

Research Article

Reproductive dynamics of *Peprilus medius* captured in the Ecuadorian Pacific

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ABSTRACT. In Ecuador, *Peprilus medius* is an important fishery resource whose destination is for local consumption and export. There are few local studies on its reproductive biology, and its capture is not regulated. Therefore, this study evaluates the most relevant aspects of its reproductive activity. Samples were obtained monthly from January to December 2017 from the capture of the purse seine fleet and the artisanal gillnet fleet landing near Manta. The morphometric analysis included the length-weight relationship, estimated using the allometry equation. The size at sexual maturity is based on the L_{50} criterion; the reproductive cycle was determined according to the monthly analyses of the gonadosomatic index (GSI), hepatosomatic index (HSI), and relative condition factor (Kn). A total of 334 specimens were analyzed, with average sizes of 22.0, 21.87, and 21.91 cm of total length (TL), for males, females, and combined sexes, respectively. Sex ratio was 1.17M:1F ($P > 0.05$), while the length-weight relationship showed negative allometric growth for both males and females ($b = 2.58$; CI95% 2.48-2.72). Size at sexual maturity L_{50} was estimated at 21.84 and 21.23 cm TL for males and females, respectively. The GSI and HSI values and Kn showed significant differences among months ($P < 0.05$), with a marked seasonality during the single reproductive period. Mean size at first capture of 21 cm TL is recommended.

Keywords: *Peprilus medius*; allometry; condition factor; gonadosomatic index; hepatosomatic index; size; sexual maturity

INTRODUCTION

The Pacific harvestfish, *Peprilus medius* (Peters, 1869), belongs to the family Stromateidae, widely distributed in the Pacific Ocean, from the Gulf of California, Mexico, to northern Chile, Galapagos Islands in Ecuador (Haedrich & Schneider 1995, Galván-Magaña et al. 1996, Chirichigno & Cornejo 2001), being a species of warm waters. It is located at depths from 10 to 40 m (Headrich & Scheneider 1995) in coastal benthic and pelagic habitats, where it usually forms schools and can penetrate estuaries (Martínez-Ortiz

2010). In Ecuador, it is known locally as pampano or gallinazo. This species represents an abundant fishery resource on the Ecuadorian continental shelf (Tume et al. 2021). It is an important resource given its meat's quality and low cost, generating an important item for artisanal and industrial fisheries whose destination is mainly for local consumption but is also exported.

In countries of the region, such as Mexico, Colombia, and Peru, *P. medius* represents a fishery very similar to that of Ecuador in terms of capture and consumption (Inga-Barreto et al. 2008, Moreira-Arcenales 2012, Martínez-Muñoz et al. 2015, Reyes-

Lucas & Reyes-Vega 2015, Maldonado-Amparo et al. 2019). It also generates an important item for the fishing communities' economies.

Studies on fisheries biology are necessary for evaluating fishery resources, and the size at sexual maturity represents one of the basic and most important parameters for evaluating stocks (Oliva et al. 1982). In the region, there is little information on the biology of this species. Some studies that can be highlighted are those on the size-weight relationship and gonadal development in the southeastern Gulf of California, Mexico (Maldonado-Amparo et al. 2017, 2019), the influence of size and sex of *P. medius* on its parasite community (Iannacone & Alvarino 2008), and population parameters of *P. medius* in the Tumbes region, Peru (Vera et al. 2006). At the same time, there is historical information regarding catches published in technical reports and bulletins of government fisheries research institutions such as the Peruvian Institute of the Sea (IMARPE, by its Spanish acronym) and the Public Institute for Aquaculture and Fisheries Research (IPIAP, by its Spanish acronym) in Ecuador.

Despite the economic and social importance that *P. medius* represents, there is little information on its biology and ecology in Ecuador, so its capture is not regulated. In this sense, the present study aimed to study the reproductive dynamics of this species landed by the artisanal and industrial fleet operating in the Ecuadorian Pacific, contributing important biological information for fishery management.

