# BIOLOGICAL AND FISHERY ASPECTS OF HAKE (*MERLUCCIUS GAYI*, GUICHENOT, 1848) CAUGHT BY TRAWL NETS IN THE GULF OF GUAYAQUIL, ECUADOR

# ASPECTOS BIOLÓGICOS Y PESQUEROS DE LA MERLUZA (*MERLUCCIUS GAYI*, GUICHENOT, 1848) CAPTURADA CON RED DE ARRASTRE EN EL GOLFO DE GUAYAQUIL, ECUADOR

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## Abstract

Fishery resources face challenges such as overexploitation, data scarcity, and climate change, highlighting the need to implement research strategies for effective management. Hake is crucial among Ecuador's fishery resources, thus periodic assessments of its status are essential. The size composition of *Merluccius gayi* caught with trawl nets in the industrial fishery was analyzed, as well as the capture size and its relationship with the size at sexual maturity, to provide a baseline for future studies and applications in the management of this fishery. Samples were obtained from landings in Puerto Bolívar, Province of El Oro, Ecuador, during November 2014 to March 2015. A total of 574 individuals were analyzed, with average capture size of 34.93 and 38.92 cm LT for males and females, respectively. The size-weight relationship showed a negative allometric growth for males and females, with exponent (*b*) of 2.30 and 2.55, respectively. It was observed that, with an 8.9 cm mesh size in the codend, the males' Lr50 was 34.35 cm LT, which was less than the ASM of 34.75 cm LT. For females, the Lr50 (37.97 cm) was greater than the ASM of 37.28 cm. This shows the importance of analyzing gender information separately during the evaluation of fishing gear.

**Key words**: Gulf of Guayaquil, mesh size, trawl fishing, average size at maturity.

## Resumen

Los recursos pesqueros enfrentan desafíos tales como la sobreexplotación, la escasez de datos y el cambio climático, lo cual enfatiza la necesidad de implementar estrategias de investigación para una gestión efectiva. La merluza es crucial dentro de los recursos pesqueros de Ecuador, por lo tanto, es fundamental realizar evaluaciones periódicas de su estado. Se analizó la composición de tallas de *Merluccius gayi*, capturada con redes de arrastre en la pesquería industrial, así como la talla de captura y su relación con la talla de madurez sexual, para proporcionar una línea base para futuros estudios y aplicaciones en la gestión de esta pesquería. Las muestras fueron obtenidas de los desembarques realizados en Puerto Bolívar, Provincia de El Oro, Ecuador, durante noviembre 2014 a marzo del 2015. Se analizaron un total de 574 individuos, con talla media de captura de 34.93 y 38.92 cm de LT para machos y hembras, respectivamente. La relación talla-peso mostro un crecimiento alométrico negativo para machos y hembras, con exponente (*b*) de 2.30 y 2.55, respectivamente. Se observó que, con una luz de malla de 8,9 cm en el copo de la red, la Lr50 de machos fue 34,35 cm LT, la cual resultó menor a la Talla Media de Madurez (TMM) de 34,75 cm LT. Para las hembras, la Lr50 (37,97 cm) fue mayor a la TMM 37,28 cm. Esto evidencia la importancia de analizar por separado la información por sexos durante la evaluación de artes de pesca.

**Palabras clave**: Golfo de Guayaquil, luz de malla, pesca de arrastre, talla media de madurez.

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# 1. Introduction

*Merluccius gayi* (Guichenot, 1848) is a species in the family Merlucciidae that inhabits coastal and oceanic areas, as well as epipelagic and mesopelagic regions, at depths of 50 to 614 m. It forms dense shoals from Ecuador to Peru, including the Galapagos Islands (Hernández-Téllez et al., 2024).

