Lat. Am. J. Aquat. Res., 44(5): 1080-1095, 2016
"Pathways for sustainable industrial fisheries in southeastern and southern Brazil"
P.M. Arana, P.R. Pezzuto, A.O. Ávila-da-Silva, D. Queirolo, J.A.A. Perez & C.A. Arfelli (eds.).
DOI: 10.3856/vol44-issue5-fulltext-18

Research Article

Stocks and management units of *Micropogonias furnieri* (Desmarest, 1823) in southwestern Atlantic

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ABSTRACT. The whitemouth croaker *Micropogonias furnieri* is a demersal coastal and estuarine sciaenid fish intensely exploited by small and large scale fisheries in Brazil, Uruguay and Argentina between 22° and 40°S. To study the stocks structure of the whitemouth croaker along southeastern (SEB) and southern Brazil (SB) between 22°28' and 33°53'S, morphometric, meristic and growth data were collected during a bottom trawl survey. Consistent differences between different latitudes were not observed neither for the univariate comparisons of the number of gill rakers and dorsal and pectoral fin rays nor for five morphometric measurements. A principal component analysis of the five morphometric measures did not show a geographical grouping pattern. However, the age structure and growth differed significantly between south and north of Cape Santa Marta Grande (29◦S). Former references and this study support the existence of two independent stocks of whitemouth croaker in southeastern and southern Brazil and diverse published studies indicate some degree of mixture between fishes spawning along southern Brazil, Uruguay and Argentina. In terms of access of the fleets there are three jurisdictions: along SB and SEB, where only Brazilian boats fish, in the common fishery zone of Uruguay and Argentina where both countries fish and south of 39ºS, where only Argentinian boats can fish but where the whitemouth croaker is not an important target. Efficient management requires the identification of management units based in stocks structure, life history, distribution of the fisheries and jurisdictions. When all these factors are taken into account, excluding local coastal small scale fisheries management, three geographical management units were identified in the shared waters of Argentinian and Uruguayan waters, southern Brazil and southeastern Brazil.

Keywords: whitemouth croaker, stock identification, populations, geographic variation, morphometry, growth, Brazil.

Stocks y unidades de manejo de la corvina *Micropogonias furnieri* (Desmarest, 1823) en el Atlántico sudoccidental

RESUMEN. La corvina *Micropogonias furnieri* es un pez demersal costero y estuarino de la familia Sciaenidae abundante e intensamente explotado por flotas costeras e industriales entre el sureste de Brasil (22°S) y el norte de Argentina (40°S). Para el estudio de la estructura de los stocks de la corvina blanca a lo largo del sureste y sur de Brasil, se obtuvieron datos morfométricos, merísticos y de crecimiento a lo largo de la costa sur (SB) y sudeste (SEB) de Brasil entre las latitudes 22º28'S y 33º53'S. No se encontraron diferencias significativas entre las diferentes latitudes de pesca en el número de radios branquiales, rayos de las aletas dorsal y pectoral, ni para las cinco medidas morfométricas. El análisis de componentes principales de las cinco mediciones morfométricas no mostró un patrón de agrupación geográfica. Sin embargo, la estructura de edad y crecimiento difirió significativamente entre el sur y norte del Cabo Santa Marta Grande (29°S). Estudios recientes y el presente estudio indican la existencia de dos stocks independientes de la corvina en el sur y sudeste de Brasil y diversos estudios publicados indican algún grado de mezcla entre los peces que se reproducen a lo largo del sur de Brasil, Uruguay y Argentina En términos de acceso de la flota existen tres jurisdicciones: a lo largo del SB y SEB, donde solo pescan embarcaciones brasileñas; en la zona común de Uruguay y Argentina donde barcos de ambos países pescan al sur de los 39°S y donde las embarcaciones argentinas pueden pescar, pero la corvina es menos

Corresponding editor: Paulo Ricardo Pezzuto

abundante. Un manejo eficiente de estas pesquerías requiere la identificación de las unidades de manejo basadas en la estructura del stock, ciclo de vida, distribución de las pesquerías y jurisdicciones. Cuando se consideran todos estos factores, excluyendo medidas locales de manejo de la pesca de pequeña escala, se identifican tres unidades geográficas de manejo en aguas compartidas de Argentina y Uruguay, sur de Brasil y sudeste de Brasil.

Palabras clave: corvina, identificación de stocks, poblaciones, variación geográfica, morfometría, crecimiento, Brasil.

INTRODUCTION

The whitemouth croacker *Micropogonias furnieri* (Desmarest, 1823) is a eurithermic and euryhaline demersal sciaenid fish that inhabits coastal waters and estuaries from the Yucatan Peninsula to the northern Patagonia (Chao, 1981; Cousseau & Perrota, 1998). It is an important component of the coastal demersal fish communities and fisheries from Rio de Janeiro State in Brazil to Bahia Blanca in Argentina (23°-40°S) (Haimovici, 1998; Chiessa & Puig, 2006; Carozza *et al*., 2010). Its record landings in Argentina, Uruguay and Brazil attained 100,000 ton in recent years (Fig. 1).

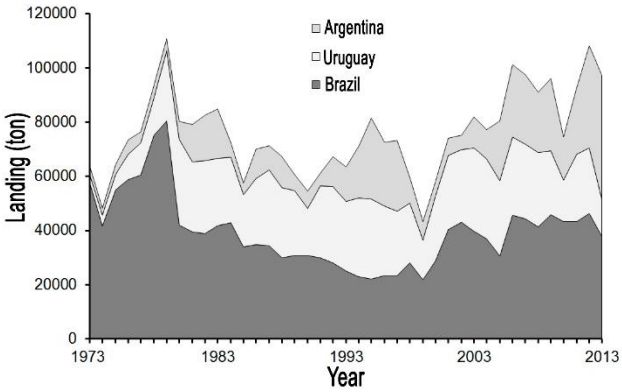

Figure 1. Landings of whitemouth croaker *Micropogonias furnieri* in the southwestern Atlantic (Fishstat 2015 and other sources).

Stock identification is a central issue for fishery assessment and management. Unit stocks are assumed to be homogeneous for particular management purposes (Begg & Waldman, 1999). From a biological point of view, unit stocks can be defined as arbitrary groups of fish large enough to be essentially self-reproducing, with members of each group having similar life history characteristics (Hilborn & Walters, 1992). In the recent decades, with conceptual developments focused on metapopulations and population connectivity, emphasis has been given to open rather than closed populations (Secor, 2014). *M. furnieri* has a large distribution range and is fished by diverse fleets in several countries in a region without geographical barriers to fish movements. For this kind of fishing resources, the "management units" for operational stock assessment and fishery management depend not only of the biological population structure but also on the geographic boundaries associated with the seasonal movements of the fish, the distribution of the fisheries and the jurisdictional borders (Cadrin *et al*., 2014). Stock identification can be attained by different methods and a holistic approach involving a broad spectrum of complementary techniques is recommended (Begg & Waldman, 1999; Cadrin *et al*., 2014).

