

Selectivity of gillnets for the capture of *Selene peruviana* and *Peprilus medius* in the Ecuadorian Pacific

Selectividad de las redes de enmalle para la captura de *Selene peruviana* y *Peprilus medius* en el Pacífico ecuatoriano

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ABSTRACT

In the Ecuadorian Pacific, *Selene peruviana* and *Peprilus medius* are target species for artisanal fishing caught with gillnets that constitute an important fishery resource for local consumption, given that they are highly valued species due to their low cost and their contribution of high biological value protein. However, no studies have determined selectivity in capturing these species. This study evaluates the selectivity of monofilament surface gillnets with mesh sizes of 3" (7.62 cm) and 3 ½" (8.89 cm), mostly used by artisanal fishers. Data was obtained from different fishing operations within the coastal zone of 8 nautical miles (nm) in Manabí, Ecuador, in 2017, between 6:00 pm and 6:00 am. Selectivity parameters and curves were evaluated through multi-model analysis using the SELEC method. The lognormal model showed the best fit with modal lengths of 24.23 and 21.96 cm for *S. peruviana* and *P. medius*, respectively, and selection factors of 3.23 and 3.11. The optimal mesh sizes were calculated at 7.20 and 6.91 cm, respectively, which are smaller than those commonly used by most local artisanal fishers. Therefore, it can be inferred that the size distribution of the captured species follows a lognormal distribution, suggesting that gillnets have a higher probability of capturing larger fish.

Keywords: Carangidae, Stromateidae, artisanal fishing, selectivity, Ecuadorian Pacific

RESUMEN

En el Pacífico ecuatoriano, *Selene peruviana* y *Peprilus medius* son especies objetivos de la pesca artesanal capturadas con redes de enmalle, y constituyen un importante recurso pesquero para el consumo local al ser especies muy cotizadas por su bajo costo y su aporte de proteína con alto valor biológico. Sin embargo, no existen estudios que determinen la selectividad en la captura de estas especies. El presente estudio evalúa la selectividad de redes de enmalle de superficie de monofilamento con luz de malla de 3" (7.62cm) y 3 ½" (8.89 cm), mayormente utilizadas por los pescadores artesanales. Los datos provinieron de diversas operaciones de pesca dentro de la zona costera de 8 millas náuticas (M) en Manabí, Ecuador, durante 2017, entre 6:00 p. m. y 6:00 a. m. Los parámetros y curvas de selectividad se evaluaron mediante análisis multimodelo utilizando el método SELEC. El modelo log-normal mostró el mejor ajuste con longitudes modales de 24.23 y 21.96 cm para *S. peruviana* y *P. medius*, respectivamente, y factores de selección de 3.23 y 3.11. Los tamaños de malla óptimos calculados fueron de 7.20 y 6.91 cm, correspondientemente, que son más pequeños que los utilizados por la mayoría de los pescadores artesanales locales. Por lo tanto, se puede inferir que la distribución de tamaños de las especies capturadas sigue una distribución log-normal, lo que sugiere que las redes de enmalle tienen una mayor probabilidad de capturar peces más grandes.

Palabras clave: Carangidae, Stromateidae, pesca artesanal, selectividad, Pacífico Ecuatoriano

INTRODUCTION

In fisheries assessment, the size of commercially important species depends on their biology, growth, and age at sexual maturity, as well as environmental conditions and availability of food in their habitat (Narváez Barandica *et al.* 2013; Altun, 2023; Balbontín *et al.* 2023).

The use of size-based methods to assess fish populations has been employed for several years and continues to be used today due to the ease and availability of data for their implementation (Gulland & Rosenberg, 1992; Fisch *et al.* 2019; Fisch *et al.* 2021). As the level of exploitation of a resource or fishing area increases, there is a tendency

among fishers to decrease the selectivity of their fishing gear, resulting in an increase in bycatch and the capture of undersized individuals (Duarte *et al.* 2006; Rezende *et al.* 2019; Martin Gonzalez *et al.* 2021). The decrease in fish abundance promotes the enlargement of fishing gear, leading to increased fishing power, which, in some cases, hinders the escape of organisms that have not reached their size at sexual maturity, hence not contributing with new individuals to the population (McClanahan & Mangi, 2004; Altamar *et al.* 2015).