The south Pacific hake *M. gayi*, is present in the coast of Ecuador between latitudes 1° and 4° S, in depths ranging from 30 to 614 m (García et al., 2014). The species was first recorded in Ecuadorian waters in March 1965 (Bourgois, 1966), but it was not exploited for several decades, possibly because the different fishing gears in use by that time did not reach the depths where the resource was located. Starting in the 1990s, technical documents related to the local hake fishery are published within the category of Class C demersal fish, i.e. low commercial value, categorization suggested by Contreras and Revelo (1992).

Martínez and Madirolas (1991) conducted studies in Ecuador on hake biomass in the Gulf of Guayaquil and estimated it in 18 046 ton, as well as a maximum precautious catch of 2000 t per year. This allowed them to establish that the potential catch did not justify the development of an industrial fishery, but instead an artisanal one for direct human consumption at the local and national levels. Other authors who conducted studies on hake were: Villón et al. (1992); Revelo (1994, 1995); Herrera and Zambrano (1998); Herrera et al. (1998); Peralta (1999); Herrera et al. (2010); Coello et al. (2017).

These studies enabled the Undersecretariat of Fishery Resources (SRP) in cooperation with the Ministry of the Environment of Ecuador and the Ministry of Marine Rural Environment of Spain, to carry out three fishery research campaigns on the Ecuadorian continental platform and slope, from where a total biomass of 340 559 t of *M. gayi* was estimated (INP 2018). And since 2013, it has been industrially exploited as an alternative to shrimp trawling and shallow water fishing (García et al., 2014).

Knowledge of reproductive aspects, such as the average size at sexual maturity, are topics relevant to understand the basic biology of the resource, and for the use of stock assessment methods (Mawa et al., 2021; Parker 1985; Rahman & Samat, 2021), allowing to determine the reproductive potential and biological characteristics of exploited populations (Williams 2007).

The efficiency of fishing gear in capturing fish according to their size is crucial for implementing effective management strategies in fisheries (Sparre and Venema, 1997). It is essential to assess whether a fish can escape through or become trapped in a mesh of specific dimensions, as the dimensions of the mesh opening play a critical role in fishing gear design (Reeves et al., 1992). The design of fishing nets can significantly impact the effectiveness of size selection. Ideally, the mesh size should allow the release of all fish smaller than a certain size (FAO, 1995; Yu et al., 2023).

In this sense, this study aims to provide information on the most relevant biological and fishery aspects of the fishery of *M. gayi* captured by the industrial trawl fleet operating in the Gulf of Guayaquil, and to supply a baseline for future studies on this fishery and its sustainable management.

# 2. Materials and Methods

The study area was located in Puerto Bolívar, province of El Oro at southern Ecuador (Figure 1). Samples were obtained during landings from the fishing vessel "Elaine" between November 2014 and March 2015. The vessel performed fishing activities off 8 nm from shore at depths 28 - 48 m within the Gulf of Guayaquil, from Puntilla de Santa Elena to the border with Peru (02° 10' S-81° 00' W; 03° 23' S-81° 00' W).

