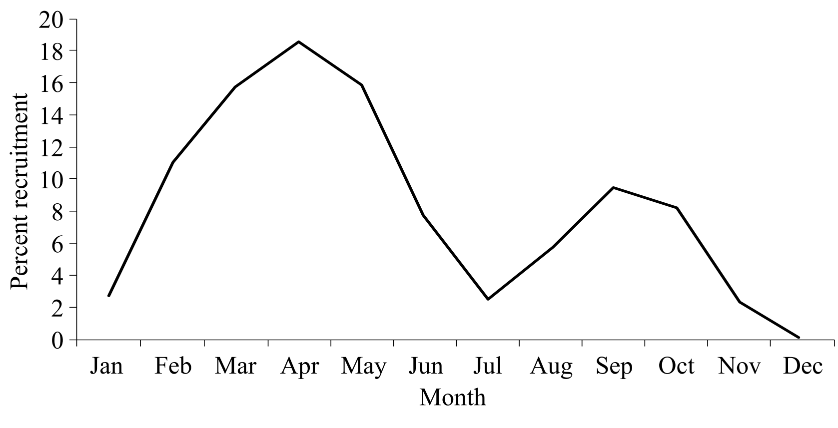

Figure 5. Recruitment pattern of *Micropogonias furnieri* in RESEXMAR-Itaipu obtained by the backward-projection of the restructured length-frequency data into one theoretical year timescale using the trajectory defined by the von Bertalanffy growth function (VBGF).

rameters (Figure 6 B). These scenarios suggested a 44% loss of spawning potential in relation to apparent conditions. These estimates showed acceptable confidence intervals for the primary and secondary datasets. The plot suggested that the species is being exploited close to the limit of 50% of its reproductive potential (Figure 6 B).

DISCUSSION

Small-scale fisheries in southeastern Brazil, particularly in RESEXMAR-Itaipu, are characterized by their multispecies composition, with catches comprising a diverse range of species that vary seasonally and interannually. Examples include *Mugil liza*, *Selene* spp., *Caranx hippos*, *Trichiurus lepturus*, *Priacanthus arenatus,* and *Thyrsitops lepidopoides*, among others (Tubino et al. 2007, 2014). In recent years, the capture of non-traditional species, such as *Porichthys porosissimus*, has increased, driven by consumer demand and new market opportunities (Loto et al. 2018). These patterns reflect the adaptability of SSF to changing ecological and economic conditions (Tubino et al. 2007; Loto et al. 2018).

Among the species supporting coastal fisheries in the region, *M. furnieri* stands out for its historical and economic importance. With estuarine-dependent early life stages and a wide distribution across the continental shelf as an adult (Costa and Araújo 2003), this demersal species has been a valuable resource for coastal communities, including those in RESEXMAR-Itaipu since prehistoric times (Lopes et al. 2016). Its slow and prolonged life cycle contributes to its vulnerability but also to its dominance in catches (Vasconcellos et al. 2011; Mulato et al. 2015; Amorim and Monteiro-Neto 2016). The local production chain of RESEXMAR-Itaipu has relied heavily on *M. furnieri*, which is primarily caught by beach trawls and other traditional fishing gear (FIPERJ 2020). The abundance of the whitemouth croaker in Itaipu is further supported by the contributions of Guanabara Bay, a large estuary that provides shelter, refuge, and food for its recruits (Mulato et al. 2015). Our results provide key life history parameters (growth, mortality, re-