Selective fishing gear is essential to ensure sustainable fishing and minimize the capture of non-target species (FAO, 2018; Lucchetti *et al.* 2023; Bhanja *et al.* 2024). This highlights the importance of selectivity as a fundamental tool in fisheries management to achieve sustainability (Troadec, 1984; Gilman *et al.* 2020; Wang *et al.* 2022).

Size selectivity, both within and among species, provides valuable information to establish management measures in fisheries (Sparre & Venema, 1997). Reeves *et al.* (1992) emphasize the need to consider the ability of a fish to escape through a mesh opening or become trapped in it, with both horizontal and vertical dimensions of the mesh opening being key factors when designing fishing gear. Size selectivity, to some extent, could be regulated by gear design. Ideally, a certain mesh size should allow for the release of all fish below a certain size (FAO, 1995; Cuende *et al.* 2020; Yu *et al.* 2023).

Gillnets are one of the most common and widely used fishing gear in artisanal fisheries (Rojo Vázquez, 1997), offering advantages over other fishing gear due to their easy use, low cost, and ability to be set at various depths (Hovgård & Lassen, 2000; Sánchez-González & Casals, 2022).

It is considered that one of the most important characteristics of gillnets is their selectivity (Rojo Vázquez, 1997; Humphries *et al.* 2019; Kim *et al.* 2021). The catch

probability of a gillnet depends on specific gear characteristics and the morphology of the target species (Gulland & Harding, 1961; Holst *et al.* 1998). The effectiveness of selectivity research with gillnets hinges on acquiring adequate catches, yet there is no exact method for determining the minimum number of attempts needed since it varies based on capture efficiency (Altamar *et al.* 2020).

In Ecuador, gillnets are not regulated, unlike other fishing gear such as trawls, beach seines, purse seines, and hooks, which have a more comprehensive regulatory framework. Furthermore, there are no studies on the selectivity of gillnets for capturing *Selene peruviana* (Guichenot, 1866) and *Peprilus medius* (Peters, 1869), despite their local commercial importance as a target for artisanal fisheries. Therefore, the present research aims to analyze the selectivity of gillnets in catching *S. peruviana* and *P. medius* in the Ecuadorian Pacific, as well as identifying the most suitable mesh sizes to promote sustainable fishing.

MATERIALS AND METHODS

For the selectivity analysis of gillnets, data was obtained through fishing operations within 8 nautical miles (nm) off the coast of Manabí, Ecuador (1° 6' 16.1" S, 80° 56' 17.0" W) and (0° 47' 17.60" S, 80° 35' 41.26" W) (Fig. 1). Fishing operations were conducted during 2017 on different trips, between 6:00 pm and 6:00 am, depending on the tide since fishers carry their boats from shore to the sea during high tide. Two surface gillnets made of monofilament with mesh sizes of 3" (7.62 cm) and 3 ½" (8.89 cm) 3.5 m long were used for capturing *S. peruviana* and *P. medius*. The net panels were attached to upper- and lower-line ropes, which were made with twisted polyethylene (PE) thread of 5

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mm in diameter, where floats and weights were hung, respectively. During the fishing operation, the catch was separated into plastic containers on board. Once organisms were collected, their total length (cm) was measured using a measuring tape with 1 mm precision.

Two methods were used to evaluate the selectivity parameters of the two mesh sizes, the indirect method proposed by Holt (1963), in which data was categorized into size intervals for each type of net used, and a multimodel analysis, using four unimodal selection curve models: normal location, normal scale, gamma, and lognormal. These models were established using the SELECT method (Millar, 1992) and implemented using the "Selec_millar" and "gillnetfit" packages (Millar, 2010) in the statistical software R. The SELECT method enables the estimation of selection curves for gillnets and their retention probabilities using comparative catch data (Queirolo *et al.* 2013). The number of fish of length l captured with a mesh size follows a Poisson distribution n_{ij} (Millar, 1995) and is defined by the following equation $n_{ij} \sim Pois(p_j \lambda_l r_j(l))$

While the likelihood function for n_{ij} is $\sum_l \sum_j \{n_j \log_e [p_j \lambda_l r_j(l)] - p_j \lambda_l r_j(l)\}$

Where: n_j is the number of fish of length l captured by mesh size j ; p_j is the relative fishing intensity, representing the probability that a fish of length l makes contact with mesh size j ; λ_l is the abundance of fish in size class l ; $r_j(l)$ is the retention probability of fish of length l in mesh size j .