Because of its economic importance and abundance, the stock structure of *M. furnieri* in southeastern Brazil (SEB), southern Brazil (SB), Uruguay and Argentina has been studied using diverse methods summarized in Table 1. In this region, *M. furnieri* inhabits muddy and sandy bottoms in coastal waters, estuaries, coastal lagoons and freshwater runoffs in which brackish waters are adequate as nursery grounds. In the La Plata River Estuary spawning occur in spring and summer associated to high gradients of bottom water salinity (Macchi *et al*., 1996; Jaureguizar *et al*., 2008). Its annual fecundity in the La Plata River Estuary (LPRE), as estimated by integrating successive batches in a spawning season, attained 3 to 7 million eggs annually (Macchi *et al*., 2003). Eggs and larvae are retained in the maximum turbidity zone of the salinity front and benefit from food accumulation, shelter against predators and closeness to the main nursery ground (Braverman *et al*., 2009). In southern Brazil, spawning occur also from spring to summer (Haimovici & Ignacio, 2005) in coastal waters and pelagic eggs and larvae are carried passively into the Patos Lagoon Estuary (PLE) where they recruit to the bottom with 20-30 mm total length (Weiss, 1981) and feed actively on infauna and epifauna as juveniles (Gonçalves *et al*., 1999; Costa *et al*., 2013). Other spawning and nursery grounds occur all along the region, as Bahia Blanca Estuary in Argentina (Lopez Cazorla, 1987), Rocha Lagoon in Uruguay (Vizziano *et al*., 2002), Santos Bay (Giannini & Paiva-Filho, 1990), Sepetiba Bay (Costa & Araujo, 2003) and Guanabara Bay in Brazil (Mulato *et al*., 2015). The whitemouth croaker attains 700 mm of total length (TL) and may reach *ca*. 40 years (Haimovici, 1977; Cotrina & Lasta; 1986; Schwingel & Castello, 1990). Different growth patterns have been observed between seasonal spawning groups in southern Brazil and in La Plata Estuary (Haimovici &

Table 1. Stock identification studies of the whitemouth croaker *Micropogonias furnieri* along its distribution in the Southwestern Atlantic Ocean. When identified in genetic population structure studies, stocks are indicated as "populational units", when identified by other techniques stocks are identified as "groups". BR: Brazil, UY: Uruguay, AR: Argentina, AUCFZ: Argentine-Uruguayan Common Fishery Zone, SB: southern Brazil, SEB: southeastern Brazil, NEB: northeastern Brazil, LPRE: Rio de la Plata Estuary.

Authors and year	Stock identification techniques	Studied Region	Proposed groups or populational units
Vazzoler (1971)	Meristics, morphometrics, reproductive cycle, growth pattern	SB and SEB (23°-33°S)	Two groups, north and south Cape Santa Marta Grande (29°S)
Cotrina (1986)	Seasonal distribution pattern, reproductive cycle	Uruguay to San Blas, AR (35°-41°S)	Two spawning groups north and south of 38°S
Castro (1988)	Meristics, morphometrics	N (2°N-2;30°S) and SEB (17º-24ºS)	Morphometric and meristic differences between both regions
Figueroa & Astarloa (1991)	Meristics and morphometrics	Chui, UY (34°30'S) to Bahia Blanca, AR (40°S)	Two groups, in LPRE and Uruguayan ocean front and another in Bahia Blanca
Haimovici & Umpierre (1996)	Age structure and growth	SB (30°-34º30'S).	Two groups mixing in winter in the continental shelf of southern Brazil
Maggioni *et al*. (1994)	Genetics:allozyme electorphoresis	Rio Grande (33°S) to Bahia Blanca, AR (40°S)	Extensive gene flow in all the study area.
Astarloa & Ricci (1998)	Meristics	UY and AR from 34°30'-39°30'S	Three groups: along the Uruguayan front, in LPRE and in Bahia Blanca Estuary
Levy *et al*. (1998)	Genetics:allozyme electorophoresis	SB and SEB (22º30'-34º40'S)	Extensive gene flow, no isolated populations
Norbis & Verocai (2005)	Otoliths morphology, growth, spawning seasonality	Rio de la Plata estuary LPRE	Two successive groups of spawners in early and late summer in the LPRE
Haimovici & Ignacio (2005)	Catch per unit effort series (1975-1998)	SB and SEB (22°-34°40'S)	Two groups in the southern and south-eastern regions
Volpedo & Cirelli (2006)	Otolith microchemical composition	Argentina: (35°-38°S) and (39°-41°S)	Cd/Ca, Cu/Ca, Mg/Ca, Sr/Ca and Zn/Ca ratios suggest two different fish stocks
Puchnik-Legat & Levy (2006)	Genetics: RFLP mitochondrial DNA	Northern to southern Brazil (1° to 34°S)	Extensive gene flow, semisolated populations north and south 29°S
Vasconcellos & Haimovici (2006)	CPUE series, modelled abundance changes	Southern Brazil Uruguay and Argentina	Similar trends for pooled or discriminated stocks
Pereira *et al*. (2009)	Genetics: mitochondrial DNA	Río de La Plata estuary and the Uruguayan shelf	Moderate gene flow between LPRE and the Uruguayan shelf
Luque *et al*. (2010)	Metazoan parasites	Fortaleza (3°44'S) to Rio Grande (32°15'S)	Three groups: in NEB, SEB and SB
D'Anatro *et al.* (2011)	Genetic population structure: microsatellites	Río de La Plata estuary, coastal lagoons and Uruguayan shelf	Moderate but significand genetic differences between the LPRE and the coastal oceanic waters
Galli & Norbis (2013)	Morphometrics	LPRE and coastal oceanic waters along Uruguay	Two groups with a high mixture rate
Vasconcellos *et al.* (2015)	Genetics microsatellite and intron size polymorphisms	Para State (1º03'S) and Rio de Janeiro (23°02'S) to Chui (33°41'S)	Three distinct stocks, one in North, one in the southeast (23°-29°S) and other in the south and another south 29ºS
This study	Meristics, morphometrics and growth pattern	SB and SEB (22°30'-34°40'S)	Growth differentiates stocks south and north Cape Santa Marta Grande (29ºS) and inconclusive evidences of a third north Cape Frio (23°S)

Umpierre, 1996; Norbis & Verocai, 2005) changes in growth rates along time due to intense exploitation were also observed (Haimovici & Ignacio, 2005). In most stocks, first maturation is attained at 2 to 3 years of life and 275 to 380 mm total length (TL) (Vazzoler, 1971; Macchi *et al*., 1996; Chiessa *et al*., 2006; Santos *et al*., 2015) but it also has been reported to mature at 200 mm TL in almost enclosed coastal lagoon along Uruguay (Vizziano *et al*., 2002). The species is a multiple spawner in spring and autumn in Argentina, Uruguay and southern Brazil (Carozza *et al*., 2004; Norbis & Verocai, 2005; Haimovici & Ignacio, 2005) and year round in southeastern Brazil (Carneiro *et al.*, 2005; Santos *et al.*, 2015).