MATERIALS AND METHODS

Sampling sites

Monthly sampling of *Peprilus medius* was carried out from January to December 2017. The study area included the fishing coves of Los Arenales (0°51'2.93"S, 80°32'2.84"W), Manta (0°57'0.18"S, 80°42'32.98"W), and Puerto López (1°33'15"S, 80°48'44"W) on the coast of Manabí, Ecuador.

Source of samples

The samples of *P. medius* were obtained from the landings of two multispecies fisheries. The artisanal fleet operates with mono and multifilament gill nets with mesh sizes from 89 to 101 mm, within the coastal band of 1 to 8 nm. The industrial fleet operates with purse seines outside of the 8 nm band in the coastal profile of Ecuador. Identification of the specimens was based on Chirichigno & Cornejo (2001) and Jiménez-Prado & Beárez (2004). The samples were processed in

the biology laboratory of the Faculty of Marine Sciences of Universidad Laica "Eloy Alfaro" de Manabí, Manta.

Measurements performed

The specimens were measured for total length (TL), with a digital ichthyometer with a precision of 1 mm, total weight (TW), the weight of the gonads (GW), and the weight of the liver (LiW), with a digital scale with a precision of 0.01 g. Sex and gonadal maturity stages were characterized according to the gonadal maturity scale of Maldonado-Amparo et al. (2017).

The length vs. weight relationship was evaluated using a regression of the potential allometry model (Ricker 1975, Froese 2006), according to the equation:

$$TW = aTL^b \quad (1)$$

where: TW is the total weight of the species, TL is the total length, and a and b are constants; exponent b describes the type of growth. The least squares regression was used to estimate parameters a and b , linearizing the equation by a logarithmic transformation of TW and TL.

The gonadal stages were taken as binomial data of maturity (mature/immature) to obtain the size at sexual maturity L_{50} , adjusting the values to the model of King (2007):

$$P_i = \frac{1}{1 + e^{-r*(TL_i - L_{50})}} \quad (2)$$

where: P_i is the proportion of mature individuals in each length interval (TL_i), L_{50} is the length at which 50% of the individuals reach sexual maturity, r is the slope of the curve describing the rate of change of P_i , and e is the base of Napierian logarithms.

The model fit was performed by minimizing the likelihood function with Newton's direct search algorithm, with the equation that assumes a binomial distribution (Brouwer & Griffiths 2005)

$$-lnL = -\sum_{i=1}^n \left[m_i \cdot \ln\left(\frac{P_i}{1-P_i}\right) + n_i \cdot \ln(1-P_i) + \ln\left(\frac{n_i}{m_i}\right) \right] \quad (3)$$

where: n_i is the total number of organisms of class i , and m_i is the number of mature organisms in class i .

The reproductive cycle was evaluated using the analyses of the temporal variation of the gonadosomatic index (GSI), relative condition factor (Kn) (Le Cren, 1951), and hepatosomatic index (HSI) (Vazzoler 1996, Smylie et al. 2016, Wang et al. 2016), to identify the periods of greatest reproductive activity (Brown-Peterson et al. 2011).

$$GSI = \left[\frac{GW}{TW} \right] \times 100 \quad (4)$$

$$HSI = \left[\frac{LiW}{TW} \right] \times 100 \quad (5)$$

$$Kn = \left[\frac{TW}{TL^b} \right] \times 100 \quad (6)$$

Statistical analyses

Statistical analyses were performed in Excel spreadsheets, Statgraphicsphics (Statpoint Technologies, Inc.), and R studio software using a confidence level of $\alpha = 0.05$. The normality of the data was evaluated with the Kolmogorov-Smirnov tests, the sex ratio (F:M) was estimated using the chi-square test (χ^2), and the growth type analysis was evaluated using Student's *t*-test (Zar 2010). The Mann-Whitney U test was used to determine if there were significant differences between the sizes of males and females. An ANCOVA test was used to estimate differences between the *b*-slope values of males' and females' length vs. weight relationship. Monthly values of GSI, HSI, and Kn were compared through a one-way ANOVA; when the data did not meet the assumptions of normality and homogeneity of variance, the Kruskal-Wallis (K-W) test was used. Pearson's correlation coefficient was used to measure the relationship of GSI values between sexes and to verify if there was a correlation between the monthly values of GSI, HSI and Kn.