The dependent variable was the retention probability of fish of length l in the gillnet of mesh size j , while the independent variables were the mesh size of the gillnet (j) and the length of the captured fish (l). The method utilizes a Generalized Linear Model (GLM), commonly used in gillnets and hooks (Millar & Holst, 1997). These models were

fitted to the capture data obtained during fishing operations, using probability functions such as the Poisson distribution and likelihood functions to assess their fit to the observed data and estimate the model parameters. To find the model with the best fit, quasi-deviance residuals were calculated and incorporated into the corrected quasi-Akaike Information Criterion (QAICc) scores for each combination of species and selection curve (Smith *et al.* 2017; Burnham & Anderson, 2002). The model with the lowest QAICc is assumed to provide the best fit to the data. The models generated using the SELECT method are presented in Table 1.

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In addition, the indirect method proposed by Holt (1963) was used, in which data was categorized into size intervals for each type of net used (Ca and Cb). The logarithms of the proportions can be expressed as a linear function of fish length (*Lt*):

$$\ln \frac{Ca}{Cb} = a + bLt \quad (1)$$

Where Cb represents the catch of the large mesh (mb) while Ca the catch of the small mesh (ma). The parameters *a* and *b* of the regression were used to calculate the optimal capture size (Lm) and the standard deviation (S) for each net using the following equations:

$$Lma = \frac{-2*a*(mb-ma)}{b*(ma+mb)} \quad (2)$$

$$Lmb = \frac{lma * mb}{ma}$$

$$S = \sqrt{\frac{-2*a*(mb-ma)}{b^2*(ma+mb)}} \quad (3)$$

The Selection Factor SF is calculated using the equation (Holt, 1963):

$$SF = \frac{-2a}{b*(ma+mb)} \quad (4)$$

The selectivity curve was fitted to the equation:

$$SL = e \left[\frac{(L-Lm)^2}{2+S^2} \right] \quad (5)$$

Where SL is the selection probability for a fish of length L; Lm is the optimal size, and S is the standard deviation.

Recommended mesh sizes (MS) were calculated based on the optimal capture size for each mesh size and the selection factors (SF) obtained from the best fit, and considering the average size at sexual maturity, $MS = \frac{L_{50\%}}{SF}$

After verifying the normality and homoscedasticity of data, a Student's t-test was applied to determine significant differences in catch sizes of each species with different mesh sizes and to compare the optimal capture sizes. When these assumptions were not met, a Mann-Whitney test was used (Zar, 2013). The statistical analysis was conducted with a 95% confidence level using the R programming language (R Core Team, 2021).

RESULTS

A total of 598 specimens were analyzed for gillnet selectivity, and 324 individuals of *S. peruviana* were obtained, with average sizes of 23.76 ± 3.84 and 22.76 ± 3.08 cm TL for gillnets with 7.62 cm and 8.89 cm mesh size, respectively (Fig. 2). Significant differences were observed ($U = 9\ 181$; $P < 0.05$) between net types. In the case of *P. medius*, 274 specimens were obtained, with average sizes of 21.14 ± 2.70 and 22.70 ± 2.74 cm TL for gillnets with 7.62 cm and 8.89 cm mesh size, respectively, also showing significant differences ($U = 12\ 151.5$; $P < 0.05$). In general, the smaller mesh size net captured smaller individuals of *S. peruviana* on average, while larger individuals of *P. medius* were captured using the larger mesh size net. However, for both species, the smaller mesh size net had the widest range of sizes (Fig. 3).

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The SELECT method applied to the lengths of *S. peruviana* determined the selectivity parameters of the models, with the lognormal unimodal model showing the best fit (QAICc 13.44) and being used for the selectivity curves with parameters $\mu = 3.23$ and $\sigma = 0.21$. Conversely, the normal scale model (normal with different variances) showed the poorest fit. For *P. medius*, the selectivity parameters also indicated the lognormal model as the best fit (QAICc 23.16), with $\mu = 3.03$ and $\sigma = 0.15$, and a modal length of 20.24 ± 0.39 and 23.42 ± 0.3 . Similarly, the normal scale model showed the poorest fit (Table 2).

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Regarding the fitted selectivity curves, two curves were estimated for each of the four adjusted models of *S. peruviana*. The deviation analysis using the lognormal distribution model provided the best fit to the size-at-capture of *S. peruviana*, which corresponded to the optimal capture sizes of 24.23 ± 0.27 and 28.20 ± 0.30 cm TL for nets with mesh sizes of 7.62 and 8.89 cm, respectively. Size intervals ranged from 16.6 to 40.80 cm TL for the net with the smaller mesh size, and from 18.70 to 36.70 cm TL for the net with the larger mesh size (Fig. 4).