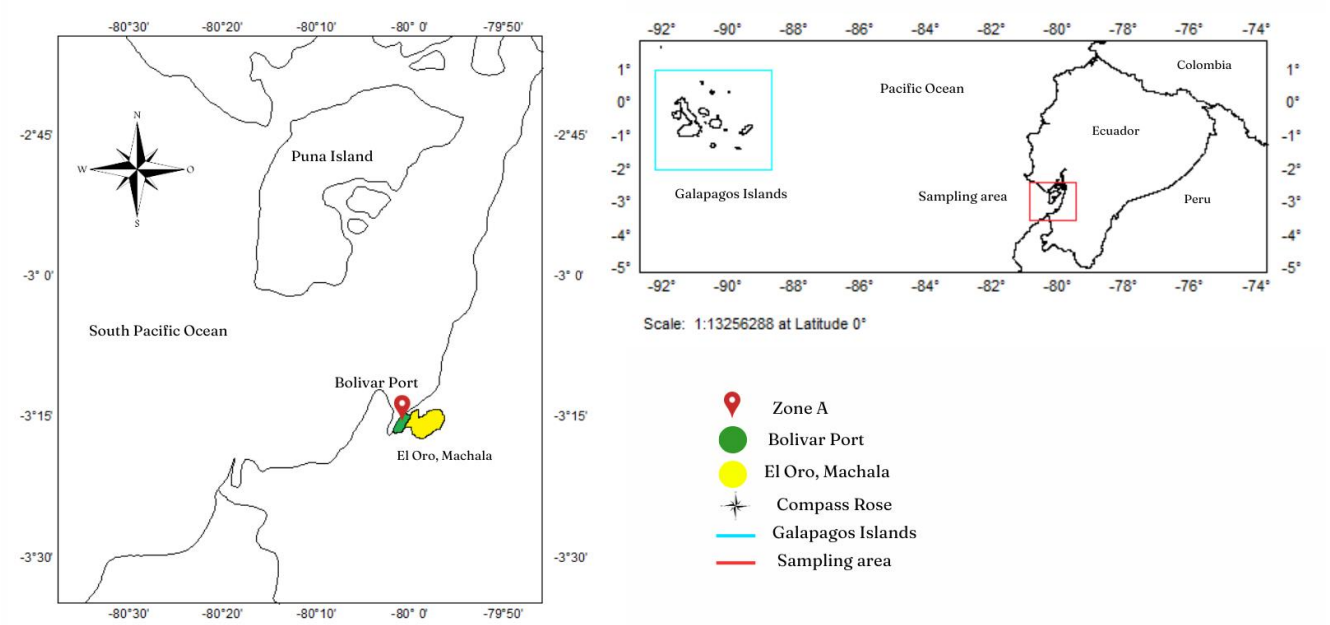


**Figure 1**. Landing area where the samples of *M. gayi* were obtained.

The collected samples were taken to the laboratory for morphometric analysis and characterization of the

gonadal developmental stages of the specimens. The total (TL) and standard lengths (SL) were estimated with a digital ichthiometer with precision 1 mm; the total weight (W) and that of the other structures were estimated with a digital balance of 0.1 g precision. The sex was determined by macroscopic observations of the gonads.

To compare whether the size frequencies between males and females could be worked together, the Kolmogorov-Smirnov statistical test was performed under the null hypothesis that the size frequency was similar for males and females. Sex ratio was evaluated under the null hypothesis of equal proportion (1M:1F) using the chi-square test ($\chi 2$).

The length - weight ratio was established using the allometric function (Ricker 1975):

$$W = aTl^b \qquad (1)$$

where: *W*-total weight in g, *TL*-total length in cm, a and b are regression constants. The values of a and b were obtained by adjusting the linearized equation as $\log10(W) = log10(a) + b\ log10(TL)$ using the least squares method (Munro & Pauly, 1983). The value of the slope was contrasted with 3 using a Student's t-test (Zar 2014), to establish the type of growth of the species as: isometric ($b$=3), negative allometric ($b < 3$) or positive allometric ($b > 3$).

In order to calculate the retention length and selection range (RS), the following equations were used:

$$\ln\left(\frac{1-p}{p}\right) = a - bL \qquad (2)$$

$$RS = \frac{2.\ln(3)}{b} \qquad (3)$$

Where $P$ is the percentage retained of each fish size, $a$ is the intercept, $b$ is the slope, $L$ the length class and $RS$ is the interval over which the fishing gear makes selection.

The ratio (*1-P*) / *P* is associated to the size or length in which the fish have the same opportunity to escape or be retained in the gear (50% chance or Lr50), so that:

$$Lr_{50} = -\frac{a}{b} \qquad (4)$$

In order to calculate the selection factor (SF), the following equation was used:

$$SF = \frac{Lr_{50}}{mesh\ size} \qquad (5)$$

Where *SF* is the factor that describes the ability of the fish to escape through the mesh, Lr50 is the retention length of 50% and MS is the mesh size (8.89 cm in the codend).