RESULTS

Size distribution

During the study period, a total of 334 individuals of *Peprilus medius* were registered, 148 (44.31%) females and 173 (51.80%) males, while the sex of 13 (3.89%) specimens could not be identified (Fig. 1). The estimated

sex ratio was 1.17M:1F (χ^2 , $P > 0.05$) which did not deviate from expected. The average size for females was estimated at 21.88 ± 2.6 cm (17-30.7 cm TL), while in males was 22.01 ± 2.66 cm (17.1-31.3 cm TL), and for combined sexes, 21.91 ± 2.6 cm TL. The sizes between males and females did not differ significantly (Mann-Whitney U test, $P > 0.05$).

The adjustment through potential regression of the length-weight relationship described a type of negative allometric growth with a *b* value significantly < 3 for females, males, and combined sexes. For females, the value $b = 2.72$ (Students' *t*-test, $P < 0.05$) and a coefficient of determination $r^2 = 0.85$, with a good association between the study variables.

A similar growth parameter was observed in males with $b = 2.48$ and $r^2 = 0.88$ between the variables (Fig. 2, Table 1). The equation for combined sexes was $W = 0.05 \times TL^{2.58}$ ($r^2 = 0.86$), which indicates that *P. medius* did not increase its weight proportionally to its length. There was no significant difference between sexes in the *b* parameter or intercepts (ANCOVA, $P > 0.05$).

The data adjustment by maximum likelihood estimated the size at sexual maturity (L_{50}) at 21.23 and 21.84 cm TL for females and males, respectively (Fig. 3), and 21.5 cm TL for combined sexes. The smallest female and male with mature gonads were both 19.5 cm TL, and the largest organisms with immature gonads were 29.9 and 28.7cm TL for females and males, respectively.

The monthly GSI and HSI values, and Kn, presented significant differences during the study period (K-W, $P < 0.05$), with marked seasonality in the reproductive period (Figs. 4-5). The monthly values of the GSI

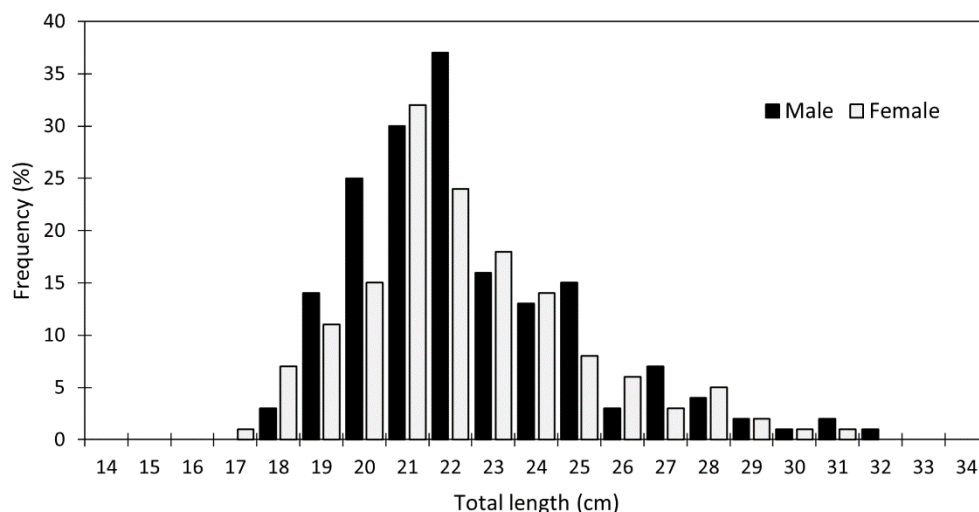


Figure 1. Size frequency of female and male *Peprilus medius* landed on the coast of Manabí, Ecuador, from January to December 2017.