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Similar fitted selectivity curves were obtained for *P. medius*, corresponding to the optimal capture sizes. Likewise, the lognormal distribution model provided the best fit with an optimal capture size of 21.96 ± 0.52 and 25.49 ± 0.30 cm TL for nets with mesh sizes of 7.62 cm and 8.89 cm, respectively, and a size interval between 17.0 and 29.4 cm TL for the net with the smaller mesh size, and a size interval between 18.70 cm and 31.30 cm TL for the net with the larger mesh size (Fig. 5).

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Using Holt's direct method, an optimal capture size of 23.7 cm LT, an SF of 3.04, and a correlation coefficient of $r = 0.95$ ($F=37.17$; $P < 0.05$) were obtained for *S. peruviana*, while, an optimal capture size of 21.9 cm TL, an SF of 2.88, and a correlation coefficient

of $r = 0.94$ ($F = 32.20$; $P < 0.05$) were obtained for *P. medius* (Fig. 6). The optimal catch sizes for *S. peruviana* and *P. medius* using Holt and SELECT methods, respectively, did not show significant differences ($t = 0.15$; $P > 0.05$) and ($t = 0.02$; $P > 0.05$).

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DISCUSSION

In the multimodel analysis of selectivity of the 7.62 and 8.89 cm mesh size gillnets, commonly used by artisanal fishers in Ecuador for the capture of *S. peruviana* and *P. medius*, it was observed that the estimated modal lengths in the present study were smaller than the reported sizes at sexual maturity in the Ecuadorian Pacific, which were 23.27 cm TL for combined sexes of *S. peruviana* and 21.5 cm TL for *P. medius* (Mendoza-Nieto *et al.* 2022; Mendoza-Nieto *et al.* 2023). Only the normal scale model showed a size below sexual maturity in *P. medius*, but overall, the lognormal model showed the best fit for both species. However, in many selectivity studies, normal scale models, as well as bimodal models, tend to provide the best fits (Fujimori & Tokai, 2001; dos Santos *et al.* 2003; Erzini *et al.* 2003; Carol & Garcia-Berthou, 2007). On the other hand, fitting with gamma, logarithmic, normal, or multimodal models is mostly used when a large number of fish are captured and data is right-skewed (Millar, 1992).

The better fit with the lognormal model can be attributed to the fact that it is a continuous probability distribution that is applied to random variables and exhibits a normal distribution when the natural logarithm of the variable is taken. It is primarily employed in modeling data with positive skewness (Nagatsuka & Balakrishnan, 2013; Limpert & Stahel, 2017; Feng *et al.* 2020).

This confirms that gillnets have a higher size selectivity, with a relatively narrow size interval (dos Santos *et al.* 2003), hence it can be inferred that the size distribution of *S. peruviana* and *P. medius* captured by gillnets follows a lognormal distribution, suggesting that gillnets have a higher probability of capturing larger fish (Saber & Aly, 2023). However, other factors such as the behavior and morphology of species also play a crucial role in the likelihood of capturing individuals of different sizes. Some species may more easily avoid or escape from nets with larger meshes, while others become trapped in smaller meshes. Furthermore, the size and body shape of individuals also affect their retention capacity, thus influencing the capture of fish of different sizes (Lemke & Simpfendorfer, 2023)

The selectivity efficiency of the fishing gear depends on the encounter probability and the likelihood of capture upon encounter (Tapia Varela, 2003). Therefore, the fishing zone should also be considered (Saber *et al.* 2022), as both *S. peruviana* and *P. medius* inhabit shallower waters close to the coast in their juvenile stages, unlike adults. Their habitat may include reef areas, bays, estuaries, and river mouths (Fischer *et al.* 1995), where they experience a higher incidence of natural mortality and lower fishing mortality due to their limited recruitment to the fishing area (Inga Barreto *et al.* 2008).

It is important to consider that *S. peruviana* is a larger species compared to *P. medius*. This is evident in the higher number of outliers in the gillnet with a mesh size of 7.62 cm, unlike *P. medius*. It should also be mentioned that the capture of *S. peruviana* and *P. medius* with gillnets is not an ongoing activity but rather one conducted by artisanal fishers seasonally and in specific areas. Therefore, the efficiency of the gear also depends

to a large extent on the stratification of the gear in the water column and the fishing season (Queirolo *et al.* 2013).