The surface circulation in coastal waters inhabited by the whitemouth croaker is characterized by the

northward flow of the inner branch of the Malvinas/ Falkland and also of the Brazilian Coastal Current that flows to the north in the cold season up to 25°S (Moller *et al*., 2008; Souza & Robinson, 2004). This northward flow is responsible for the enhanced primary and benthic productivity in winter and spring along southern Brazil (Ciotti *et al*., 1995; Capitoli & Benvenuti, 2004). From 30° to 23°S, wind induced seasonal intrusion of cold deep South Atlantic Central Waters on the shelf enhances planktonic production along southeastern Brazil (Brandini, 2006; Gaeta & Brandini, 2006).

There are no evident critical geographical barriers for fish migration between the southern and southeastern regions as long range seasonal migrations of several species as the Argentine croaker *Umbrina canosai*, the bluefish *Pomatomus saltatrix* and the mullet *Mugil liza* have been reported (Gonzalez-Alberdi & Nani, 1967; Haimovici & Krug, 1996; Lemos *et al*., 2014). However, there are no evidences of long-distance directional migrations of *M. furnieri* in spite of reproductive concentrations in the Rio de La Plata and Patos Lagoon coastal region in spring and early summer have been reported to disperse in autumn and winter (Cotrina, 1986; Haimovici & Umpierre, 1996; Norbis & Verocai, 2005; Carozza *et al*., 2010; Sanchez *et al*., 2011).

The efficient management of fisheries of white-mouth croaker requires the discrimination of adequate management units. In this paper, two issues were addressed. As a first objective, we analyzed meristic, morphometric and growth data of whitemouth croakers obtained in a research survey along southern and southeastern Brazil, integrating them to previous results about stock identification and structure in the region. The second is to discuss the possible management units for the species in the region based in the literature on its life history, stocks identification, fisheries and jurisdictional aspects.

MATERIALS AND METHODS

Data to investigate the stock structure of *Micropogonias furnieri* along southern and southeastern Brazil were collected along a bottom trawl survey in coastal waters at depth under 50 m between latitudes 34° and 22°30'S in December 1989 and February 1990 in which tissue samples for transferrin electrophoresis (Levy *et al*., 1998), as well as morphological and meristic data and otolith for ageing were collected (Fig. 2).

Six hundred and fifty four whitemouth croakers from 176 mm to 705 mm total length (TL) were collected along the cruise. On board, each fish was sexed and the maturity stage and gonadal weight were recorded. On fresh fishes laying on their left side over a measuring board, the distance from the snout to the end of caudal fin in normal position (TL), the last vertebra (standard length, SL), the end of the operculum (head length, HL), the beginning of the dorsal fin (pre-dorsal length, PDL) and pre-anal fin length (PAL), anal fin length (AL) and pectoral fin length (PL) were measured in millimeters. The number of soft rays of the second dorsal fin, the left pectoral fin and of gill rakers of the first left gill arch were counted. Otoliths were collected and preserved dry for ageing.

For comparisons, samples were grouped in five latitudinal geographic regions (Fig. 2) along the states of Rio Grande do Sul (RS), Santa Catarina (SC), Paraná (PR), from Santos in the state of São Paulo to Ilha Grande in southern Rio de Janeiro State (SIG) and in a small area to the north of the upwelling of Cape Frio (22°46'-22°48'S) near the city of Macaé (MAC). The number and geographic range of the groups was a compromise between the available information on distribution and biology of *M. furnieri* and the number of specimens obtained along the survey.

Statistical analysis of meristic and morphometric data

As a first step, outliers were detected by regression analysis and by scatter-plots of residuals versus predicted values and excluded from former analysis. Meristic counts had not a normal distribution, therefore the non-parametric Mann-Whitney test was used for comparisons between sexes and Kruskal-Wallis test was used for comparisons among size groups and regions (Zar, 1984). No statistically significant differences between sexes were observed neither for the number of gill rakers ($P = 0.354$), second dorsal fin rays number ($P = 0.944$) and pectoral fin rays number ($P = 0.687$) nor between 200 mm length classes: gill rakers ($H = 0.12$; $P = 0.940$), 2nd dorsal fin rays ($H = 0.58$; $P = 0.90$) and pectoral fin rays ($H = 3.43$; $P = 0.330$). For this reason, meristic comparisons between regions were done with pooled data of both sexes and length classes.

As the size composition of the whitemouth croakers differed between regions, morphometric comparisons were performed only between individuals over 350 mm TL. The regression procedure applied to *Thunnus albacares* from the Pacific Ocean by Schaefer (1991) was followed to further reduce the size effects in the analysis: measurements were transformed to decimal logarithms and size adjustments for each character were based on the common within-group slopes among samples calculated from the analysis of covariance. All measurements were adjusted to the expected values for the overall mean standard length as:

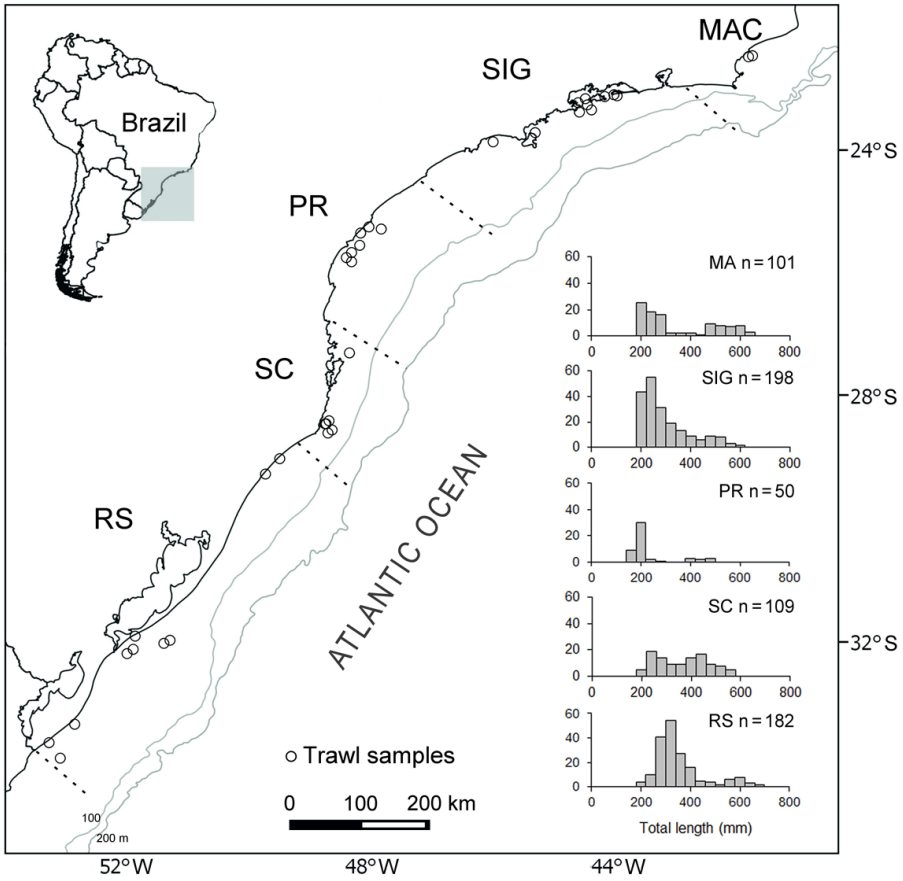

Figure 2. Sampling locations (empty circles) in a bottom trawl survey by the R/V Atlântico Sul in December 1989. In the box the total length (LT) compositions and numbers (in brackets) of white croaker *Micropogonias furnieri* in five latitudinal strata. RS: Rio Grande do Sul, SC: Santa Catarina, PR: Paraná, SIG: Santos-Ilha Grande, MAC: Macaé.

$$Yi = \log_{10} y_i - [\beta(\log_{10} L_{Si} - \log_{10} L_S)]$$

where

Y_i = adjusted logarithm character measurement of the i^{th} specimen

y_i = unadjusted character measurement of the i^{th} specimen

ß = common within-group regression coefficient of $\log_{10} y_i$ against $\log_{10} L_{st}$,

L_{S_i} = standard length of the i^{th} specimen

L_S = overall mean standard length

Adjusted measurements were all normally distributed and were compared between sexes using *t*-tests and between regions using the one way variance analysis (ANOVA) (Zar, 1984). No statistically significant differences were observed between sexes, so the measurements were compared between regions with sex pooled data.

As an attempt to identify diferent groups based in all adjusted measurements, a principal component analysis (PCA) was performed to analyze the dataset in relation the two most important components in terms of variance explanation (Johnson & Wichern, 1998). The plot was visually assessed.

Ageing and growth

The whitemouth croaker is a long living species and up to more than 35 pairs of translucent bands may be counted in transverse sections of the otoliths (Haimovici, 1977). Evidences of annual formation of one opaque and one hyaline band from marginal increment analysis from southern Brazil were found by Schwingel & Castello (1990) and Haimovici & Umpierre (1996). Thus, the number of opaque bands in the otoliths was assumed to represent the age in years. Transverse sections of the otoliths were examined with transmitted light (Fig. 3). Otoliths were examined by two readers and those with discrepancies of up to one band were

reexamined and removed from analysis if disagreement persisted.

Only whitemouth croakers over two years old were included in the growth analysis because young-of-the-year and one year old individuals that grew in the Patos Lagoon can have multiple thin opaque checks in their otoliths that can be wrongly considered as annuli (Cavole & Haimovici, 2015) and affect growth estimates. ANOVA was used to compare the mean age by TL range between regions.

A Bayesian approach was used to fit the von Bertalanffy growth model to the data. A multiplicative error was assumed which implied that, for individual [i] the length[i], given age[i], follow a log-Normal distribution with mean μ[i] and a precision τ, where μ [i] were fitted in the von Bertalanffy equation that follows:

$$\mu[i] = \log(L_\infty) + \log(1 - e^{-k(age[i]-t_0)})$$

where L∞ is the theoretical maximum length reached; k is the growth coefficient expressed in years^{-1} and t_0 is the theoretical age that a fish would have at length zero.

In the Bayesian approach, the estimates of the growth parameters are given as a probability distribution denoted "posterior distribution", which is the most complete expression of the plausibility of different parameter values (Kinas & Andrade, 2010). The comparison of the posterior distributions of the growth parameters between regions eliminates the need for statistical tests (Kinas & Andrade, 2010).

Posterior distributions of each parameter, with its median and Credibility Intervals of 95%, were obtained using the simulation method of Monte Carlo Markov chains (MCMC). Weakly informative priors were used.

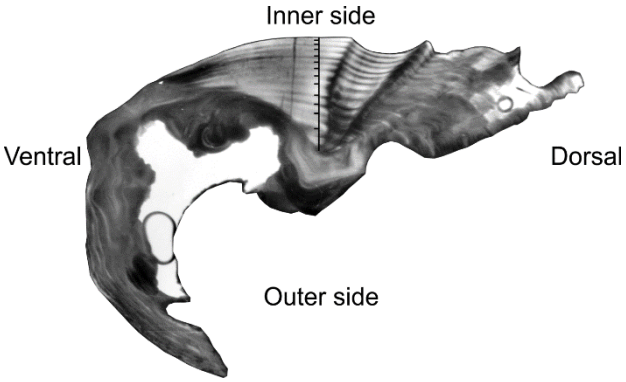

Figure 3. Traversal section of an otolith of a 12 years old whitemouth croaker *Micropogonias furnieri* from southern Brazil. Horizontal bars indicate the end of opaque zones interpreted as annual rings.

To assess convergence of the posterior distribution, three Markov chains were simulated with a total of 31,000 iterations, burn in of 10,000 and a thinning of 2. The MCMC was performed by OpenBUGS, using the libraries R2WinBUGS (Sturtzet *et al.*, 2005) and BRugs (Thomas *et al.*, 2006).

RESULTS

Meristic and morphometric analysis

The number of second dorsal fin rays ranged from 24 to 31 with an overall mean of 27.79 and no significant differences between regions were observed (P = 0.816). The number of pectoral fin rays ranged from 16 to 19 with an overall mean of 17.37 without significant differences between regions (P = 0.241). Gill rakers counts ranged from 21 to 29 with a mean of 25.59. The means were not homogeneous among regions (P < 0.05) and Mann-Whitney pairwise post hoc test showed significantly higher numbers in RS when compared with SC, PR and SIG but not among the extremes of the study area (Table 2).

Univariate comparisons of the morphometric indices detected significant differences for three characters between SC and other sampling sites: dorsal fin length (F = 2.999; P = 0.0197) was significantly longer in SC as compared to the three northern areas. Anal fin length (F = 3.374; P = 0.011) and pre-anal fin length (F = 3.266; P = 0.0128) were also longer in SC than in SIG and in RS and SIG, respectively. No significant differences among regions were observed for head length (F = 0.265; P = 0.900) and pectoral fins length (F = 0.593; P = 0.668).

The two principal components identified by the PCA analysis accounted for 72.8% of the variance. The plot of the two principal components did not show any grouping pattern between individuals from different sampled areas (Fig. 4). Therefore, the multivariate assessment of the adjusted measurements did not evidence heterogeneity between individuals from different sampled areas.

