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ORIGINAL ARTICLE

Age, growth, and reproduction traits of *Pontinus sierra*, captured by the artisanal fisheries in Ecuador

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Abstract
This study evaluated the age, growth, and reproduction traits of *Pontinus sierra*, captured by the artisanal longline fleet in the Las Piñas Fishing Cove, Manabí, Ecuador, from May 2018 to April 2019, with an analysis of 253 specimens. Samples were transported to the biology laboratory of the Faculty of Marine Sciences at the Universidad Laica Eloy Alfaro de Manabí, where the corresponding morphometric analyses were conducted. The length-weight relationship was established ($W=0.02TL^{2.69}$), indicating negative allometric growth. Otolith analysis identified up to 16 age groups and was consistent among the three readers, APE=1.70, CV=5.64. Bayesian multimodel analysis selected the von Bertalanffy model as the best fit (Looic=639.40), with growth parameters $L\infty=43.44$cm TL, k=0.10. The mean size and age at sexual maturity were 22.64cm LT and 7.41, respectively. Reproductive dynamics, evaluated using the Gonadosomatic Index (GSI), showed reproductive activity and significant differences throughout the study period (K-W=89.01 $P<0.05$). *P. sierra* exhibited moderately slow growth, being a long-lived species with continuous reproduction. These findings provide crucial information for the sustainable management of this important fishing resource in the region.

Keywords: Age, Growth, Reproduction, Otolith.

INTRODUCTION

The Scorpaenidae family is commonly known as scorpionfish due to the presence of venomous spines in the fins of some of its species; this family comprises over 430 species worldwide (Froese & Pauly, 1999) and inhabits a variety of marine habitats, from shallow waters to deep ocean bottoms (Fricke et al. 2018; Pedraza et al. 2002).

Pontinus sierra (Gilbert 1890) occupies demersal environments in its adult stage, but juveniles tend to be pelagic. It is distributed in the central-eastern Pacific, from the Gulf of California to Peru (Jiménez Prado & Beárez 2004; Moser 1996). In Ecuador, Garcia et al. (2014) report its presence in trawl catches at depths ranging from the coast to over 400 m on the Ecuadorian continental shelf.

In Ecuador, *P. sierra* stands out as a species of abundant catch throughout the year using the widespread practice of bottom longlines, a technique widely adopted by artisanal fishermen in the province of Manabí (Herrera et al. 2013). In addition to being a food source for local consumption, *P. sierra* is commonly used as bait for catching other commercial species such as silver croaker, croaker, hake, bighead tilefish, sole, southern rock bass, sand perches, catfish, among others.

In fisheries biology, assessing fish age, growth, and reproduction is important to advance our understanding of population dynamics (Morales & González 2010). These studies provide information about the life stage at which fish reach optimal size for commercial catch, their rate of development, and the determinants of their reproductive capacity (Abellán et al. 2001). Additionally, possessing a comprehensive understanding of fish biology is essential for the formulation and execution of strategies aimed at effectively managing and conserving natural populations (Oliva et al. 1986; Ruiz-Ramírez et al. 2012; Mendoza-Nieto et al. 2022).

In the literature, documentation regarding the biology and life history of fish species belonging to the Scorpaenidae family is available. However, globally, the information available for species of the genus *Pontinus* is limited. Particularly concerning *P. sierra* in continental Ecuador, information is practically non-existent. Therefore, the purpose of this