Despite the lack of fishery management measures for gillnets targeting *S. peruviana* and *P. medius* in Ecuador, data analysis—considering the optimal catch sizes for each mesh size and the specific selection factors for each species based on the best fit—suggests that the recommended mesh sizes (RMS) are 7.20 cm and 6.91 cm for capturing *S. peruviana* and *P. medius*, respectively, based on the average size at sexual maturity reported in the literature for similar gillnets. These recommended mesh sizes are smaller than the 7.62 cm and 8.89 cm meshes evaluated in this study, which are commonly used by artisanal fishers in Ecuador, implying that at least 50% of organisms would have contributed with new individuals to the population. However, the use of 6.35 cm (2 1/2”) gillnets has also been observed to a lesser extent.

Although the SELECT method is primarily used to assess selectivity with more than two mesh sizes, some authors have applied it to assess selectivity even with just two gillnets. This is because these log-linear models have the advantage of assuming that the variances of the two selectivity curves are heterogeneous, unlike the linear regression model (González *et al.* 2008; Intchama, 2023).

It is also important to highlight that, despite the selectivity of gillnets, their improper use and abandonment due to wear and tear, which shortens their lifespan (Brinkhof *et al.* 2023), can harm aquatic ecosystems. It has been reported that artisanal fishers in Ecuador may lose up to a maximum of 2 net panels per fishing trip (Zambrano *et al.* 2021). These abandoned nets can act as ghost fishing gear since they are made of non-biodegradable monofilament material, persisting for years and causing ecological

damage to marine fauna (Campoy & Beiras, 2019). An alternative could be to use gillnets made of multifilament material of natural fibers, which makes them more environmentally friendly and reduces the impacts of ghost fishing. However, selectivity studies are needed to assess their effectiveness.

To promote sustainable fishing, it is important to expand the analysis beyond modifications in mesh size (Breen *et al.* 2020). Considering other adaptations in the design of nets is crucial. Aspects such as the hanging ratio, which affects the mobility of the net in the water and can increase the likelihood of catching more active and agile species; the type of mesh material (monofilament and multifilament), where multifilament nets, due to their finer texture, can impact selectivity by allowing the capture of unwanted or juvenile species; and the position in the water column, as some species tend to swim at different depths at various stages of their life cycle. Additionally, more detailed patterns of selectivity have been uncovered, including the relevance of visual, auditory, and tactile signals for species, which play an essential role in fish capture (Abangan *et al.* 2023). Therefore, these factors require detailed analysis to accurately determine their effectiveness (Brandt von, 1975; Altamar *et al.* 2020) .

CONCLUSIONS

The analysis of gillnet selectivity in the artisanal fishing of *S. peruviana* and *P. medius* in Ecuador reveals significant differences in capture sizes depending on mesh size. Lognormal models showed the best fit, suggesting high size selectivity in the nets. Despite the lack of fishery management measures, recommended mesh sizes for more sustainable fishing are smaller than those commonly used, aiding in the contribution of new individuals

to the population. However, challenges such as material abandonment and improper use remain significant concerns. Additionally, the importance of considering further studies and promoting more sustainable fishing practices is emphasized.

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TABLES AND FIGURES

Table 1. Selectivity curve equations for evaluated models and equations for calculating modal lengths (cm) of *S. peruviana* and *P. medius*

Cuadro 1. Ecuaciones de curvas de selectividad para los modelos evaluados y ecuaciones para cálculo de longitudes modales (cm) de *S. peruviana* y *P. medius*

	Model	Modal length
<i>Normal location</i>	$\exp\left(-\frac{(l - k \cdot m)^2}{2\sigma^2}\right)$	$k \cdot m_j$
<i>Normal scale</i>	$\exp\left(-\frac{(l - k_1 \cdot m_j)^2}{2(k_2 \cdot m_j)^2}\right)$	$k_1 \cdot m_j$
<i>Gamma</i>	$\left(\frac{l}{(\alpha - 1) \cdot k \cdot m_j}\right)^{\alpha-1} \exp\left(\alpha - 1 - \frac{l}{k \cdot m_j}\right)$	$(\alpha - 1) \cdot k \cdot m_j$
<i>Log-normal</i>	$\frac{m_j}{l \cdot m_1} \left(\mu - \frac{\sigma^2}{2} - \frac{\left(\log(l) - \mu - \log\left(\frac{m_i}{m_1}\right)\right)}{2\sigma^2} \right)$	$\exp(\mu \cdot \sigma^2) \cdot \left(\frac{m_j}{m_1}\right)$

