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*Research Article*

# Gillnet selectivity for whitemouth croaker (*Micropogonias furnieri*) from southeastern and southern Brazil

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**ABSTRACT.** The whitemouth croaker is one of the most important demersal resources of southeast and southern Brazil, and it is caught mostly by bottom gillnets. This fishing system has the advantage of a unimodal distribution of size selectivity, where the optimum length corresponds to the mode of the distribution. This study is aimed to calculate the selection factor of gillnets from fishery studies and monitoring programs, and to estimate a generic curve that represents the retention size probability of the most commonly used mesh sizes for catching whitemouth croaker. Data on capture frequencies using 70, 90, 100, 110, 120, and 130 mm mesh were obtained from the states of São Paulo, Santa Catarina and Rio Grande do Sul between 1998 and 2012. The selection factor calculated corresponds to 3.73. Based on the general equation of retention size, we estimated a modal length of 261 mm for the 70 mm mesh, 336 mm for the 90 mm mesh, 373 mm for the 100 mm mesh, 411 mm for the 110 mm mesh, 448 mm for the 120 mm mesh and 485 mm for the 130 mm mesh. The modal lengths estimated in this study were consistent with previous estimations obtained by experimental approach. We discuss the appropriate mesh sizes with respect to the biology of the species, along with the possibility of considering gillnet selectivity to improve fishery catch.

**Keywords:** *Micropogonias furnieri*, fisheries, gillnet, selectivity, Brazil.

# Selectividad de enmalle para la corvina (*Micropogonias furnieri*) del sureste y sur de Brasil

**RESUMEN.** La corvina es una de los recursos demersales más importantes del sureste y sur de Brasil, mayormente capturado con redes de enmalle de fondo. Este sistema de pesca tiene la ventaja de permitir una distribución unimodal de la selectividad de tamaños, donde la longitud óptima corresponde aproximadamente a la moda de la distribución. Este estudio tuvo por objetivo calcular el factor de selección de redes de enmalle a partir de estudios pesqueros y programas de monitoreo, y estimar una curva genérica que represente la probabilidad de retención por tallas para los tamaños de malla comúnmente usados para la captura de corvina. Los datos de frecuencias de captura usando mallas de 70, 90, 100, 110, 120 y 130 mm fueron registrados en los estados de São Paulo, Santa Catarina y Rio Grande do Sul entre 1998 y 2012. El factor de selección calculado correspondió a 3,73. En base a la ecuación general de retención a la talla, se estimó una longitud modal de 261 mm para la malla de 70 mm, 336 mm para la malla de 90 mm, 373 mm para la malla de 100 mm, 411 mm para la malla de 110 mm, 448 mm para la malla de 120 mm y 485 mm para la malla de 130 mm. Las estimaciones obtenidas en este trabajo son consistentes con las longitudes modales previamente estimadas mediante una aproximación experimental. Se discute acerca de los tamaños de malla apropiados respecto a la biología de la especie, junto con la posibilidad de considerar la selectividad de las redes de enmalle para mejorar el rendimiento pesquero.

**Palabras clave:** *Micropogonias furnieri*, pesquerías, enmalle, selectividad, Brasil.

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## INTRODUCTION

The whitemouth croaker (*Micropogonias furnieri*) is widely distributed off the western coast of the Atlantic Ocean, from the Yucatan Peninsula (25ºN) in Mexico to the Gulf of San Matias (41ºS) in Argentina (Chao, 1981; Cousseau & Perrota, 1998). This species sustains the most important coastal demersal fisheries along southern and southeastern Brazil, Uruguay and northern Argentina (Pin *et al*., 2006; Valentini & Pezzuto, 2006; Carozza, 2010; Defeo *et al*., 2011; Ligrone *et al*., 2014). Landings in the region amount to around 100,000 ton (FAO FishStat Plus, 2013). Because of its importance in the three countries, several authors have studied the stock structure. In Brazil, recent studies comparing temporal trends in catch per unit effort (CPUE), differences in growth and age structure (Haimovici & Ignacio, 2005), and advanced molecular methods (Vasconcellos *et al*., 2015), presented strong evidences for the existence of two distinct stocks. One between 23º and 29ºS, and another between 29º and 34ºS, which suggests that different management measures could be applied to both areas to prevent declines in these stocks.