The overall conclusion regarding the meristic and morphometric analysis is that, based in the selected meristic counts and morphometric indices and despite some significant difference between pairs of latitudinal ranges in the study area, no consistent pattern of geographical grouping was observed.

Growth comparisons

Overall 350 fishes were aged. Older female and male were 33 and 22 years old, respectively. As the TL composition of the samples was heterogeneous, mean ages of females were compared in the 400-499 mm

Table 2. Frequency distribution means and Kruskal-Wallis test results comparing latitudinal strata along southern and southeastern Brazil for the number gill rakers, second dorsal fin rays and pectoral fin rays of the whitemouth croaker *Micropogonias furnieri*. RS: Rio Grande do Sul, SC: Santa Catarina, PR: Paraná, SIG: Santos Ilha Grande and MAC: Macaé, SD: standard deviation.

Number of gill rakers	RS	SC	PR	SIG	MAC
21		1			
22	1				1
23	4	5	1	4	2
24	9	6	13	18	11
25	43	39	12	72	41
26	74	35	18	67	30
27	38	18	1	23	7
28	10	1	1	6	3
29	1				
Mode	26	25	26	25	25
Mean	25.9	25.5	25.0	25.6	25.4
SD	1.1	1.1	1.3	1.0	1.0
Number	178	104	46	190	94
Kruskal-Wallis			$P < 0.05$		
Number of second dorsal fin rays	RS	SC	PR	SIG	MAC
24			1		
25	1				1
26	10	11	3	22	9
27	49	26	11	55	30
28	82	49	25	79	40
29	33	23	9	36	21
30	5		1	6	1
31	1				
Mode	28	28	28	28	28
Mean	27.86	27.77	27.80	27.74	27.73
SD	0.93	0.90	1.01	0.98	0.96
Number	174	109	48	192	100
Kruskal-Wallis			$P = 0.815$		
Number of pectoral fin rays	RS	SC	PR	SIG	MAC
16	13	1	4	11	8
17	80	62	25	122	49
18	73	43	17	57	39
19	6	1	2	4	3
Mode	17	17	17	17	17
Mean	17.42	17.41	17.35	17.28	17.37
SD	0.68	0.53	0.70	0.60	0.68
Number	166	106	46	190	96
Kruskal-Wallis			$P = 0.241$		

length class interval, in which the range of ages was sufficiently small to allow comparisons. The mean age was lower in RS (3.76 yr) and MAC (5.25 yr) compared to the three central areas: SC (9.50 yr), PR (11.17 yr) and SIG (11.66 yr) (Fig. 5). *Post-hoc* Tukey tests of one-way ANOVA showed significant differences between RS and SC ($P = 0.0091$) and between RS and SIG ($P = 0.0078$) but not between SC and SIG ($P = 0.9950$). The mean age of individuals from MAC did not differ from other areas.

The growth parameters and their credibility intervals were calculated for both sexes and all areas, except PR, for which only a few aged individuals were available. The von Bertalanffy growth curves (Fig. 6) show two different patterns, one of faster growth for RS and MAC and other of slower growth in the intermediate areas of SC and SIG. Both k and t_o 95% credibility intervals overlapped for both males and females among all four areas (Table 3). The L_∞ were larger in RS and MAC than in the central areas as the

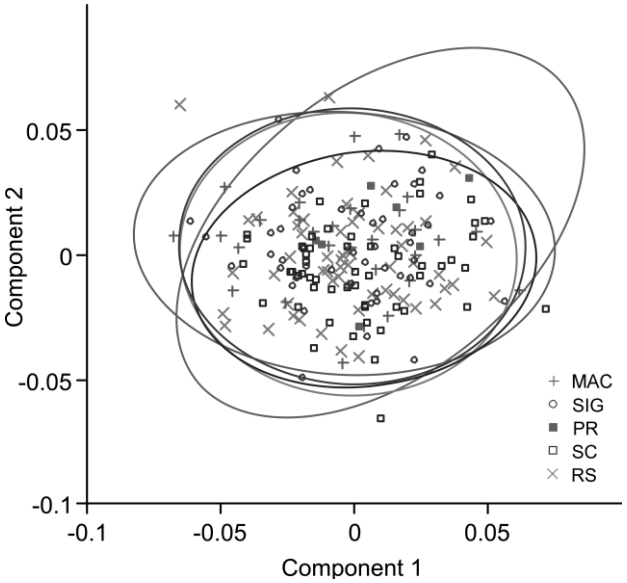

Figure 4. Ordination of the two main multivariate components obtained from the principal component analysis of five morphometric characters of *Micropogonias furnieri* in five latitudinal strata along southern and southeastern Brazil. Ellipses delimit 95% of data from each sampled area. RS: Rio Grande do Sul, SC: Santa Catarina, PR: Paraná, SIG: Santos-Ilha Grande, MAC: Macaé.

posterior distributions of the L_∞ overlapped between the SC and SIG for males and females but not between SC and RS, which are adjacent, nor between the adjacent areas SIG and MAC (Fig. 7).

The larger L_∞ and the lower mean ages in the 400-499 mm length range were considered strong evidences that the whitemouth croakers from southern Brazil (RS) grew in a different environment than those from the southeastern Brazilian Bight (SC, PA, SIG). Evidences to differentiate individuals from MAC and the southeastern Brazil Bight are less clear, as the mean age in the 400-499 mm TL interval is not significantly lower, and the infinite length is significantly higher.

DISCUSSION

Stock identification

Since the 1960, the stock identification of *Micropogonias furnieri* from southeastern Brazil to Argentina has been a recurrent research issue. Diverse techniques based in phenotypes, population dynamics, microchemistry, genetics and parasites were used (Table 1). Studies evolved along time in the accuracy of the analytical techniques and in the use of statistical methods for the comparisons. Vazzoler (1971, 1991) was the first to compare morphometric indices, meristic

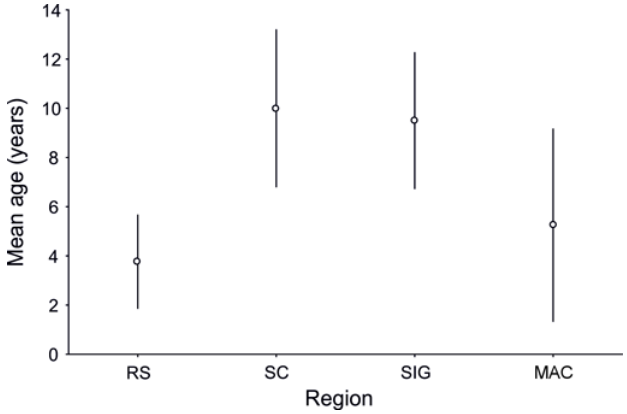

Figure 5. Mean age and 95% confidence intervals of 400 to 500 mm TL whitemouth croakers *Micropogonias furnieri* in four latitudinal strata along southern and southeastern Brazil. RS: Rio Grande do Sul, SC: Santa Catarina, SIG: Santos-Ilha Grande, MAC: Macaé.