Table 2. Parameters of selectivity, mode and deviance of models for *S. peruviana* and *P. medius*

Cuadro 2. Parámetros de selectividad, moda y desviación de modelos para *S. peruviana* y *P. medius*

Species	n	Model	Parameters	Mode	Deviance residuals	QAICc
<i>Selene peruviana</i>	324	<i>Normal location</i>	$k, \sigma = (3.21; 5.84)$	24.53±1.01	5.81	15.66
		<i>Normal scale</i>	$k1, k2 = (3.35; 0.54)$	25.52±1.13	9.07	22.18
		<i>Gamma</i>	$\alpha, k = (21.61; 0.15)$	24.23±1.01	5.81	15.66
		<i>Log-normal</i>	$\mu, \sigma = (3.23; 0.21)$	24.23±0.97	4.7	13.44
<i>Peprilus medius</i>	284	<i>Normal location</i>	$k, \sigma = (2.89; 3.89)$	22.05±0.52	10.17	24.38
		<i>Normal scale</i>	$k1, k2 = (2.95; 0.22)$	20.50±0.54	11.78	27.60
		<i>Gamma</i>	$\alpha, k = (38.46; 0.07)$	22.13±0.53	10.17	24.38
		<i>Log-normal</i>	$\mu, \sigma = (3.11; 0.16)$	21.96±0.52	9.56	23.16

Fig. 1. Location of the study area, Los Arenales and Las Piñas, Manabí, Ecuador

Fig. 1. Ubicación de la zona de estudio, Los Arenales y Las Piñas, Manabí Ecuador

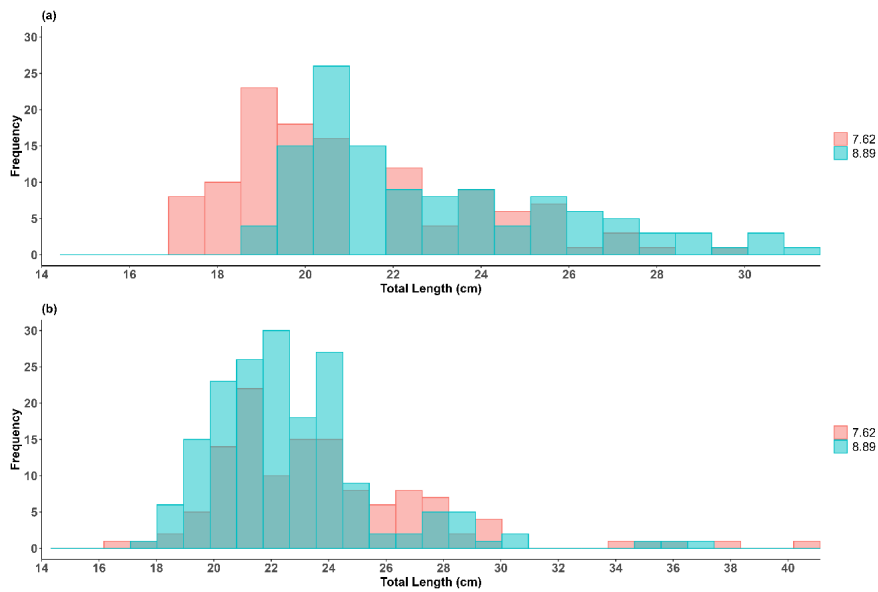


Fig. 2. Size frequency for a) *Peprilus medius* and b) *Selene peruviana* by mesh size

Fig. 2. Frecuencia de tallas para a) *Peprilus medius* y b) *Selene peruviana* por luz de malla