To obtain the selection curve, the models were adjusted separately according to the sex to compensate for the differences in composition by size, as proposed by Queirolo et al. (2013).

The determination of the Mean Size at Sexual Maturity (MSM) was made by macroscopic cataloguing of the validated gonadal maturity scale for hake (*Merluccius gayi*) (Perea et al. 1997). For estimating the MSM, a logistic function was adjusted to the proportion of mature individuals per size class, considering the maturity stages III, IV and V, using the equation proposed by King (1995):

$$P = \frac{1}{1+exp^{-r(L-L_{50})}} \qquad (6)$$

Where *P* is the proportion of mature individuals in each size Interval (*L*), *L50* is the length at which 50% of individuals reach sexual maturity and r is a constant.

## 3. Results

A total of 574 individuals were sampled, showing a sex ratio of 1.65M:1H, with a significant predominance of males ($p < 0.001$). Male sizes ranged from 26 to 48 cm TL, and female sizes ranged from 28 to 72 cm TL, with an average size of 36.21 cm TL for combined sexes (Table 1). The size structure differed significantly between the sexes (*Kolmogorov-Smirnov test*; $p < 0.05$), so the analyses that follow were processed separately by sex (Figure 2).

**Table 1.** Statistical briefing of size frequency of *M. gayi* landed in Puerto Bolivar, El Oro Province, Ecuador, between November 2014 and March 2015.

| *Sex* | *N* | *Min* | *Max* | *Average* | *SD* | *p* |
|---|---|---|---|---|---|---|
| Males | 358 | 26 | 48 | 34.93 | 3.65 | <0,001 |
| Females | 216 | 28 | 72 | 38.32 | 6.05 | <0,002 |
| Sexes combined | 574 | 26 | 72 | 36.21 | 4.98 | <0,003 |