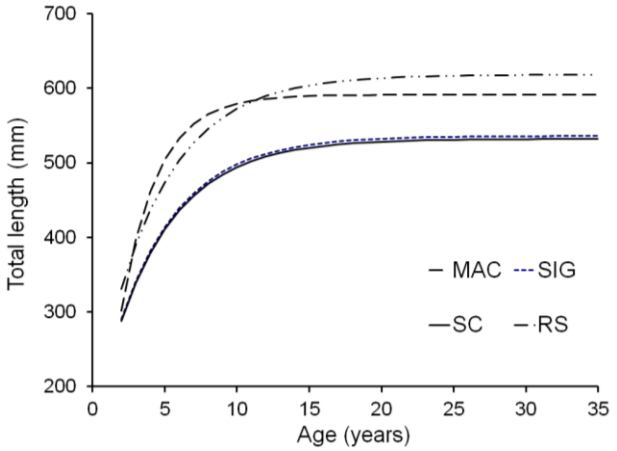

Figure 6. Von Bertalanffy growth curves of female whitemouth croakers *Micropogonias furnieri* from four latitudinal ranges along southern and southeastern Brazil. RS: Rio Grande do Sul, SC: Santa Catarina, SIG: Santos-Ilha Grande, MAC: Macaé.

counts, growth, based scales readings, and spawning season and postulated the occurrence of two populations North and south of Santa Marta Grande Cape at 29ºS. Most of her morphometric and meristic analysis were not confirmed in the present study but the overall conclusion of independence between the stocks from SB and SEB was also observed in our growth comparisons based in ageing of otolith sections. It was also supported by Haimovici & Ignacio (2005) that observed opposite trends in the catch per unit effort (CPUE) by trawlers fishing north and south of Santa Marta Grande Cape between 1975 and 1985: CPUE increased in SEB associated to a decrease in the total effort (Valentini *et al.*, 1991), while it increased in SB

Table 3. Mean and 95% credibility intervals of the parameters L_∞, k and t_o of the von Bertalaffy growth equation calculated based in the total length and ages of whitemouth croackers *Micropogonias furnieri* sampled from Rio Grande do Sul (RS), Santa Catarina (SC), Santos-Ilha Grande (SIG) and Macaé (MA).

	2.5	L_∞	97.5	2.5	k	97.5	2.5	t_0	97.5
Pooled sex									
RS	589.0	620.4	655.7	0.16	0.21	0.26	-2.64	-1.72	-0.98
SC	490.1	520.3	556.4	0.16	0.23	0.35	-2.87	-1.69	-0.49
SIG	485.2	519.9	558.7	0.14	0.17	0.22	-2.98	-2.45	-1.56
MAC	565.7	608.3	661.4	0.18	0.27	0.36	-1.71	-0.54	-0.02
Males									
RS	541.2	635.8	764.5	0.12	0.19	0.31	-2.96	-2.15	-0.88
SC	463.1	502.7	551.7	0.16	0.26	0.44	-2.90	-1.56	-0.16
SIG	435.5	468.6	506.2	0.16	0.20	0.27	-2.98	-2.47	-1.46
Females									
RS	586.5	620.4	660.6	0.16	0.22	0.29	-2.68	-1.57	-0.67
SC	497.0	539.8	588.4	0.15	0.23	0.36	-2.89	-1.59	-0.25
SIG	502.2	546.4	606.2	0.14	0.23	0.35	-2.65	-1.20	-0.14
MAC	568.3	612.7	673.0	0.16	0.26	0.38	-2.57	-0.98	-0.06

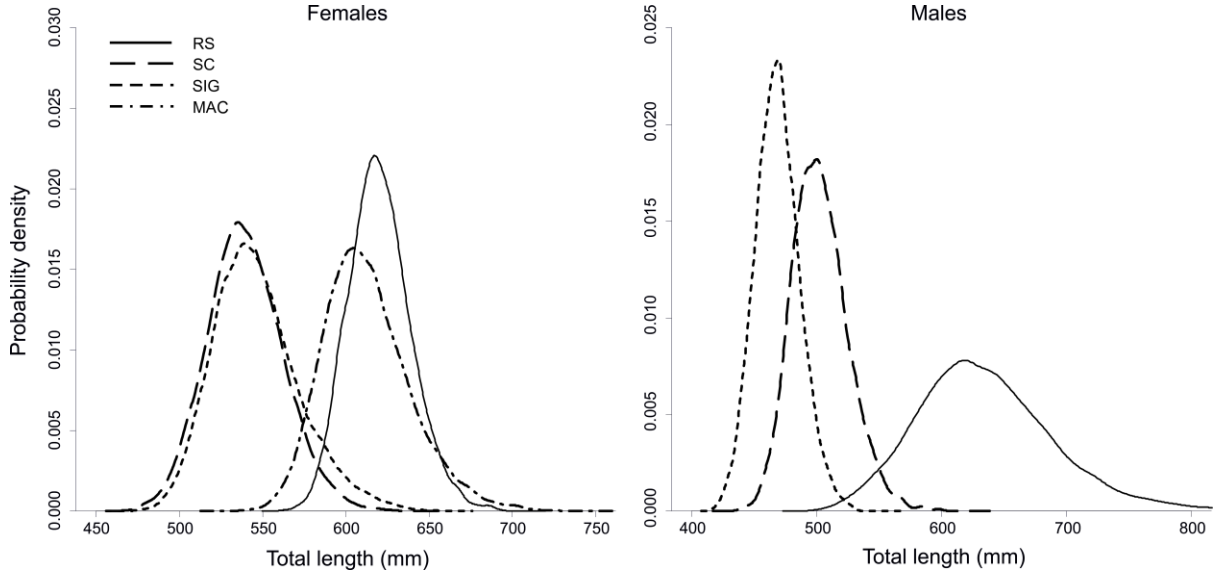

Figure 7. The posterior distribution of the estimated infinite length (L_∞) for females and males of *Micropogonias furnieri* from four latitudinal ranges along southern and southeastern Brazil. RS: Rio Grande do Sul, SC: Santa Catarina, SIG: Santos-Ilha Grande, MAC: Macaé.

associated to a high level of total effort (Haimovici *et al*., 1989).

Early biochemical analysis of total crystalline lens (Vazzoler & Phan, 1989) did not find differences between samples from SEB and SB. Levy *et al*. (1998) compared 17 enzymes and one protein encoding loci by starch and polyacrylamide gel electrophoresis in samples from the same specimens utilized in this study and found high degree of genetic homogeneity in the allele frequencies and a high level of gene flow along the study area. Puchnik-Legat & Levy (2006) analysed mitochondrial DNA of specimens from northern to southern Brazil and found significant differences between these regions but not between SB and SEB. New and more precise genetic studies with microsatellites and intron size polymer-phism identified distinct groups with populational status south of Torres (29ºS) and northward up to Rio de Janeiro (Vasconcellos *et al*., 2015). Recent studies by Luque *et al*. (2010) observed differences in the metazoan parasites community of individuals from SB and SEB.