In southeast and southern Brazil, between 2008 and 2012, whitemouth croaker fishing was mainly conducted using bottom gillnet and bottom pair trawl, and secondarily with double rig trawl, single trawl and purse seine (Pio, 2015; www.propesq.pesca.sp.gov.br). In this area, gillnets operations can also aim at the capture of other species such as the Argentine croaker (*Umbrina canosai*), stripped weakfish (*Cynoscion guatucupa*) and bluefish (*Pomatomus saltatrix*) (Lucena & O'Brien, 2001; Vasconcellos *et al*., 2014; Pio *et al*., 2016). Bottom gillnets are also used on the slope for the capture of anglerfish (*Lophius gastrophysus*) (Perez *et al*., 2002) and gulf-hake (*Urophycis mystacea*) (Pio *et al*., 2012, 2016). From 34 fishing trips between 2008-2011, Schroeder *et al*. (2014) identified 240 different species as bycatch in bottom gillnets for whitemouth croaker.

One of the favorable characteristics of gillnets is the capacity to reduce mortality over a relatively narrow range of sizes, mainly because retention probability is described by a unimodal distribution whose peak represents maximum retention, known as the optimum length (Holt, 1963; Hamley, 1975; Millar & Holst, 1997; Sparre & Venema, 1998). Unlike other fishing gear, such as trawl nets, where selectivity is described by a logistic distribution, gillnets avoid the overfishing of some fish sizes by the proper use of the mesh size and hanging ratio, by either catching fewer small fish and preventing overfishing by recruitment or allowing the escape of spawning stock (Caddy & Mahon, 1995). Gillnets contribute, therefore, with versatility, to management strategies as required by the condition of the stock.

Size selectivity in gillnets is usually estimated by applying an experimental design using various mesh sizes simultaneously (at least three or more) to capture the target species (Millar & Holst, 1997; Madsen, 2007). Former whitemouth croaker selectivity estimations in gillnets were obtained experimentally by Puzzi & Andrade e Silva (1981) using simultaneously nine stretched mesh sizes between opposite knots from 60 to 140 mm, and applying the method proposed by Gulland (1969), and Reis & Pawson (1999) using three mesh sizes between 50 and 70 mm applying the method proposed by McCombie & Berst (1969). Among the results, in both studies it was observed that whitemouth croaker was mainly caught by the gilled process, directly related with the girth perimeter of the fish and the mesh size used for its catch. The possibility of conducting a new study of gillnet selectivity is limited by the extensive area in which the species is distributed, forcing to deploy large nets which do not ensure a similar probability of encounter along its extension. Thus, the use of secondary sources of information such as data on size frequency can be analyzed to indirectly obtain the gillnet selectivity, considering that previous evidences confirmed that fish are mainly gilled. The present study utilized information available from different studies and monitoring programs on the size composition of the whitemouth croaker fishery in southeastern and southern Brazil to calculate a selection factor for the gillnets and to estimate a generic curve of retention probability to the mesh size used in the fishery. The results obtained were compared respect to the previous selectivity estimation, and recommendations for the fishery management were made.

## MATERIALS AND METHODS

Analyzed data included capture frequency of reported sizes, from different fishery studies and monitoring programs conducted in the states of Rio Grande do Sul, Santa Catarina and São Paulo (Fig. 1), between 1998 and 2012. In particular, data from the São Paulo State corresponded to five years over two periods (1998-1999 and 2009-2011), where gillnets operated using five mesh sizes, either individually (70 and 120 mm) or in combination using two mesh sizes during the same fishing trip (70, 100, 110, 120 and 130 mm) (Table 1). For the Santa Catarina State, samples from trips carried on during 2008-2011 were analyzed, in which mesh sizes of 120 and 130 mm nets were recorded. Between 2006 and 2012, Rio Grande do Sul State had data records for 90, 100 and 130 mm nets. In general terms, the database used in the analysis consisted of 3,264