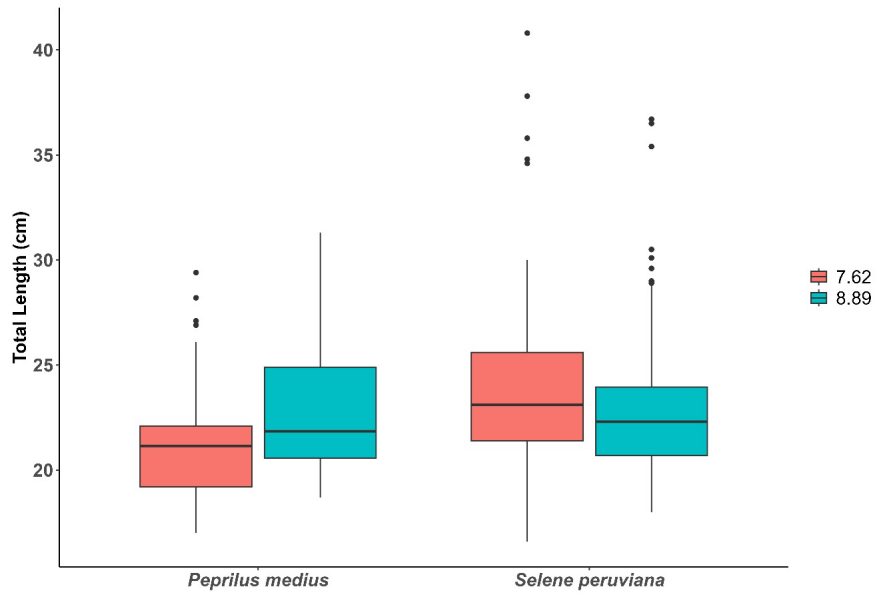


Fig. 3. Total length of captured *P. medius* and *S. pruviana* from nets with mesh sizes 7.62 and 8.89 cm

Fig. 3. Longitud total de ejemplares capturados de *P. medius* y *S. pruviana* con redes de luz de malla 7.62 y 8.89 cm

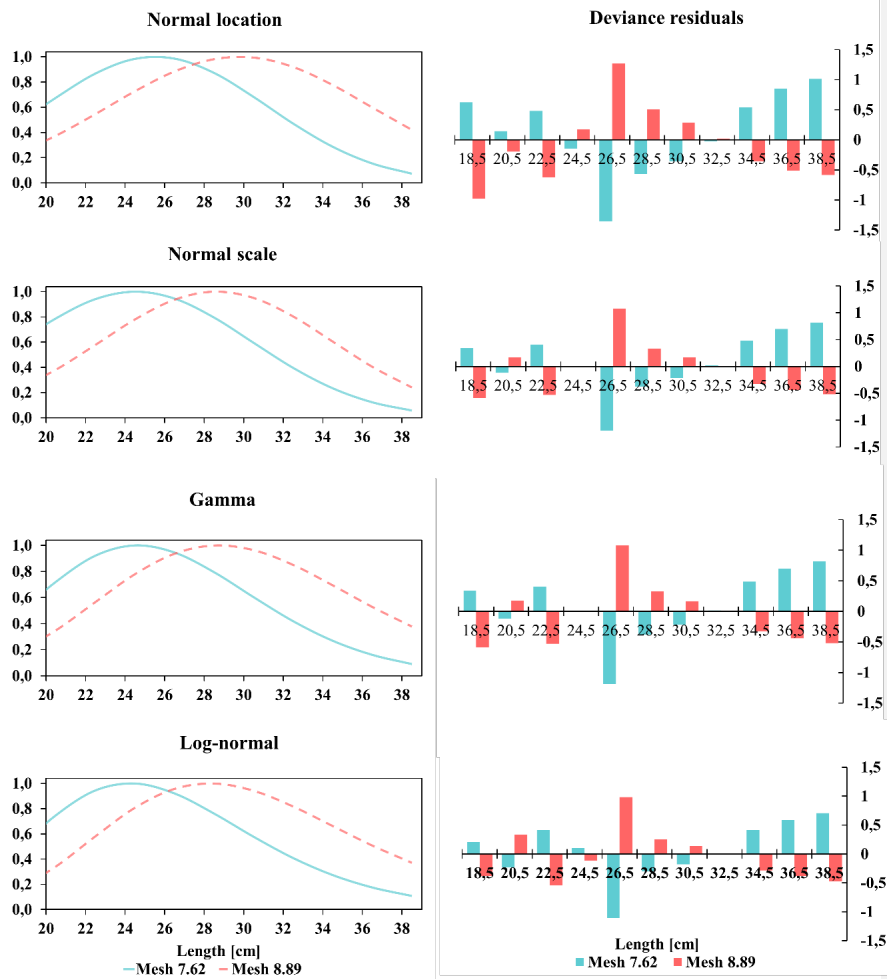


Fig. 4. Adjustment to models and residual deviation of *S. peruviana* with nets with mesh sizes 7.62 cm and 8.89 cm

Fig. 4. Ajuste a los modelos y desviación residual de *S. peruviana* con redes de malla de 7.62 cm y 8.89 cm