From all this studies, those on differences in catch per effort trends (Haimovici & Ignacio, 2005), parasites assemblages (Luque *et al*., 2010), advanced molecular

methods (Vasconcellos *et al*., 2015) and growth (present paper) are strong evidences to support that there is a limited connectivity between whitemouth croakers from SB (29º-32ºS) and SEB (29º-23ºS).

Along Uruguay and Argentina, Cotrina (1986) observed seasonal changes in the sexual maturation timing between north and south 38°S. Figueroa & Astarloa (1991) analyzed several morphometric and meristic characters of individuals sampled along the Atlantic Uruguayan coast, the northern and southern margins of the La Plata River and Bahia Blanca and found differences between the three former and the last regions. Astarloa & Ricci (1998) compared meristic counts in the same latitudinal range and observed three groups: the Atlantic Uruguayan coast, the La Plata River Estuary and Bahia Blanca. Volpedo & Cirelli (2006) compared the otolith chemical composition (Cd/Ca, Cu/Ca, Mg/Ca, Sr/Ca and Zn/Ca ratios) along the Argentinian coast and their results suggested two different stocks from the La Plata River Estuary to Mar del Plata (35°-38°S) and southwards up to San Blás (39°-41°S). Maggioni *et al*. (1994), failed to detect stock differences from Rio Grande in Brazil (33°S) to Bahia Blanca, Argentina (40°S) based in alloenzymes electrophoresis. Pereira *et al*. (2009) analysed mitochondrial DNA and observed a discreet genetic flow between samples from La Plata River Estuary to the Uruguayan Atlantic coast. Comparing microsatellites DNA sequences, D´Anatro *et al*. (2011) differentiated a semi-isolated small group of whitemouth croakers in the brackish water of Rocha Lagoon, in Uruguay. Galli & Norbis (2013) found significant differences in morphometric and meristic characters sampled in the la Plata River and the Uruguayan Atlantic coast, but discriminant analysis showed a high rate of misclassification of individuals. On the other hand, Chiessa *et al*. (2006) mentioned, but gave no detailed information, that individuals marked in the la Plata River Estuary in 1989 were recovered in Bahia Blanca (40°S).

The picture along Argentina and Uruguay is less clear. Several authors agree in discriminating the Bahia Blanca region from the rest (Cotrina, 1986; Figueroa & Astarloa, 1991; Astarloa & Ricci, 1998; Volpedo & Cirelli, 2006). Marquez & Pereira (2013), based in studies of Pereira *et al*. (2009) and D´Anatro *et al*. (2011) suggest that the Rio de la Plata front spawners and those from coastal marine waters of Uruguay and southern Brazil are genetically distinct enough to be considered distinct populations.

There are no environmental barriers between the Uruguayan and southern Brazil coastal waters, therefore some degree of mixture between individuals from these regions should exist as suggested by Marquez & Pereira (2013). Incidental evidences of this mixture were presented by Haimovici & Umpierre (1996) that observed a high proportion of slow growing and old specimens dispersed over the southern Brazilian shelf in winter when compared to those caught in the pre-spawning concentrations in spring, in the vicinity of the mouth of the Patos Lagoon. They concluded that part of the winter catches could be of fishes that spawn in Uruguayan waters. Furthermore, Norbis & Verocai (2005) found two distinct spawning groups in spring and summer in the Uruguayan margin of the Plata River with different growth parameters and age and size structures. They suggest that the larger and older summer spawners may include specimens that migrate northwards towards Brazilian for feeding in winter. Finally, Carozza *et al*. (2010) concluded that larger individuals caught in trawl surveys along northern Uruguay come from southern Brazil. Therefore it was concluded that whitemouth croaker in southeastern and southern Brazil pertains to different stocks. On the other hand, some degree of mixture, that cannot be easily quantified, exist between fishes spawning in Argentinian, Uruguayan and southern Brazilian waters (Fig. 8).

Fisheries and management

Important small to large-scale whitemouth croaker fishing occur in all three countries. Along Uruguay and Argentina *M. furnieri* is targeted by small scale fisheries and by bottom trawl and gillnet fleets which fish in the shared common fishery zone. South of 39ºS, the species is not an important target and is caught only by Argentinian fleet (Carozza, 2010; Defeo *et al*., 2011).

In Argentina, annual recorded landings were of almost 26,000 ton between 2004 and 2013 (Fig. 1). Small artisanal fisheries along the Buenos Aires Province marine coast land small quantities of whitemouth croakers (Elias *et al*., 2011; Perez & Ruarte, 2013). In 2007, around 183 pair and otter doors trawlers from 9 m to over 27 m long based in Mar del Plata, General Lavalle and Salinas ports were responsible for most of Argentinian catches of the species. Most catches occurred in the southern margin of the outer La Plata Estuary and in shelf waters between 36° and 38°S under 50 m deep mostly between June to September (Carozza, 2010; Garcia, 2011; Sanchez *et al*., 2011). In Uruguay, annual recorded landings were in mean of over 24,000 ton between 2004 and 2013 (Fig. 1). The 2007 census of the small scale fishery in coastal waters between Montevideo and Chuy recorded over 500 boats under 15.6 m long fishing with gill nets and long lines and a catch of around6,200 ton of whitemouth croaker (Puig *et al*., 2010). The Uruguayan industrial fleet was formed by 33