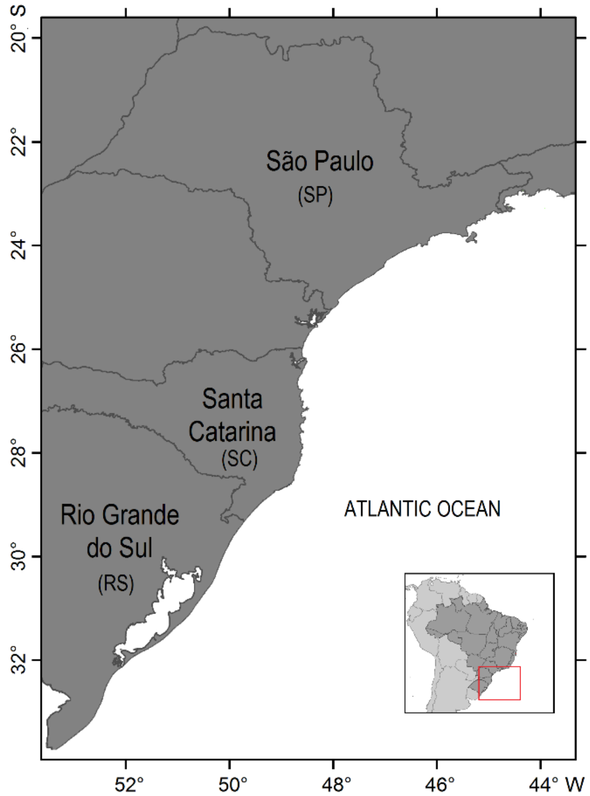


**Figure 1.** States of the southeastern and southern Brazil which recorded data was used in selectivity analysis of whitemouth croaker.

specimens of fish sampled in the São Paulo, 60,650 from Santa Catarina and 5,855 from Rio Grande do Sul states.

To obtain the gillnet selection factor for the whitemouth croaker fishery, it was necessary to assign a modal or optimum retention length to each mesh size using an indirect approach, derived from the size frequency distributions of fish samples. Some indirect methods were described by Sparre & Venema (1998) based on the ratio between catch sizes and length of fish caught by two mesh sizes, requiring that a) fishes of a given size are equally available to nets of different mesh size, and b) selectivity depends on the fish size and mesh size only. Because the data used in this study came from commercial fishing trips, the compliance of the Baranov's principle of geometric similarity based on previous exploration of the size frequency distributions was assumed.

Due to the high imbalance in the quantity of data available for the different areas and periods, size frequencies grouped by state and year for each mesh size resulted in 32 size frequency distributions. Normal and bi-normal probability distribution models were fitted to size frequency distributions, according to whether the origin corresponded to one or two mesh sizes on the same fishing trip, respectively. For each distribution, the mode of the fitted curves was assumed equal to the optimum or modal retention length. Parameters representing the modal lengths and the standard deviations of each curve were estimated using the least squares Solver function in MS Excel. The bi-normal selection curve is the addition of two normal curves with a weighting factor (*w*) (Santos *et al.*, 2003; Madsen, 2007) and the relative retention in this case is given by:

$$r(l) = \exp\left(-\frac{(l-ml_1)^2}{2*\sigma_1^2}\right) + w * \exp\left(-\frac{(l-ml_2)^2}{2*\sigma_2^2}\right) \qquad (1)$$

where $l$ is the observed length and $ml_j$ and $\sigma_j$ correspond to the modal length and standard deviation adjusted for every mode of the distribution.

A fit between the estimated modal lengths (*ml*) and its respective mesh size (*ms*) was then performed, using a linear function with an intercept at the origin, and the slope assumed to be equal to the selection factor (SF) (Sparre & Venema, 1998). Thus, $\mathrm{SF} = ml/ms$ while the coefficient of variation (CV) of each distribution corresponds to $\mathrm{CV} = \sigma/ml$. The equality of means of the CV for different mesh sizes was tested using analysis of variance (ANOVA), and their average value was calculated. The size range of fish that would be captured with each mesh size was calculated as $ml \pm 0.2\ ml$ according to a simple rule proposed by Baranov (1948), who suggested that fish less or greater than 20% of the optimum capture length are rarely caught by the net. While recognizing that the principle of geometrical similarity is an oversimplification (Hamley, 1975), its use is very informative to support management decisions based on operational results obtained for fishing fleets.