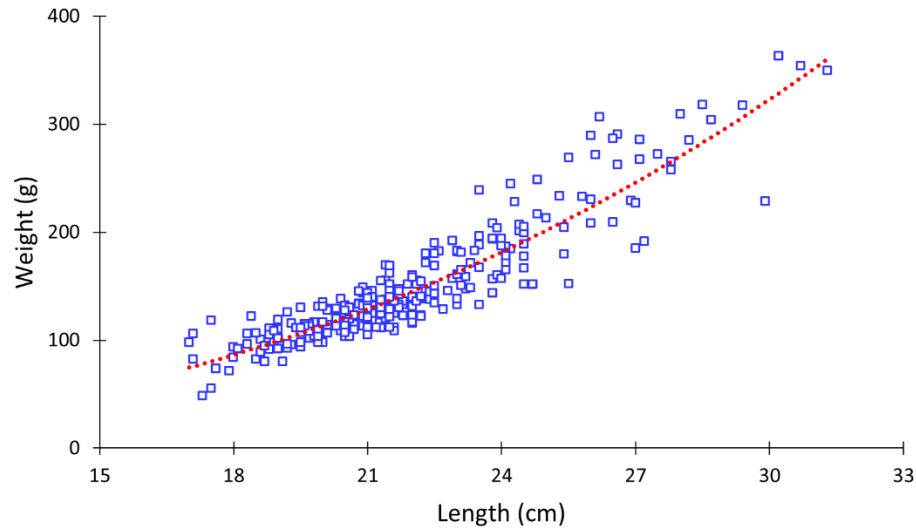


Figure 2. Weight-length relationship for sexes combined of *Peprilus medius* landed on the coast of Manabí, Ecuador, from January to December 2017.

Table 1. Statistical resume of the weight-length relationship of *Peprilus medius*. r^2 : coefficient of determination, t: Student’s *t*-test.

Sex	r^2	<i>a</i>	<i>b</i>	t	<i>P</i> -value
Male	0.88	0.067	2.48	6.92	<0.05
Female	0.85	0.033	2.72	2.83	<0.05
Combined	0.86	0.049	2.58	6.86	<0.05

showed an increase during the rainy season, with the highest peaks in January and February with values of 2.98 and 3.96, respectively. A similar pattern was observed in the HSI, with higher fluctuations in the rainy season and maximum values observed in February, March, and April. On the contrary, Kn presented its lowest values in the rainy season and the highest in the dry season, from August to December.

The correlation analysis between GSI, HSI and Kn estimated a good relationship between the GSI vs. HSI ($r = 0.72, P < 0.05$). At the same time, Kn did not show a significant relationship with the values of GSI and HSI ($r = -0.25, r = -0.36$, respectively, $P > 0.05$).

DISCUSSION

The size range of *Peprilus medius* differed among studies from Pacific coastal locations, even from localities in proximity. Perez-Huaripata & Castañeda-Condori (2018) report that in the Puerto Pizarro and Huarmey areas off the coast of Peru, a size range of 15 to 29 cm TL, with an average size of 23.5 cm TL, which

is greater than that recorded in the present study. The same authors report a sex ratio of 1.2F:1M, different from that recorded in the present study. Prado (2008) also estimated a sex ratio of 1F:1.2M, with the same predominance of males on the Ecuadorian coast from January to December 2008. Inga-Barreto et al. (2008) recorded a similar size structure in the Tumbes region of Peru, with TL ranges between 12 and 35 cm and an average length of 23 cm TL for combined sexes during the years 2004 and 2005. Finally, Maldonado-Amparo et al. (2019) recorded a range of 15 to 30 cm in the southeastern Gulf of California (Table 2). The smaller average size of *P. medius* in Ecuadorian waters compared with other regions of the Pacific Ocean could be attributed to a higher fishing effort by the Ecuadorian fleet.

Furthermore, the proximity of the average landing size (22 cm TL for sexes combined) to the size at sexual maturity (21.5 cm TL) suggests that a large proportion (close to 50%) of landed individuals are below L_{50} . The origin of data could also affect the average size estimations since data from Ecuador came from capture evaluations with drift nets and purse seines. The other studies were based on oceanographic campaigns, which commonly use trawl nets with smaller mesh sizes and could include smaller individuals in the samples.