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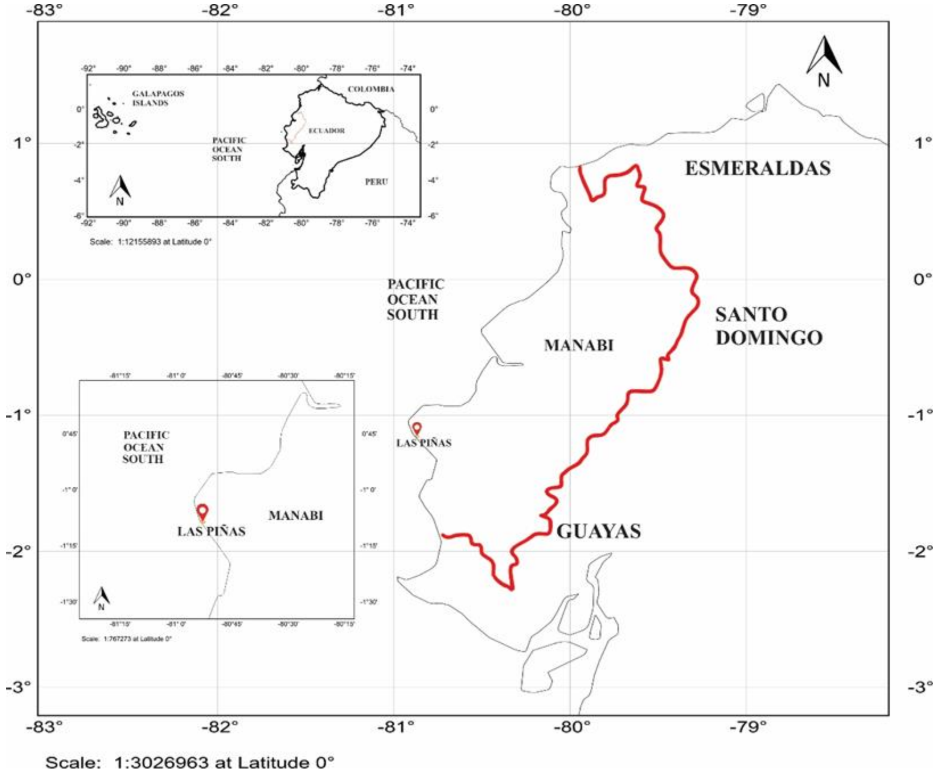

Fig.1. Sampling site of the study area, "Las Piñas", Manabí, Ecuador.

study is to provide scientific information related to the age, growth, and reproduction of *P. sierra* captured in the Ecuadorian Pacific, to provide a reference point for future management practices that are sustainable and environmentally sound for the resource.

MATERIALS AND METHODS

Study area and sample collection: Samples were recorded monthly at the Las Piñas fishing cove, located in the San Lorenzo parish of the Manta Municipality, Manabí, Ecuador (Fig. 1), from May 2018 to April 2019.

Samples were obtained from catches of the artisanal fleet using different fishing gears such as bottom gillnets and bottom longlines. Individuals were identified using the FAO guidelines (Fischer et al. 1995). Specimens were transferred in isothermal containers to the biology laboratory of the Faculty of Life Sciences and Technologies at the Universidad Laica Eloy Alfaro de Manabí, where morphometric data were collected and otoliths were extracted. A Fluke 4190 digital caliper with precision of 1 mm was used. Total weight and evisceration were estimated using an electronic scale, with an accuracy of 0.01 g. Sex determination was established through direct observation of the gonads.

Age in fish can be estimated by analyzing hard structures such as otoliths (Casselman 1983). Sagittal otoliths were extracted from the specimens, as they are the most commonly used for growth ring readings (Morales-Nin 1992). Subsequently, they were cleaned and stored in 1.5 ml Eppendorf tubes containing distilled water and labeled for later reading. Otolith readings were conducted using a stereomicroscope to determine the percentage of otoliths with readable and unreadable rings. Small, medium, and large otoliths were used at different times for staining techniques. For staining, selected otoliths were submerged in any of the reagents: alizarin red, malachite green, methylene blue, or crystal violet, for 5, 10, 10 or 15 min, respectively (Richter & McDermott 1990).

Analysis of precision and bias between readers: The precision of ring readings between the readers was evaluated by calculating the average percentage error (APE), following the approach proposed by Beamish & Fournier (1981).

$$APE = \frac{1}{N}\sum_{J=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{(|Xij - Xj|)}{Xj}\right] * 100$$

Here *N* is the number of individuals aged, *R* is the number of readings performed on the fish, *Xij* is the age (number of rings) determined for specimen *j*, and *Xj* is the calculated average age of each organism.