## RESULTS

The fit of 32 retention equations (Fig. 2), corresponding to 23 uni-modal and 9 bi-modal distributions, allowed the estimation of 42 modal lengths for the mesh sizes used in the three states during the periods from which length samples were available. A linear relationship, whose slope (selection factor) corresponds to 3.73, was confirmed between the mesh size used in capture and the modal retention length (Fig. 3a). The CV ranged between 0.076 and 0.127, without a trend related to the mesh size used (Fig. 3b) using ANOVA to verify the equality of the means ($P$ = 0.49). The mean CV value corresponded to 0.0997 (10%). From the above calculations, it was possible to establish a general equation for estimating the probability of retention to the size *S(l)* of any mesh size (*ms*) used to capture whitemouth croaker, corresponding to:

$$S(l) = \exp\left(-\frac{(l-ms*3.73)^2}{2*(ms*0.372)^2}\right) \qquad (2)$$

**Table 1.** Number of specimens measured by state of origin (*i.e.,* landings), mesh size (mm) used for their capture and the year. *Corresponds to two different mesh sizes used during the same fishing trips.

| State | Mesh size (mm) | Acronym | Period | Fish sampled |
|---|---|---|---|---|
| Rio Grande do Sul (RS) | 90 | RS90 | 2006 - 2007, 2009, 2011 - 2012 | 1724 |
| | 100 | RS100 | 2006 - 2007, 2009, 2011 | 1660 |
| | 130 | RS130 | 2006 - 2007, 2009, 2011 - 2012 | 2471 |
| Santa Catarina (SC) | 120 | SC120 | 2009 | 4480 |
| | 130 | SC130 | 2008 - 2011 | 56170 |
| São Paulo (SP) | 70 | SP70 | 2010 - 2011 | 423 |
| | 120 | SP120 | 2011 | 225 |
| | 70-100* | SP70-100 | 2011 | 125 |
| | 70-110* | SP70-110 | 2009 - 2010 | 365 |
| | 70-120* | SP70-120 | 2009 - 2010 | 770 |
| | 70-130* | SP70-130 | 1998 - 1999, 2009 - 2011 | 1356 |