The negative allometric growth observed for *P. medius* in the present study was also recorded by several authors, such as Vera et al. (2006) in the Tumbes region of Peru; Pérez-Huaripata & Castañeda-Condori (2018) in the continental shelf of the Peruvian

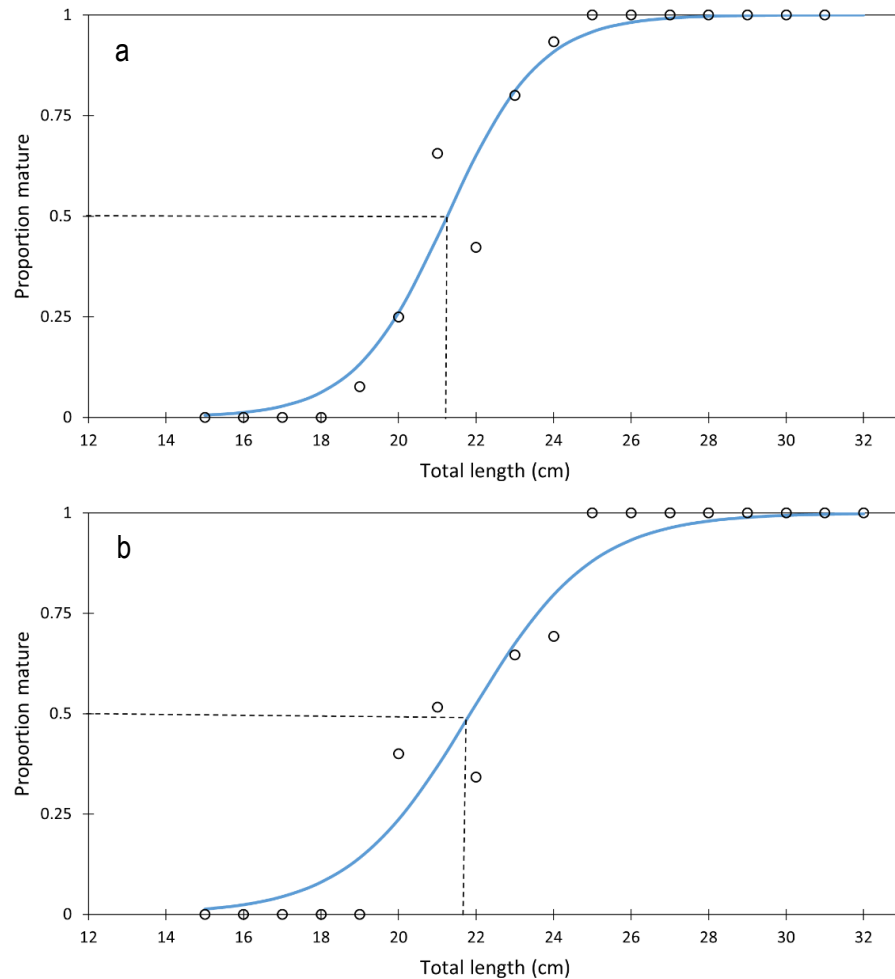


Figure 3. Size at sexual maturity L_{50} for a) female and b) male *Peprilus medius* landed on the coast of Manabí, Ecuador, from January to December 2017.

sea and Maldonado-Amparo et al. (2019) in the southeastern Gulf of California. All values of b were significantly different from 3. However, Rodríguez-Romero et al. (2009) on the west coast of Baja California Sur, Mexico, reported a value of $b = 3.07$ that did not differ from 3 ($P > 0.05$), and this difference could be attributed to the small size of the evaluated individuals, in the range 12-18.7 cm TL. Values of b parameter smaller than 3 have been reported in other species of the same genus, like *P. crenulatus* in estuarine areas of northeastern Brazil, $b = 2.57$ (Fernandes et al. 2020) and *P. paru* in southern Brazil (Haimovici & Velasco 2000).