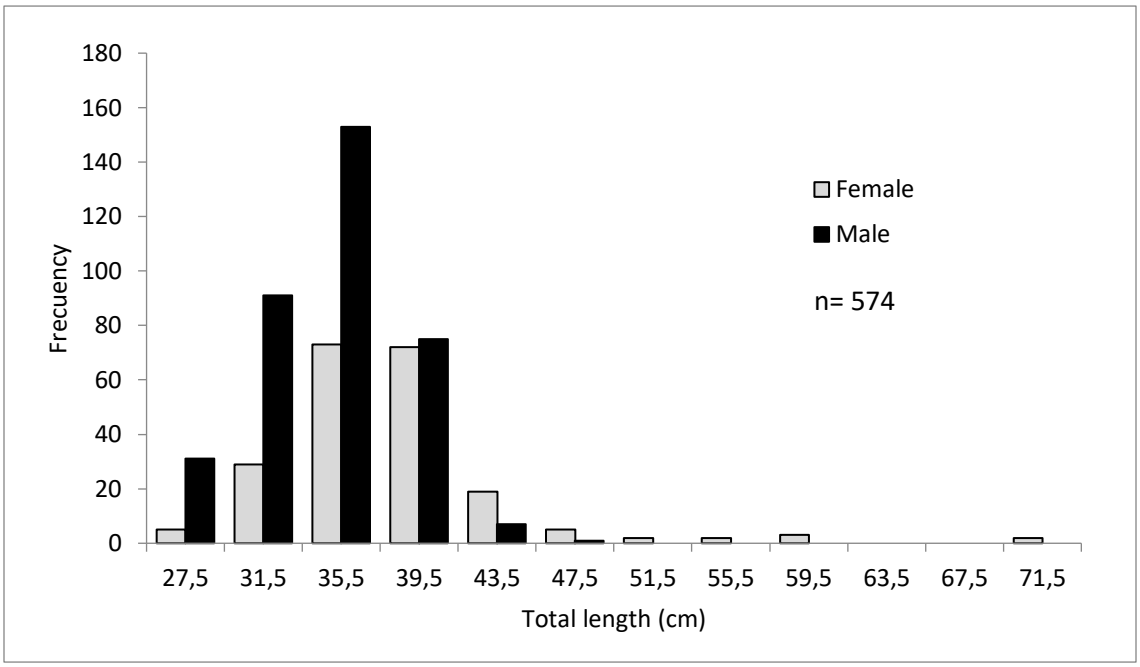


**Figure 2.** Size frequency distribution of male and female *M. gayi* captured using codends with 8.9 cm mesh size.

**Length – weight relationship.**

The length – weight relationship for males was W = 0.084 TL 2.3018, $r^2$ = 0.79 (Figure. 3A), and for females W = 0,035 TL2.5588, $r^2$ = 0.88 (Figure. 3B). The b exponents differed significantly between sexes and were smaller than 3 (*Student's t test*, $p < 0.05$), so the growth of the species was considered to be negative allometric.

**Size at sexual maturity.**

For estimating MSM, the gonads of 378 specimens were analyzed corresponding to 229 males and 149 females of *M. gayi*. For males, the MSM was estimated in 34.75 cm TL, while for females the MSM was 37.28 cm TL (Figure. 4) and an average MSM of 36.02 cm TL for sexes combined.

**Selectivity of the trawl net.**

To obtain the selectivity curve of the trawl, 574 size data were used, of which 358 corresponded to males and 216 to females.From the male data, the parameters obtained were *a*= 17.884, *b*=-0.521, and a Pearson correlation coefficient (*r*) of 0.995 ($p < 0.001$). The catch size at which 50% of the males were retained in the gear was Lr50 = 34.35 cm LT, with a selection range of 4.22 and a net selection factor *SF* = 3.86.

For females, the estimated parameters were: *a* = 7.380, *b* = -0.194, Pearson correlation coefficient *r* = 0.939 ($p < 0.05$), capture size Lr50 = 37.97 cm LT, a selection range of 11.31 and a net selection factor of *SF* = 4.27. For sexes combined, the estimated parameters were *a* = 7.880; *b* = 0.220, Pearson correlation coefficient *r* = 0.933 ($p < 0.001$), capture size Lr50 = 35.84 cm LT, a selection range of 9.98 and a net selection factor *SF* = 4.03 (Figure. 5).

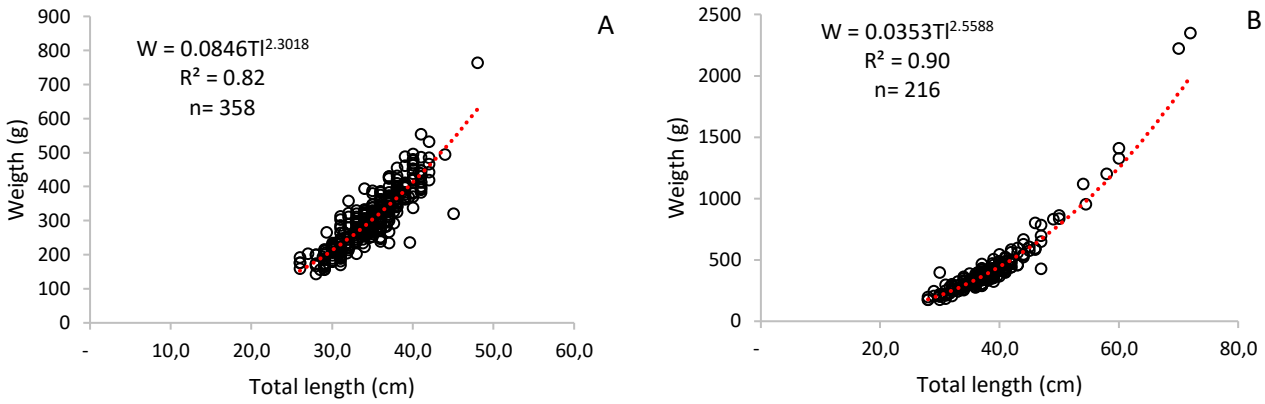


**Figure 3**. Length – weight relationship of *M. gayi* landed in Puerto Bolivar, El Oro Province, Ecuador, from November 2014 to March 2015. A. Males. B. Females.