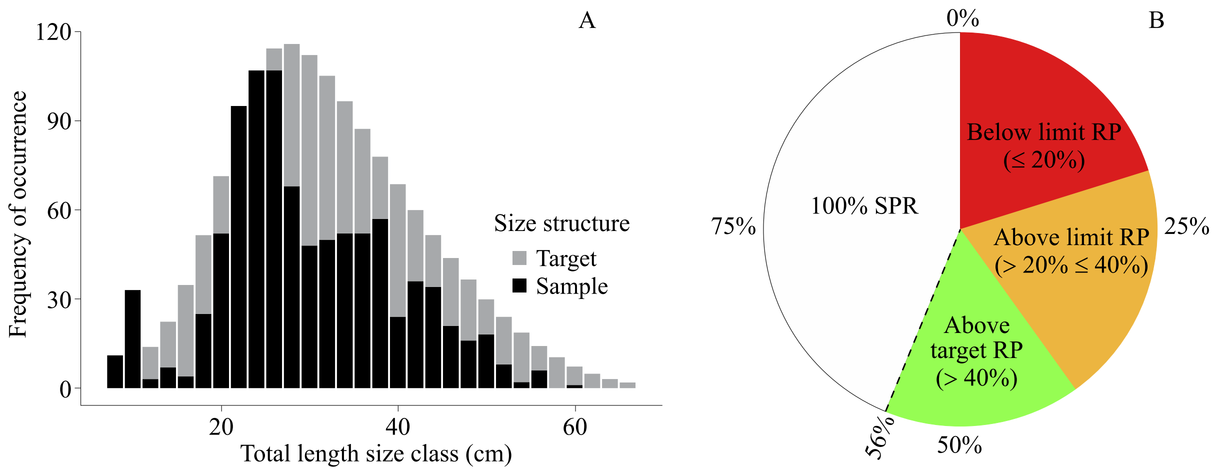

Figure 6. Outputs of the length-based spawning potential ratio (LBSPR) model include two main visualizations. A) Length-frequency distribution of sampled fished population of *Micropogonias furnieri* (black) caught by artisanal fisheries in coastal waters of Itaipu compared to the target size composition predicted by the fitted LBSPR model (grey). B) Reference Points (RP) derived from the fitted LBSPR model. The chart categorizes the Spawning Potential Ration (SPR) into four zones: below the limit RP, above the limit RP, above the target RP, and the theoretical 100% SPR. The dotted line indicates the estimated SPR for the sampled population.

cruitment patterns, and spawning potential) for *M. furnieri* captured using fishing gear traditionally employed by the SSF in RESEXMAR-Itaipu. We hypothesize that these traditional fishing practices maintain their selective character through sustainable techniques, such as catch seasonality and the watchman practice, both of which are rooted in local ecological knowledge (FLEK). This traditional knowledge complements scientific and technical expertise, offering valuable insights for fisheries management (Silva et al. 2020). In support of this, growth parameters for *M. furnieri* presented here highlight the variability in life history traits across different regions and fisheries types. These data, including asymptotic length, growth rate, and performance index, provide a useful comparison to the life history traits observed in *M. furnieri* within the SSF of RESEXMAR-Itaipu, reinforcing our hypothesis that traditional fishing practices influence the life history characteristics of the species.

Our study used a maximum length (L_{max}) of 60.50 cm as a seed value for estimating L_∞, which was larger than the 48.00 cm reported by Santos et al. (2017) for samples from artisanal catches off the coast of São Paulo. Additionally, experimental studies on spatial and temporal distribution patterns by Costa and Araújo (2003) and Mulato et al. (2015) in the bays of Sepetiba and Guanabara observed maximum TLs of 30.00 and 53.00 cm, respectively, which were lower than those found in this study. According to these studies, fish in semi-enclosed environments seek refuge in shallow waters, with continuous recruitment peaks from autumn to spring. This information on L_{max} and recruitment patterns is essential for obtaining accurate estimates of growth parameters from length-frequency data.

Our findings are consistent with those of Santos et al. (2015, 2017), who studied reproductive aspects, age, and growth of *M. furnieri* in Ubatuba Bay, São Paulo. They identified gonadosomatic index (IGS) peaks for females in August, November, April, and May, and observed the formation of one annual growth ring during autumn/winter. These reproductive patterns align with the recruitment peaks observed in our study, where smaller individuals (recruits) were more abundant, confirming the timing of reproduction and enhancing the accuracy of the modal progressions used to estimate growth parameters. Furthermore, genetic studies by Vasconcelos et al. (2015) identified three distinct stocks of *M. furnieri* along the Brazilian coast: one in northern Brazil (1° S), another between 23° S and 29° S, and a third south of 29° S. These findings, along with the phenotypic and genotypic differentiation observed by Franco et al. (2023), emphasize the importance of managing these fisheries as separate stocks. Such management should account for regional variations in population structure and dynamics, ensuring more effective and sustainable fisheries management.