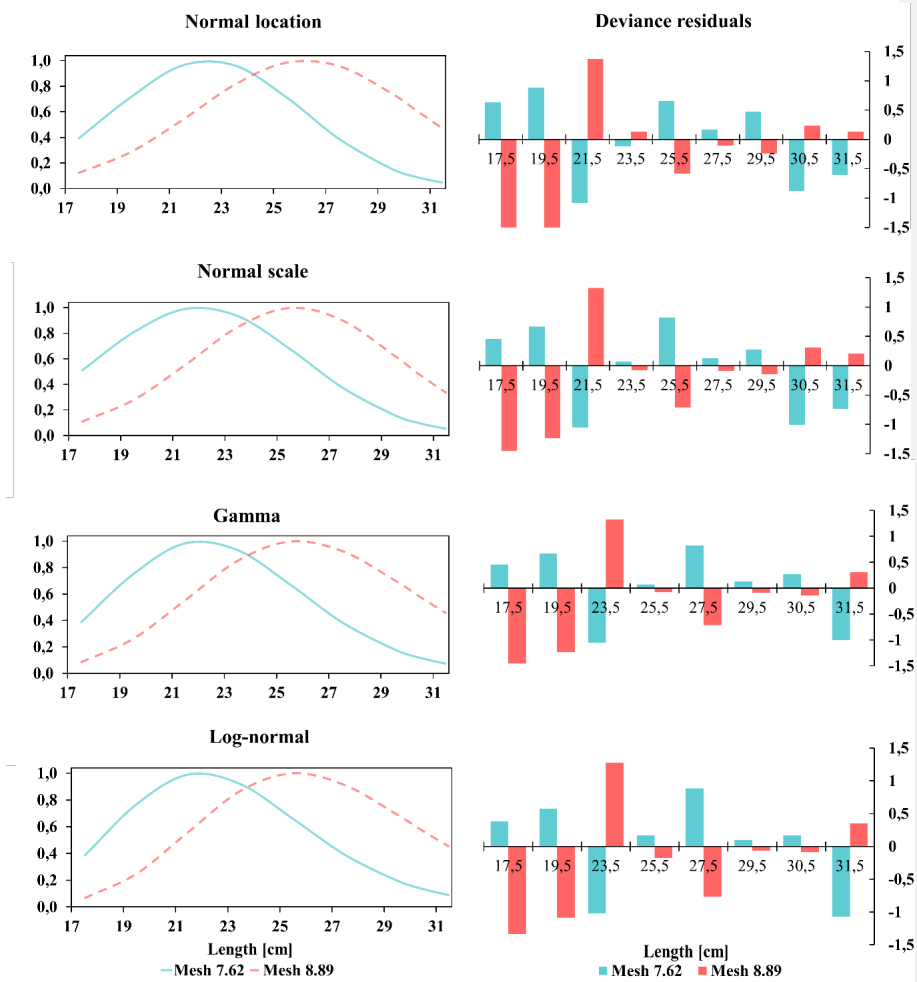


Fig. 5. Adjustment to models and residual deviation of *P. medius* captured with nets with mesh sizes 7.62 cm and 8.89

Fig. 5. Ajuste a los modelos y desviación residual de *P. medius* capturado con redes de luz de malla 7.62 cm y 8.89

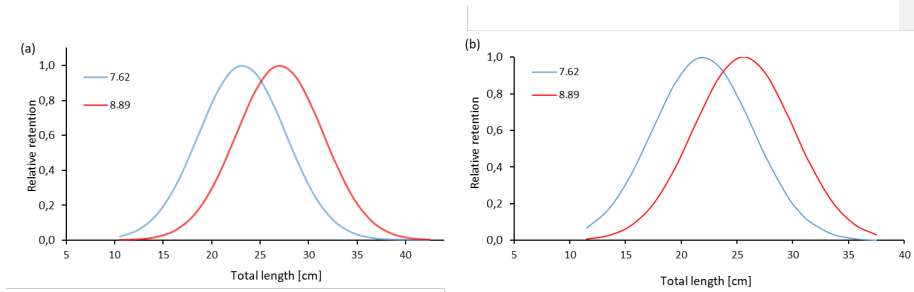


Fig. 6. Selectivity curves using Holt's 1963 indirect method for a) *S. peruviana* and b) *P. medius*

Fig. 6. Curvas de selectividad utilizando el método indirecto de Holt 1963, para a) *S. peruviana* y b) *P. medius*