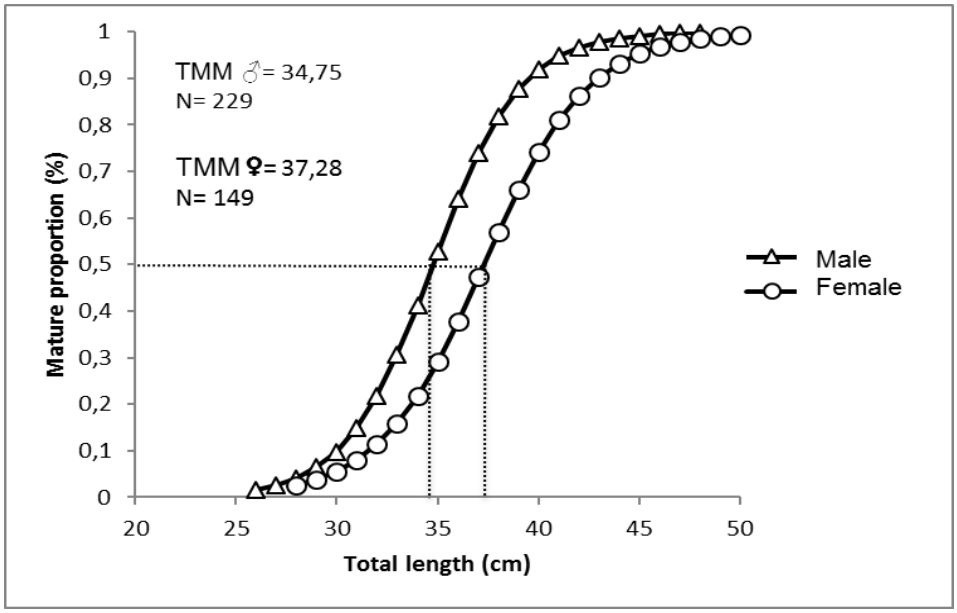


**Figure 4**. Mean size at sexual maturity (MSM) of *M. gayi* by sex, applying the logistic model to the proportion of males and females by size. The intersections of vertical lines with the abscissa axis show the MSM.

Considering the recommended mesh size (MS) in the codend for the capture of *M. gayi*, values of 8.99 cm for males and 8.72 cm for females were obtained, while for the combined sexes it was 8.93 cm (Table 2).

The capture size Lr50 34.35 cm TL for males (Table 2), was less than the MSM (34.75 cm LT), while the Lr50 of 37.97 cm TL for females (Table 2), was larger than their MSM (37.28 cm LT).