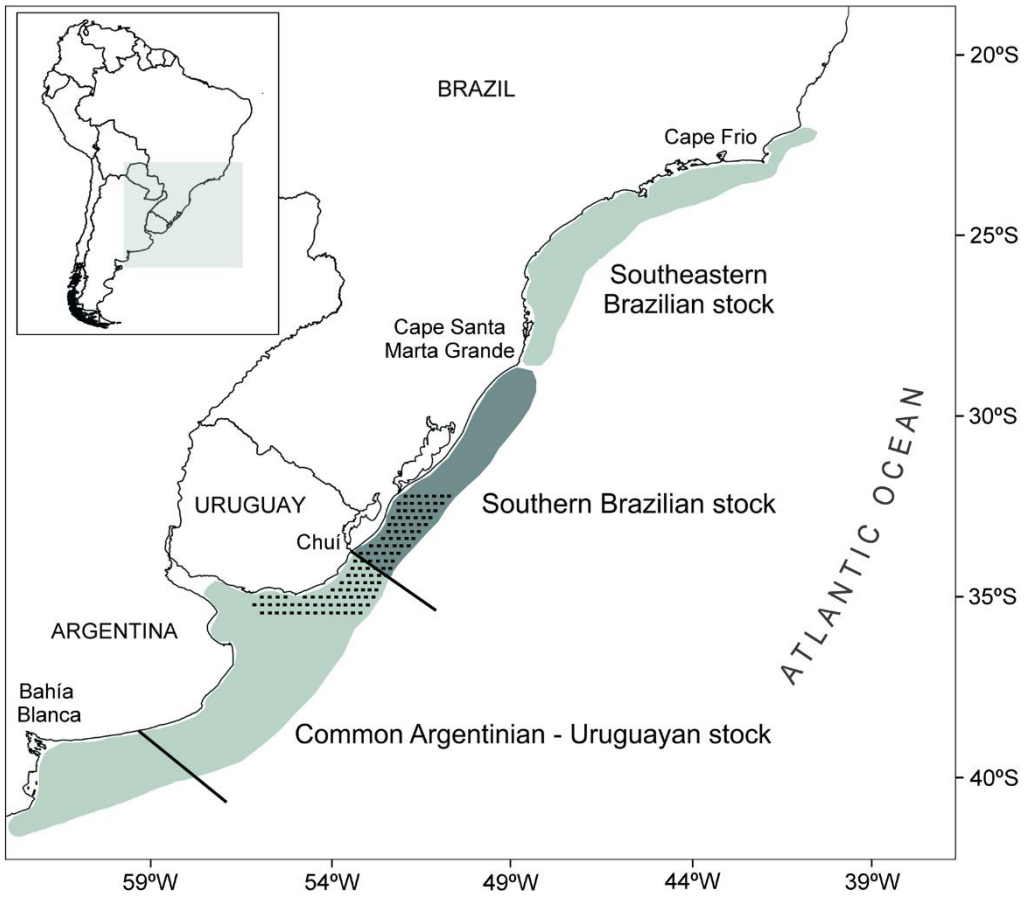

Figure 8. Exclusive fishing zones of Brazil (<34°S), Uruguayan Argentinian common fishery zone (29°-34°S) and Argentina (>39°S) and distribution and stocks and proposed management units for whitemouth croaker *Micropogonias furnieri* in the Southwestern Atlantic Ocean. In gray: southern Brazilian stock, pointed: Common Argentinian-Uruguayan stock.

otter board and pair trawlers from 19 to 33 m long in 2003, and had the species as one of its main targets along the northern margin of the La Plata River Estuary and Uruguayan Atlantic coast (Norbis *et al*., 2006). The stock of *M. furnieri* exploited in the AUCFZ is managed by a binational commission since 1974. Management includes seasonal fishing bans, closure for fishing in the nursey grounds in the La Plata River Estuary and setting total annual fishing quotas. In 2011, the species was considered fully exploited (Carozza & Lorenzo, 2011; Lorenzo *et al*., 2011). For 2016, a maximum of 21,000 ton for each country was agreed in the AUCFZ (http://www.ctmfm.org/).

In southern and southeastern Brazil annual recorded landings were of ca 30,000 ton between 2002 and 2011 (Fig. 1). The species is fished mainly with gillnets and bottom trawling (Haimovici, 1998; Corrêa, 2013; Vasconcellos *et al*., 2014; Pio *et al*., 2016) but landings from illegal catches with purse-seining are still important in Rio de Janeiro (Fiperj, 2013). Fishing boats based in the port of Rio Grande (RS) fish almost exclusively south of Santa Marta Grande Cape (29°S) (Klippel *et al*., 2005; Haimovici *et al*., 2006; Vasconcellos *et al*., 2014), and those from São Paulo and Rio de Janeiro fish mostly north of Santa Marta Grande (Corrêa, 2013). Those based in Santa Catarina State fish all along the southern and southeastern region (UNIVALI/CTTMar, 2010). Overall, the industrial fleet was estimated in over 700 boats (Perez *et al*., 2001). The industrial trawl fishing is multispecific and the whitemouth croaker rarely attains over 30% of the catches (Haimovici, 1998). In contrast, gillnet fishing can be very specific when targeting pre-reproductive concentrations (Vaconcellos *et al*., 2014; Pio *et al*., 2016).

In Brazil, the species comprises a single management unit along which industrial fishing licences are valid from southern (34°S) to southeastern coast (20°S). In this region, the most important demersal coastal species, including *Micropogonias furnieri*,

Umbrina canosai, *Cynoscion guatucupa* and *Macrodon atricauda* are considered overexploited due to excessive fishing effort (Haimovici, 1998; Haimovici *et al*., 2006; Vasconcellos & Haimovici, 2006; Miranda & Haimovici, 2007; Cardoso & Haimovici, 2015; Pio *et al.,* 2016).

The whitemouth croaker and other fishes targeted by small scale and industrial fisheries in southern Brazil are subject to a large number of regulations including spatial controls, gear type and size type restrictions and mesh sizes (Kalikoski *et al*., 2002), however enforcement and compliance is poor and most Brazilian marine fisheries suffer of a kind of anomie (Kalikoski & Vasconcellos, 2006; Haimovici *et al*., 2014). There is a consensus in the academia that licences restricted to either the southern or the southeastern region should help to manage the demersal fisheries as suggested by Perez *et al*. (2001) and Ross & Pezzuto (2016). Two management units for demersal fisheries should be useful to orientate the choice and enforcement of administrative measures as seasonal and areal closures, meshes and sizes of the gears for the stocks of *M. furnieri*. This proposal may face resistance by holders of fishing licences that fish all along the region but ultimately may benefit all stakeholders.

Therefore excluding local coastal small scale fisheries management, and taking into account stocks identifications, life history, distribution of the fisheries and jurisdictions three geographical management units were identified: a distinct stock of whitemouth croaker occur between Rio de Janeiro to Santa Catarina states (23º-29ºS) and two partially connected stocks occur in southern Brazil (29º-34°S) and in Uruguay and Argentina (34°-41°S) (Fig. 8). As major spawning and nursery grounds exist the La Plata River Estuary in the AUCFZ and in the Los Patos Lagoon Estuary in southern Brazil it is not likely that intense fishing in any of these regions lead to the collapse of the fishery in the other. Therefore, independent management is possible in each of the three contiguous regions of the southwestern Atlantic.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Captains José Anchieta Pinto and Homero Poujeaux Alvariza, crew of the research vessel Atlântico Sul and graduate students (FURG) and to the former students for their participation in the data collection as well as to Ana Emilia Moraes Vazzoler and Jose Levy for their partnership in the elaboration of the project. We acknowledge The Brazilian Interministerial Commission for Sea Resources (CIRM) for financing the cruise and the Brazilian National Scientific and Technological Research Council (CNPq) for the research fellowship to the first author (Proc. 309282/ 2011-0).

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Received: 15 April 2016; Accepted: 28 September 2016

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