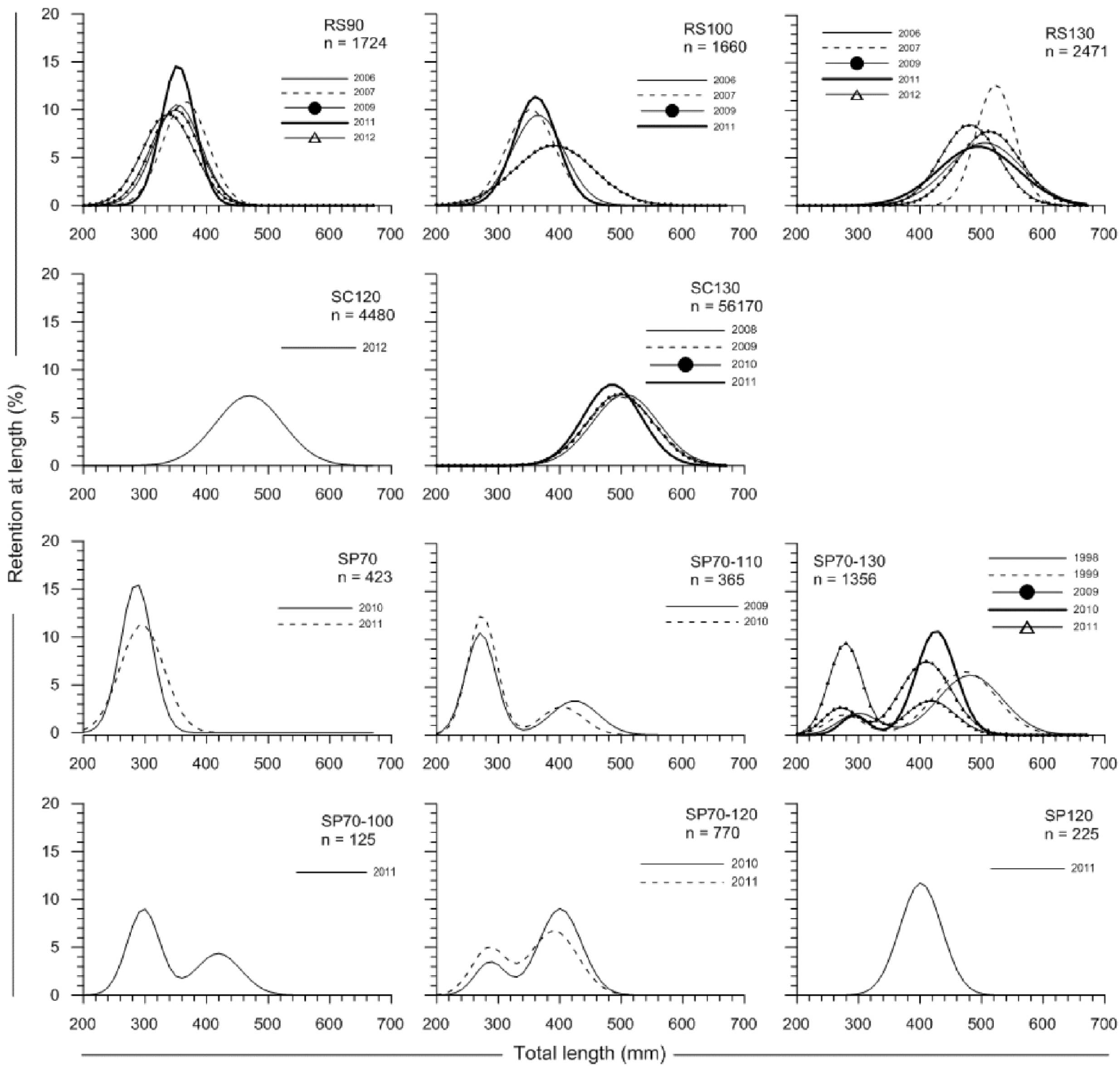


**Figure 2.** Curves fitted to the percentages of the retention size of whitemouth croaker (*Micropogonias furnieri*) as a function of the mesh size used and the sample origin (RS: Rio Grande do Sul, SC: Santa Catarina, SP: São Paulo).

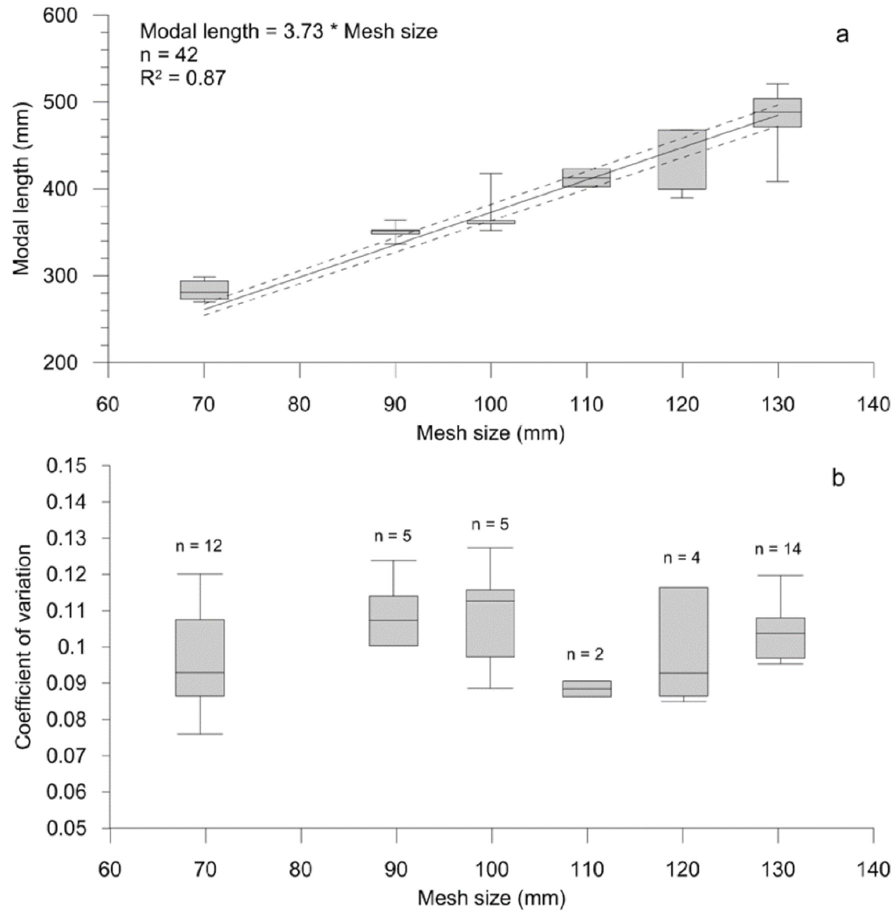


**Figure 3.** Box-plots of observed modal lengths of whitemouth croaker (*Micropogonias furnieri*), linear regression and 95% confidence intervals with discontinuous lines (a), and box-plots of the coefficients of variation of modal lengths based on the mesh size used (b).