Additionally, the Coefficient of Variation (CV) formula was used to measure the precision of the otolith readings proposed by Chang (1982), expressed as follows:

$$\mathrm{CV} = \left[\frac{1}{\mathrm{n}} \mathrm{x} \left(\frac{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{R}} \frac{(\mathrm{xij} - \mathrm{xj})2}{\mathrm{Rj}}}}{\mathrm{Xj}}\right)\right] \mathrm{x}\ 100\%$$

Here n is the number of individuals with estimated age, and R is the number of times they were aged.

Age and growth: To estimate the length-weight relationship, the allometric equation of Ricker (1975) and Froese (2006) was used.

$$W = a * Tl^b$$

Here, *W* is the total weight, *a* is the intercept, *Tl* is the total length, and *b* is the slope, which determines the type of growth. The Student's t-test, was used to verify allometry (Zar 1999).

To determine growth parameters, a multimodel analysis with a Bayesian approach was employed using the BayesGrowth package (Smart 2020; Smart & Grammer 2021). The considered models were as follows:

Von Bertalanffy Growth Model (VBGM) (von Bertalanffy 1938):

$$L_t = L_0 + (L_\infty - L_0)\left(1 - e^{(-K_t)}\right)$$

Gompertz Growth Model (GGM) (Gompertz 1997):

$$L_t = L_0 e^{log}\left(\frac{L_\infty}{L_0}\right)\left(1 - e^{(-K_t)}\right)$$

Logistic Growth Model (LGM) (Ricker 1979):

$$L_t = \frac{(L_\infty * L_0 * e^{ga})}{L_\infty + L_0 * e^{ga-1}}$$

Here Lt is the expected length at a certain age, L∞ is the asymptotic length, *k* and g are the growth coefficients, and L_0 is the length at birth.

The leave-one-out information criterion (LOOIC), calculated using the 'BayesGrowth' package, was used to select the best-fitting model. Additionally, a length at birth ($L_0 = 0.01$) and a maximum recorded length in the literature of 28 cm (Jiménez Prado & Beárez, 2004) were considered as prior information.

Reproduction analysis: To estimate the size at sexual maturity L_{50}, a generalized binomial model was used, where 0 represents immature organisms (stages I and II) and 1 represents mature organisms (stages III, IV, and V), using the 'Estimate_Len_Maturity' package (AquaticLifeHistory).

$$P(l) = P_{max}\left(1 + e^{-\ln\left(\frac{L-L50}{L95-L50}\right)}\right)$$

Here Pmax represents the proportion of mature individuals, while *L50* and *L95* correspond to the length at which 50% and 95% of individuals have reached sexual maturity, respectively.

Reproductive activity was assessed via monthly analysis of fluctuations in the gonadosomatic index (IGS).

$$IGS = \frac{Pt}{Pg} * 100$$

Assumptions of normality and homocedasticity of the monthly values of reproductive activity were evaluated using the Kolmogorov-Smirnov and Levene's tests, respectively. If such condition were not met, the Kruskal-Wallis test was used to examine for differences among months. The Mann-Whitney U test was applied to analyze size structure by sex. All statistical tests were carried out with a confidence level of 95%, using Statgraphics Centurion and the R programming language (Tea 2018).

RESULTS

A total of 253 specimens were analyzed. The Kolmogorov-Smirnov test indicated that the data did not follow a normal distribution (K-S, $P<0.05$) and variances were not homoscedastic (Levene's test, $P<0.05$), therefore non-parametric statistics were used. The Mann-Whitney U test between the sizes of males and females showed statistically significant differences ($U=2937.5$; $P< 0.05$). In the size structure analysis, a range of 12-36cm TL and an average size of 20.75cm TL (SD 5.36) were obtained for combined sexes, 13.5-33cm and 12.5-36.5cm TL for females and males respectively (Fig. 2 and Table 1).