The high GSI values reported in the rainy season from January to February in the present study were also described by Inga-Barreto et al. (2008) and Llanos-Urbina et al. (2010) in the Tumbes region of Peru, with a slight increase in November and December. The

reproductive season perhaps begins in November and runs until February. Having an asynchronous development probably lengthens their reproductive period. It could be attributed to the fact that *P. medius* presents an asynchronous gonadal development (Marza 1938) with partial spawning (Maldonado-Amparo et al. 2017); due to their proximity, they share environmental similarities in the geographical areas where they are distributed.

Histological validation of gonadal stages is necessary to understand their reproductive biology and interaction with physiological processes. After February, when the highest reproductive activity was recorded, the oocytes could have a reabsorption process during March and April and then go on to a period of reproductive inactivity until November with GSI values below 1. This type of reproduction would represent an energy expenditure to maintain the production of game-

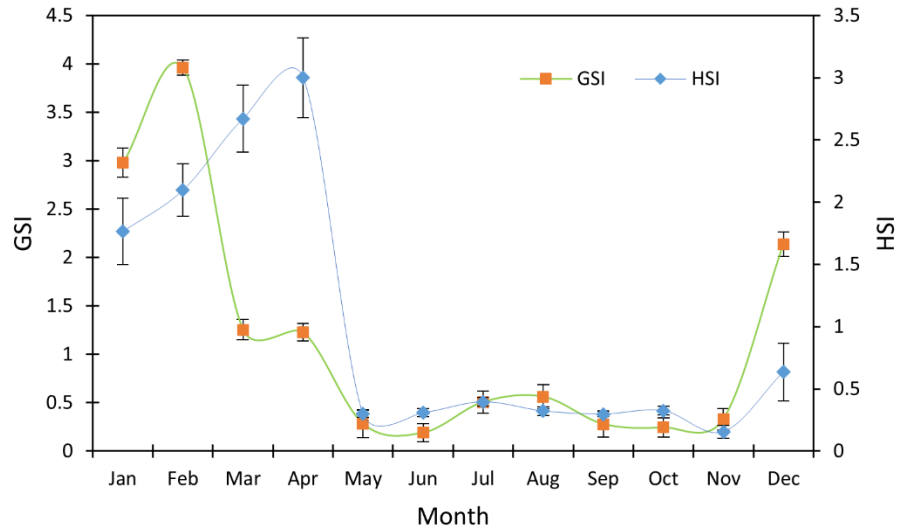


Figure 4. Monthly variation of the gonadosomatic index (GSI) and hepatosomatic index (HIS) for sexes combined of *Peprilus medius* landed on the coast of Manabí, Ecuador, from January to December 2017. Values are mean \pm SD.

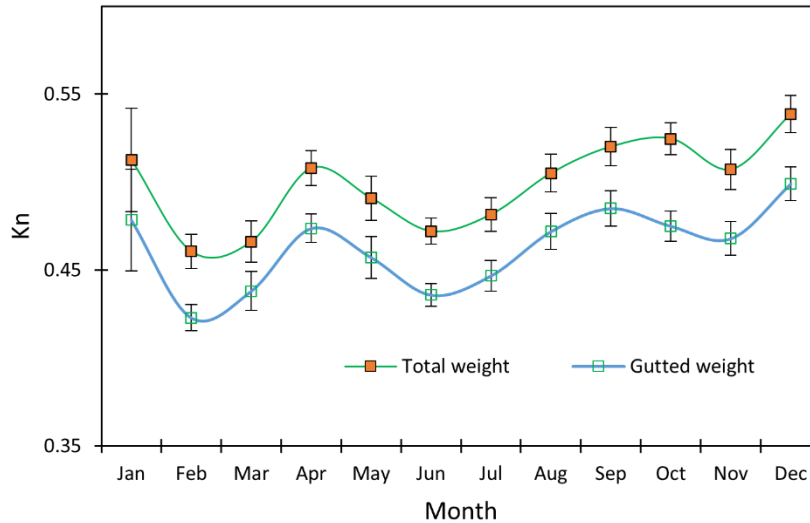


Figure 5. Monthly variation of the condition factor (Kn) for sexes combined based on total weight and gutted weight of *Peprilus medius* landed on the coast of Manabi, Ecuador, from January to December 2017. Values are mean \pm SD.

tes during spawning periods, allowing *P. medius* to withstand environmental variations (Lluch-Cota 1995, Carocca & Chong 2010). However, the GSI analysis and the macroscopic cataloging of the gonads show *P. medius* as a partial breeder, characteristic of species from tropical regions, with short life cycles and constant recruitment of juveniles (Tapia-García 1997, Perera-García et al. 2008).