Figure 4 shows the retention curves resulting from the generalization obtained using the previous equation between 70 and 130 mm mesh size. Since the standard deviation is proportional to the modal length, wider size ranges of retained fish were estimated using larger mesh sizes. Thus, the 70 mm mesh size nets, the smallest used to capture whitemouth croaker, retained fishes from 209 to 313 mm with a modal or optimum capture length of 261 mm (Table 2). This mesh size is commonly used in gillnets in São Paulo, either individually or simultaneously with other mesh sizes (100, 110, 120 and 130 mm).

The 130 mm mesh size is used individually both in the fishery of Rio Grande do Sul, and Santa Catarina, and simultaneously with nets of 70 mm mesh size, as in São Paulo (Table 1). The 130 mm mesh exhibited a modal capture length of 485 mm, with expected retention of fish length ranging from 388 to 582 mm (Fig. 1; Table 2). Meanwhile, the mesh size of 90 mm was used exclusively in Rio Grande do Sul, and its selectively captured fish between 260 and 440 mm. The modal length estimated for this mesh was 336 mm, with a capture range between 268 and 403 mm (Fig. 1; Table 2).

## DISCUSSION

In the last decade, the recorded landings of whitemouth croaker in southern and southeastern Brazil ranged between 25,000 and 35,000 ton annually. However, the CPUE trend of the trawling vessels in the southern region indicates that the biomass of whitemouth croaker is decreasing, evidencing that the resource is being overexploited at rates that are not sustainable (Haimovici, 1998; Vasconcellos & Haimovici, 2006). The stock abundance of whitemouth croaker from south and southeast was recently estimated by a virtual population analysis (VPA), and both stocks were considered to be overexploited (Pio, 2015). These findings indicate the need for enforcement of measures that reduce fishing mortality of the species in the region. Without quota or extraction limits, the main currently enforced measures correspond to closing access to new vessels and reducing the fishing effort of

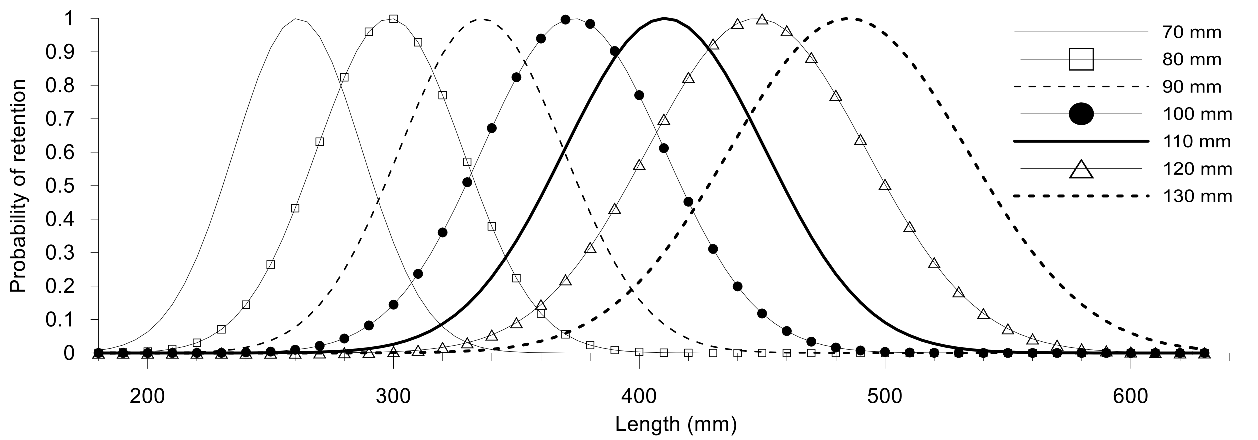


**Figure 4.** Probability of retention of whitemouth croaker in gillnets estimated as a function of the mesh size.

**Table 2.** Estimated values of modal length (*ml*) of whitemouth croaker (*Micropogonias furnieri*), size range of retained fish and standard deviation (SD) with respect to the modal length for each mesh size.