For the length-weight relationship and reproductive analyses, data were processed as

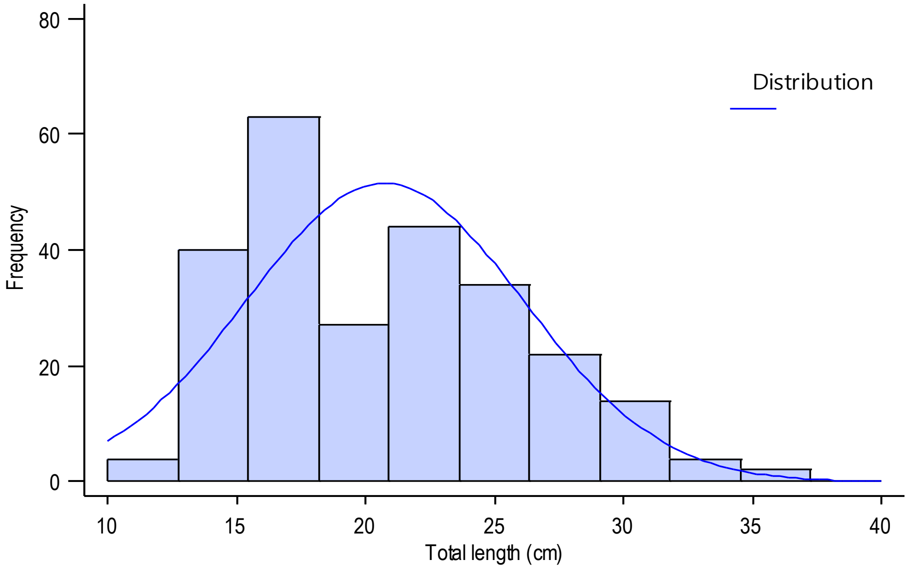

Fig.2. Size frequency distribution for combined sexes of *Pontinus sierra.*

Table 1. Statistical summary of size TL (cm) and length-weight relationship parameters of *Pontinus sierra.*

	N	Min	Max	Mean	SD	a	95% CIa	95% CIb	b	r^2
Female	83	13.5	33	20.93	4,41	-3.51	-3.51±0.34	2.72±0.11	2.72	0.96
Male	53	12.5	36.5	24.31	6.28	-3.54	-3.54±0.43	2.74±0.13	2.74	0.96
Combined sexes	253	12	36.5	20.76	5.37	-3.40	-3.40±0.16	2.69±0.05	2.69	0.96

combined sexes because 117 (46.25%) of the individuals were juvenile organisms whose sex could not be identified, while 83 (32.81%) were females, and 53 (20.95%) were males, with an estimated sex ratio of 1.6F:1M (X^2= 6.61; $P<0.05$). The length-weight relationship using a power equation was estimated as $W=0.03TL^{2.69}$ with a coefficient of determination r^2 of 0.96, indicating a strong correlation between the study variables. The slope *b* was statistically different from 3 (t=5.38, $P<0.05$), indicating that the growth of the species was considered negatively allometric (Fig. 3 and Table 1).

The Average Percentage Error (APE) and Coefficient of Variation (CV) indicated that age determination was consistent among the three readers, with APE=1.70 and CV=5.64. When correlating the readings, a correlation coefficient (r=0.95) was observed, indicating a strong relationship in age determination among the readers.

Based on the lengths calculated at each growth ring on the otoliths, a maximum age of 16 years was recorded. Bayesian statistical analysis identified the von Bertalanffy model as the winning model, with a fit of Looic=639.40, estimating the growth parameters as follows: $L\infty$=43.44 cm TL, k=0.10. Table 2 presents the parameters of the multimodel inference analysis, and Figure 4 shows the growth curves of the models.

The youngest individual found in a mature state was a female with a total length of 14.49 cm, while for males it was 15.60 cm. The logistic curve, using a binomial model, fitted the size at sexual maturity (L_{50}) at 22.64±0.44 cm of total length for both sexes, while the age at sexual maturity was 7.41 years (Fig. 5). In the analysis of reproductive activity, the months of May, June, and July 2018 (Dry season) exhibited the highest gonadosomatic index (GSI) values, while the lowest values were recorded in August, September,