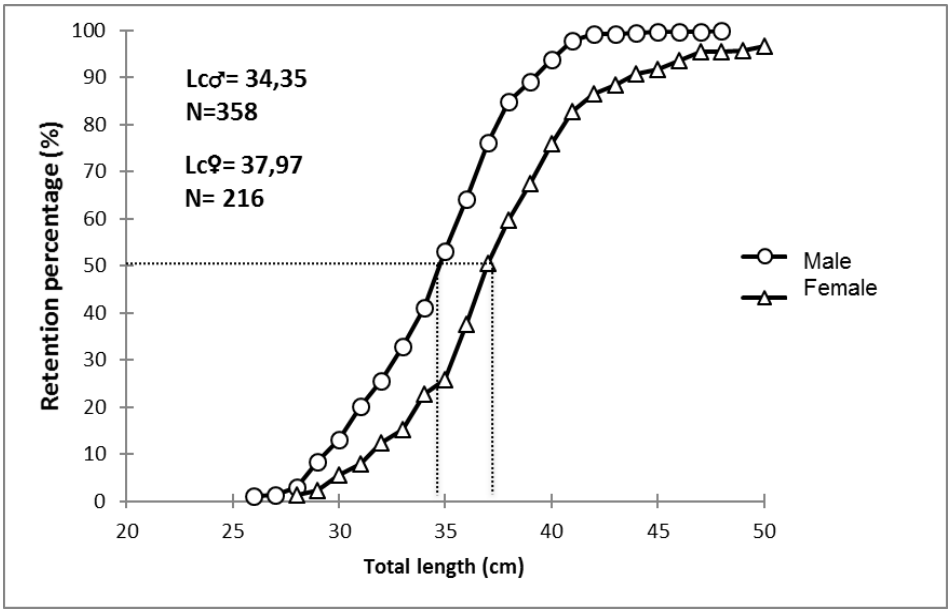


**Figure 5**. Selectivity for size of males and females of *M. gayi* retained in the codend with mesh size 8,9 cm. The intersections of vertical lines with the abscissa axis represent the optimal capture lengths ($L_{50}$).

**Table 2**. Selectivity parameters for males, females and sexes combined. *L50* (length of first capture), *SR* (selection range), *SF* (selection factor of net), *a* (y-axis intercept), *b* (slope), and *MS* (recommended mesh size, cm).

| *Group evaluated* | *a* | *b* | *L25* | *L50* | *L75* | *SR* | *SF* | *MS* |
|---|---|---|---|---|---|---|---|---|
| **Males** | 17.88 | 0.52 | 32.24 | 34.35 | 36.46 | 4.22 | 3.86 | 8.99 |
| **Females** | 7.38 | 0.19 | 32.35 | 37.97 | 43.66 | 11.31 | 4.27 | 8.72 |
| **Sexes combined** | 7.88 | 0.22 | 30.81 | 35.84 | 40.79 | 9.98 | 4.03 | 8.93 |

# 4. Discussion

The sex ratio observed in this study, 1.65M: 1H ($\chi 2$ $p < 0.05$), differed from the one reported by Instituto Nacional de Pesca (2014), 1,25M:1H, although both show the male predominance in the population of *M. gayi* in Ecuadorian waters. However, larger sizes were recorded among females, coinciding with what was stated by Iwamoto et al. (2010), who show that females grow faster and reach a much larger size than males. Determining the sex ratio is important to have a full knowledge of the general biology of an exploited population and is part of its fundamental assessment (Holden and Raitt, 1975).

Size frequencies for combined sexes were in the range 26-72 cm TL, with an average size of 36.21 cm. These values resembled those found in the coast of mainland Ecuador by García et al. (2014) who report hake sizes in the range 17-81 cm TL. However, the values found in this study differed significantly from the size intervals of 14-71 and 15-77 cm TL reported in 2009 and 2010, respectively, for Ecuadorian coastal waters by MAGAP (2009; 2010). Variations compared to previous studies underscore the importance of maintaining continuous monitoring of populations, while similarities with other regions highlight the need for international cooperation to promote long-term sustainability (Mytilineou et al., 2020).

The study of length-to-weight relationships in fish provides indirect information on growth, maturity, reproduction, nutrition and therefore the health status of populations. This allows interpopulation comparative studies to be carried out (Lorencio 1996). The results obtained in the current study indicated that the type of growth of *M. gayi* can be considered negative allometric, which coincides with what is described in the oceanographic campaigns of MAGAP (2008; 2009) in coastal waters of Ecuador, when values of exponent *b* were 2.98 and 2.83, respectively. Based on this, it is suggested that *M. gayi* preferentially increases its relative length more than its weight.