| Mesh size (mm) | Modal length (mm) | Size range (mm) | SD (mm) |
|---|---|---|---|
| 70 | 261 | 209 - 313 | 26.0 |
| 80 | 299 | 239 - 358 | 29.7 |
| 90 | 336 | 269 - 403 | 33.5 |
| 100 | 373 | 298 - 445 | 37.2 |
| 110 | 411 | 328 - 493 | 40.9 |
| 120 | 448 | 358 - 537 | 44.6 |
| 130 | 485 | 388 - 582 | 48.3 |

the authorized fleets. In the latter case, regulations limit the total net length that can be used in the gillnet fisheries in general (including the whitemouth croaker fishery) according to the vessel's gross tonnage (Instrução Normativa Interministerial MPA/MMA N° 12, 22/08/2012). As such, vessels under and over 50 GT can operate 10,000 m and 13,000 m long nets, respectively. The same regulation establishes the hanging ratio (0.5), twine type (monofilament), maximum height (4 m), and mesh size (between 70 and 140 mm between opposite knots). For Santa Catarina State, according to Pio *et al.* (2012), the industrial bottom gillnet fisheries comply these measures (hanging ration, twine type and height).

The mesh size is one of the gillnet main characteristics that might be modified to achieve sustainability goals of the fishery. For most fishing gears, the length of 50% retention ($l_{50}$) is commonly used to establish fisheries management rules taking the length at first maturity as a biological reference point. In the case of the bell-shaped selectivity curve of gillnets, the length at first maturity could be compared to the modal length and the lower value of $l_{50}$ (at the left of the modal length in the curve). In this sense, the previous results obtained by Puzzi & Andrade e Silva (1981) and Reis & Pawson (1999) are relevant. These authors made an experiment with eight meshes between 60 to 140 mm and the differences in modal lengths estimated respect to the present study are around one centimeter. For example, in the case of the 70 mm mesh size, the modal length estimated by Puzzi & Andrade e Silva (1981) was 269 mm, while in this work the estimated value was 261 mm (Table 3). For another commonly used mesh size as the 90 mm, estimates were 346 and 336 mm, respectively.

In the case of $l_{50}$, the differences between the two compared studies were larger in smaller mesh sizes (Table 3). Such differences can be attributed to the narrower bell obtained using the present method as a result of the coefficient of variation, while Puzzi & Andrade e Silva (1981) calculated $l_{50}$ using constant values. Reis & Pawson (1999) examined the selectivity for young whitemouth croaker and their $l_{50}$ estimate for the 70 mm mesh was 242 mm very near the 232 mm estimated in this study (Table 3). Overall, the results show coherence between former studies and its correct interpretation could support management measures in the fishery. In particular, a selection factor estimate for whitemouth croaker of 3.7-3.8 seems robust, as independently calculated by the experimental approach (Puzzi & Andrade e Silva, 1981) and the one presented here that used the size frequency distributions obtained from the fishing activities.

In terms of a proposal to improve management, Alves *et al.* (2012) recommended a review of the technological aspects in the bottom gillnet fishery for whitemouth croaker, particularly with respect to using mesh sizes of 70 mm, as the fleet would be capturing specimens that may be smaller than the size at first sexual maturity. The maximum retention efficiency ($ml_{70}$) of this mesh size is for fish of 261 mm, with a capture range of 209 and 313 mm, thus there would be

**Table 3.** Comparative results of the modal length (*ml*) and the lower value of $l_{50}$ estimated by Puzzi & Andrade e Silva (1981), Reis & Pawson (1999) and the present work. **ml* for 80 mm mesh was estimated from eq. 2.

| Mesh size | Present work | | Puzzi & Andrade e Silva (1981) | | Reis & Pawson (1999) | |
|---|---|---|---|---|---|---|
| (mm) | *ml* (mm) | $l_{50}$ (mm) | *ml* (mm) | $l_{50}$ (mm) | *ml* (mm) | $l_{50}$ (mm) |
| 50 | - | - | - | - | 175 | 183 |
| 60 | - | - | 230 | 164 | 200 | 214 |
| 70 | 261 | 232 | 269 | 203 | 230 | 242 |
| 80 | 299* | 263 | 307 | 241 | - | - |
| 90 | 336 | 296 | 346 | 280 | - | - |
| 100 | 373 | 329 | 384 | 318 | - | - |
| 110 | 411 | 362 | 422 | 356 | - | - |
| 120 | 448 | 395 | 460 | 395 | - | - |
| 130 | 485 | 429 | - | - | - | - |
| 140 | - | - | 538 | 472 | - | - |