The sex ratio throughout the study period differed from the expected 1:1. However, it was biased toward females from January to April (rainy season) and then changed in favor of males during the dry season. It could indicate areas of reproductive aggregation by

females near the coast where they find favorable environmental conditions for reproduction.

The HSI usually has an inverse relationship to the GSI. The Kn is considered an indicator of fish health, while the HSI indicates the availability of metabolic energy (Mancera-Rodríguez 2017, Contreras-Almazo et al. 2019). In the present study, the highest values of the HSI observed in March and April coincide with the drop in the GSI values, which suggested the occurrence of the period of reabsorption and reconstruction of the reproductive tissue due to the accumulation of yolk precursor lipids stored in oocytes during vitellogenesis. Then, it decreased in May, with an idle period until

Table 2. Size and maturity data of *Peprilus medius* in the Pacific Ocean. TL: total length.

Parameter	TL (cm)	Reference	Zone
Size range	12-35	Inga et al. (2008)	Peru
	14-24	Prado (2008)	Ecuador
	15-36	Llanos et al. (2009)	Peru
	6-29	Rujel & Castañeda-Condori (2011)	Peru
	15-29	Perez & Castañeda (2018)	Peru
	15-30	Maldonado-Amparo et al. (2019)	Mexico
Average catch size	23	Inga et al. (2008)	Peru
	23.9	Llanos et al. (2009)	Peru
	14.6	Rujel & Castañeda-Condori (2011)	Peru
	23.5	Perez & Castañeda (2018)	Peru
Size at sexual maturity L ₅₀	21.3	Inga et al. (2008)	Peru

November, when lipid reserves could be used for the general metabolism of the individual (Saborido-Rey 2004).

In the present study, the variation of Kn monthly values was like that recorded by Vera et al. (2006) in the Tumbes region of Peru, with the lowest values in February caused by changes in reproductive activity. The Kn values presented a similarity when the total weight and the eviscerated weight were used, showing the use of substances deposited in the tissue that provide at least a part of the energy substrates during spawning. Then the rest of the energy can be used for survival, growth, and reproduction (Saborido-Rey 2004).

The size at sexual maturity recorded in the present study was very close for males and females of *P. medius*, 21.23 and 21.84 cm TL, respectively. A similar value (21.3 cm TL) was reported by Inga-Barreto et al. (2008) in the Tumbes region of Peru. The similarity between the results on the species' reproductive aspects in this study, and those carried out by several authors, can be attributed to some landings of *P. medius* made in the Tumbes region of Peru from January to December 2005, which came from fishing areas off Ecuador coasts. Therefore that data would come from the same exploited population.

In this study, *P. medius* showed a reproductive period that began in December, having its maximum in February, to later enter a period with a lower reproductive activity until November. This pattern was different from other reported species of the family Stromateidae. Two annual spawning peaks have been described in other regions, such as *Stromateus stellatus* in Chile (Carocca & Chong 2010), *Pampus argentus* in the waters of Kuwait (Dadzie et al. 2003), and *Peprilus burti* in the western Atlantic (Haedrich 2003), likely

associated to the particular environmental conditions of the different study zones (temperate and tropical).

It is necessary to point out that the size at sexual maturity L₅₀ of *P. medius* reported in this study, 21.5 cm TL for combined sexes, is slightly lower than the average capture size, 21.91 cm TL. An indication that at least 50% of the captured organisms already reproduced at least once in the population. This information can be used as a basis for decision-making by the Ecuadorian Fisheries Authority, so a minimum size at first capture of 21 cm TL would perpetuate the species' sustainability.

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