Comparisons with population parameters from other studies revealed differences between species occurrence areas. The two individual growth parameters (L_∞ and K), determined from the TL, showed inverse trends. Species with rapid growth reach their maximum length more quickly, resulting in a smaller size, while species that grow slowly tend to reach larger sizes (Fonteles-Filho 2011). The phi (Φ) growth performance index for this species, based on the L_∞ and K estimates, was 2.68, similar to values observed in the southeast region of Brazil. This supports results from Pauly (1991), who suggested that Φ is constant for a family or similar taxa. The estimated longevity of 27.2 years, derived from the K values, is consistent with the evidence presented here (Table 1), which demonstrates the capacity of the species to live for more than a decade. Thus, our findings support the postulate of Haimovici et al. (2021), who described *M. furnieri* as a medium-sized, long-lived species (i.e. with an average maximum length of 65 cm) and a lifespan ranging from 27 to 38 years.

In stock assessment models, mortality, longevity, and exploitation rates are dependent on primary variables (number of individuals, length, and weight) and secondary variables (L_∞ and K) to generate accurate predictions of stock status (Velasco et al. 2007). These rates for the *M. furnieri* population can be comprehensively understood through integrated analyses, including natural mortality (M = 0.30 year^{-1}), fishing mortality (F = 0.05 year^{-1}), total mortality (Z = 0.35 year^{-1}), and exploitation rates (E_{cur} = 0.14), along with reference points such as F_{opt} = 0.15 and F_{limit} = 0.20. All mortality rates contribute to the reduction in the number of individuals, both in a cohort and in the population as a whole (Pauly 1980; Sparre et al. 1989). Therefore, density-dependent relationships may determine physiological (individual-level) or ecological (environmental-level) variations in the number of individuals. Additionally, various capture methods (such as fishing gear selectivity) influence the different population size classes.

Length-based models used for estimating Z, including the length-converted catch curve and Beverton and Holt equation, are based on the steady-state premise of constant recruitment and mortality according to age class over time. However, in practice, these conditions are rarely met, making such estimates biased (Pauly 1990). Such bias, can be related to the C value, which represents the amplitude of seasonal oscillation (Sparre et al. 1989). When C = 0, no growth seasonality is observed. As C increases, seasonal oscillations become more pronounced. When C = 1, the growth rate becomes zero at the winter point. The winter point refers to the period when growth slows down or is at its slowest. The longer the time series of tropical species length-frequency data (long-lived or not) associated with ambient temperature data, the greater the probability that length-structured catch curves will produce Z values equal to or similar to those from length-based curves. Age-structured catch curves are unbiased because age growth is not seasonally based. In this context, the Z-value appears to be accurate and reliable. The total mortality (Z) estimated in southern Brazil between 1976 and 1998 was 0.075 (1976-1980) and 0.11 (1989-1992) for age ≅ 30 year^{-1} and 0.22 for age = 22 year^{-1} (1997-1998) (Haimovici and Ignácio 2005). For southeastern Brazil, Z = 0.59 (1997-1998) and age = 15 years^{-1} (Carneiro 2007). For Trinidad waters, Z = 1.2 (1977-1982) and age ≅ 7 years^{-1} (Manickchand-Heileman and Kenny 1990). In the Caribbean Sea, Z = 2.16 (1995) and age ≅ 7 years^{-1} (Mozo et al. 2006), and for this study, Z = 0.35 and age ≅ 27 years^{-1} (number of cohorts observed for LFD data). In addition, several studies on biological parameters of *M. furnieri* have suggested a discontinuity in the population/stock along its geographic distribution area. For whitemouth croaker, estimates of longevity and L_∞ vary from 5.71 year^{-1}/38.60 cm (García and Duarte 2006) to 51.5 year^{-1}/53.15 cm (Santos et al. 2017) and 27.50 year^{-1}/65.86 cm in this study. Thus, this species exhibits clear species-specific behavior along its distribution area, and our data fall within the expected range for the species and its distribution.