**Table 4.** Length at first maturity estimates for whitemouth croaker. M: male. F: female. *Sex not identified.

| Area | Length at first maturity (mm) | Author |
|---|---|---|
| Sta. Catarina, São Paulo, Rio de Janeiro (23º-29ºS) | 250 (M); 275 (F) | Vazzoler (1971) |
| Sta. Catarina, São Paulo, Rio de Janeiro (23º-29ºS) | 243 (M); 292 (F) | Carneiro *et al.* (2005) |
| Rio Grande do Sul (29º-33ºS) | 330 (M); 350 (F) | Vazzoler (1971) |
| Argentina and Río de la Plata (33º-41ºS) | 300 – 400 * | Haimovici (1977) |
| Río de la Plata (34º-40ºS) | 310 * | Arena & Herti (1983) |
| Rio de Janeiro | 329 (M); 341 (F) | Santos *et al*. (2015) |

a high probability of retention of fish that still have not reached the length at first sexual maturity in the area between 23º and 29ºS (Table 2). Furthermore, the minimum allowed landing size for whitemouth croaker is 25 cm (Instrução Normativa Nº53 (22/11/2005), MMA, 2005), and a mesh size of 70 mm can catch large quantities of fish that must be discarded which increases the risk of punishment for fishermen.

Regarding the southern stock, the risk of overfishing by recruitment is increased because the size at first sexual maturity of females (350 mm; Table 4) is very close to the modal length of a 90 mm mesh ($ml_{90}$ = 336 mm). In this case, the use of a mesh size of 100 mm or larger (modal length 373 mm or greater) is recommended and smaller mesh sizes are to be avoided. It should be noted that in the 1990s, the use of 140 and 160 mm mesh for the capture of whitemouth croaker was recorded along the southern coast of the State of Rio Grande do Sul (Reis *et al.*, 1994; Boffo & Reis, 2003; Vasconcellos *et al.*, 2014), while along the northern coast, 130 and 140 mm mesh sizes were recorded between 2002 and 2004 (Moreno *et al*., 2009).

The decrease in the current mesh size to 90, 100 and 130 could reflect a change in the target species or a reduction in the average size of the population, with the latter possibly being a symptom associated with overfishing. However, the increasing demands for middle size fishes could also be an incentive to reduce the mesh size and maximize economics benefits. In southern Brazil, meshes between 90 and 100 mm are commonly used to catch other abundant croakers (*Umbrina canosai)* and weakfishes *(Cynoscion guatucupa*), while bigger meshes as 130 and 140 mm are used when the target is whitemouth croaker. Instead, in the State of Santa Catarina there is a continuous fishing activity over whitemouth croaker as target species using mainly 130 mm mesh size in gillnets, which seasonally alternates the fishing zones between southeastern and southern stocks.

Gillnet possess the capacity to produce fishing mortality to a range of relatively narrow sizes, with a traditionally unimodal selectivity curve. Its effectiveness upon population sustainability can be assessed using different exploitation strategies. For this purpose, the use of age-structured models can respond not only to how much of a population should be caught but also to which fish should be caught (Diekert *et al*., 2010) by selecting the mesh size that provides an optimal selectivity. Cardinale & Hjelm (2012) demonstrated that the use of different exploitation strategies resulted in significant changes in the range of captured sizes and increased both yield and economic returns in the Baltic cod fishery. Colloca *et al*. (2013) stated that the sustainability of fisheries in the Mediterranean could be reached by substantially modifying current selectivity, and increasing the size at which commercial species are caught by fishing fleets. Whitemouth croaker is submitted to multi-fleet fisheries in the southern and southeastern Brazil. Besides gillnet fleets, trawlers play an important role in the exploitation of its stocks. This study demonstrated how a selectivity analysis can be helpful to understand and evaluate the impact of a fishery on a stock. In order to achieve the objectives of a sustainability management for whitemouth croaker, the studies that periodically evaluate the status of each stock should consider fishing patterns and the selectivity of the fishing gears.

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