In the present study, the Mean Size at Maturity (MSM) for males was established at 34.8 cm TL, while for females it was 37.3 cm TL and an average MSM of 36.0 cm LT for sexes combined. Although, the reported MSM data were within the range previously reported, these results differed from what was described by Instituto Nacional de Pesca (2014), who reports a MSM of 33.7 cm LT for combined sexes in the industrial hake fleet. Castro-Moreira et al. (2023) also report that in bottom longline fishing in Ecuadorian waters, females reach sexual maturity at a larger size than males. Moreover, Cerna and Oyarzún (1998) in Chile, for the same species, established the MSM at 38.9 cm TL, which is larger than the one described in this study. Subsequent studies are necessary to determine whether these variations are due to the samples belonging to different populations or to a pattern of size variation due to changes in latitude or fishing exploitation. Although it has been demonstrated that the decrease in maturity size may be associated with environmental changes (Legaki et al., 2024).

The values obtained for Lr50, 34.35 and 37.97 cm TL for males and females, respectively, resembled what is described by Queirolo et al. (2013), in a selectivity study conducted on the coasts of Chile between 50 and 370 m deep, where the selective effect of trawls was 30 and 36 cm TL in the codend and cover bag, respectively. From a perspective for the conservation of the resource, the catch size (Lr50) is sought to be greater than the MSM (Subsecretaría de Pesca-Chile, 2001). This would imply a natural impact on the capturable stock of males, while for females it would confirm the efficiency of the selectivity of the trawl gear in catching females of *M. gayi*, after their contribution of new individuals to the population.

The calculation of the recommended mesh size for the codend of trawls based on the combined sex data was established in this study at 8.93 cm. This would be in accordance with Article 9.2 of the 018 agreement of Ministerio de Agricultura, Ganadería y Pesca (MAGAP 2013), where it is established that the codend must have a mesh size of 8.9 cm (3 1/2 inches). However, when information is disaggregated by sex, it is evident that this mesh opening would be functional for females (8.72 cm of recommended mesh size), but would be at the limit for males, where the recommended mesh size was 8.99 cm. MAGAP (2009), in its fisheries research campaign report, states that "the distribution of hake sizes does not vary substantially with latitude, but it does with depth, with the size range being significantly smaller and farther from the mean as the depth increases". Thus, it is feasible to think that the differences found in this study with the provisions of the ministerial agreement, are due to the different depth interval of the trawls performed in this study, 28 – 48 m, while those of the reference studies of that regulatory framework were 0-100 m. On the other hand, authors such as Gálvez and Rebolledo (2005), recommend a mesh opening of 12.0 cm in the codend, to protect the spawning fraction of the common hake and to maximize the biomass of the cohorts.

The percentage of captured hake that did not reach the MSM was 41.06 and 50.46% for males and females, respectively, coinciding with Instituto del Mar del Peru (1996), who shows that the industrial trawl fleet exploits an available and accessible resource, whose characteristic is the

presence of young specimens, the vulnerability of which is significantly increased by their concentration and the operational characteristics of the fleet. This proportion indicates that a significant part of the captured hake consists of young specimens that have not yet reached reproductive age. This could affect the population's ability to sustain and renew itself naturally, increasing the pressure on the most vulnerable segments (García-Fernández et al., 2021).

Since selectivity studies are aimed at conserving the reproductive potential of species (Pavéz, 1989), and it is necessary to look for mechanisms that allow immature individuals not to be susceptible to capture.

While the method proposed in this study is sustainable, it is important to validate the obtained results with experimental tests in the codend and cover bag or the use of juvenile reduction devices, such as those applied in neighboring countries Peru and Chile with good results. Likewise, it is necessary to continue the selectivity studies in other landing ports with different fishing depths, several seasons and atypical years.

## 5. Conclusions

The analysis of the information collected in this case study shows that, with a mesh size of 8.9 cm in the codend of the trawls, for males the Lr50 was 34.35 cm which was less than the MSM 34.75 cm, while for females the Lr50 37.97 cm was greater than the MSM 37.28 cm. In consequence, when information is disaggregated by sex, it is evident that this mesh size would be functional for females, but it would be very tight for males. However, network selectivity does not distinguish sexes, so the selectivity response would be decreased.

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