Estimates of the exploitation rate (E_{cur} = 0.14) were lower than the E = 0.5 value, which is the exploitation level that maintains the spawning stock biomass at 50% of the virgin spawning biomass (Gulland 1971). Biological reference points were higher than the estimated F values. Maximum limits of fishing mortality values, which should not be exceeded to maintain the self-renewal capacity of the stock, were F_{opt} = 0.15 and F_{limit} = 0.20. This indicates that fishing of this species in the RESEXMAR-Itaipu region provides regular fishing income with low local fishing pressure on the available southeast stock. Although this species may be considered overexploited in other regions, such as the southern Brazilian stocks (Haimovici and Cardoso 2017), Uruguay (Vögler et al. 2020), and the Colombian Caribbean (Mozo et al. 2006), the fishing pressure in Itaipu appears to be sustainable. The fishing power in Itaipu comprises 21 motorized aluminum boats with an average size of 5.3 m. Loto et al. (2018) evaluated temporal changes in fishing activities carried out at RESEXMAR-Itaipu and observed that between the 1970s and 2013, the whitemouth croaker emerged as the main target of fisheries, reaching stable catches of approximately 33 t year^{-1}.

Another point of biological reference is the species spawning potential determined from the size of the sampled individuals. This correlates with the size at sexual maturity and L_∞. Using this approach, we observed that the SPR (56%) was higher than 20% (limit reference point) and 40% (target reference point), as suggested by Cope and Punt (2009). Other estimates of L_{S50}, L_{S95}, and F/M corroborated with our hypothesis that the fishing community operating in RESEXMAR-Itaipu did not exert fishing pressure on the southeastern stock to the point of collapse. However, the fishing pressure F/M metric estimated by our model was relatively low (0.17) when compared with the expected values for sustainable catches (F/M = 0.8-1.0), which is when both rates are almost equivalent (Zhou et al. 2012). Our results recorded catches of immature individuals along with adults because of the use of non-selective (beach seine) and selective (gillnet) fishing gear. Such evidence was also corroborated by the L_{S50} and L_{S95} estimates whose values were close to main modes of the LFD of both catches (beach seine: 21.57 cm, ± CV and gillnets: 31.62 cm, ± CV). As expected, the effect of size-dependent mortality was more noticeable in catch-size structures under these conditions. This occurs whenever there are high M/K values, where the expected size structure of the catch consists of a proportionally greater number of smaller-sized individuals with increased size-dependent natural mortality. Hordyk et al. (2015a) and Prince et al. (2015) demonstrated that the expected unfished size distribution is dependent primarily on the M/K ratio, with L_∞ working effectively as a scaling parameter. The M/K ratio for fish stocks is often believed to be approximately 1.5, which is a typical value for adults of species growing throughout their life, reaching a maximum size at the maximum age (Taylor 1958; Jensen 1996; Hordyk et al. 2015b; Froese et al. 2016). Prince et al. (2015) demonstrated that this ratio is much more variable in fish stocks and ranges from 0.5 to above 3.0.

By integrating different approaches, our analysis indicated that a portion of the southeastern population available for capture by the fishing community at RESEXMAR-Itaipu did not show evidence of overexploitation at the local level. Furthermore, life history parameters investigated in this region can aid in managing the southeastern stock by consolidating data for comparative assessments based on catches from different areas. At the local level, Loto et al. (2018) evaluated the spatial distribution of whitemouth croaker catches and their relationship with the RESEXMAR-Itaipu area. Their findings highlighted the capacity of this small-scale fishing system to adapt to changes over time. A clear example of this is the exploitation of *M. furnieri*, which was initially an accessory resource in the 1970s but became the main resource for the local community starting in 2000. The rapid expansion of its exploitation has created a need for more information on the biological status of this species to develop effective conservation and management measures. Overall, results reinforce the importance of integrating biological, ecological, and fishery parameters to support conservation strategies and sustainable management of the resource.

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Author contributions

Marcus R. Costa: conceptualization; formal analysis; supervision; validation; writing-review and editing. Rafael de Almeida Tubino: methodology; visualization; writing-review and editing. Pablo Mendonça: methodology; visualization; writing-review and editing. Felipe Douglas Mendonça

Cadilho: methodology; software; writing-review and editing. Cassiano Monteiro-Neto: conceptualization; resources; data curation; formal analysis; writing-review and editing.

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