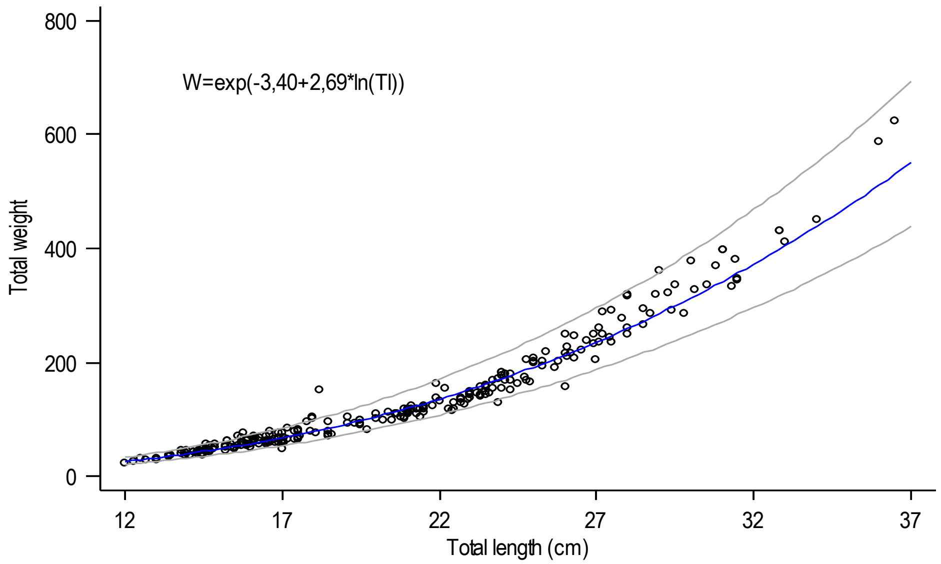

Fig.3. Size-weight relationship for combined sexes of *Pontinus sierra*.

Table 2. Bayesian analysis of fit and multimodel inference of growth parameters for combined sexes of *Pontinus sierra.*

Models	Parameters			
	L∞	*K/G*	*Looic*	*Wi*
von Bertalanffy	43.44	0.10	639.4045	1
Gompertz	36.56	0.47	1034.0933	0
Logístico	44.08	0.99	1345.3326	0

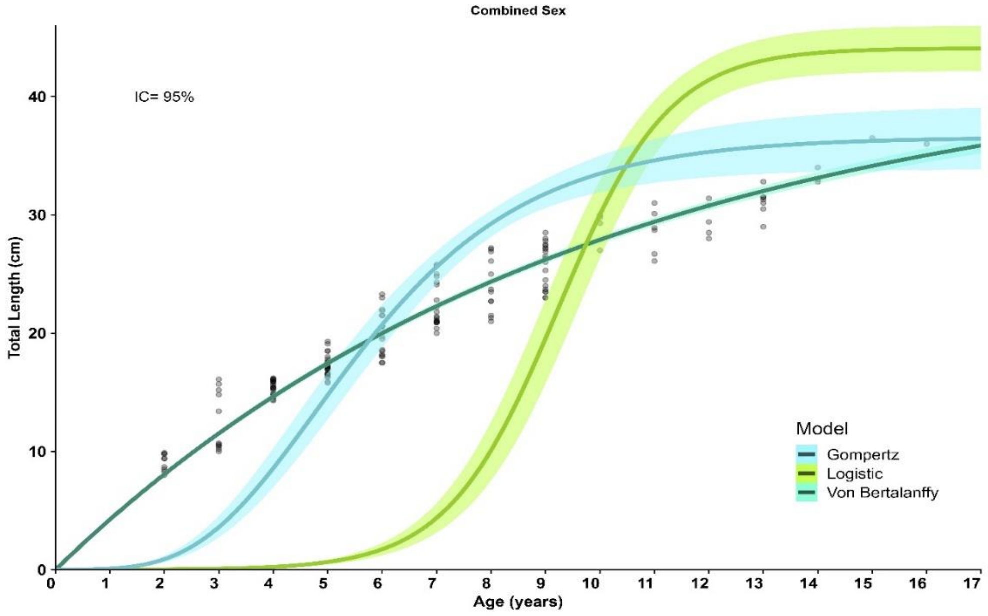

Fig.4. Sexual maturity curves for combined sexes of *Pontinus sierra*.

and November 2018. During the rainy season months, fluctuations in GSI remained constant from December 2018 to April 2019. Overall, reproductive activity showed significant differences throughout all months of the study (K-W=89.01, $P<0.05$) (Fig. 6).

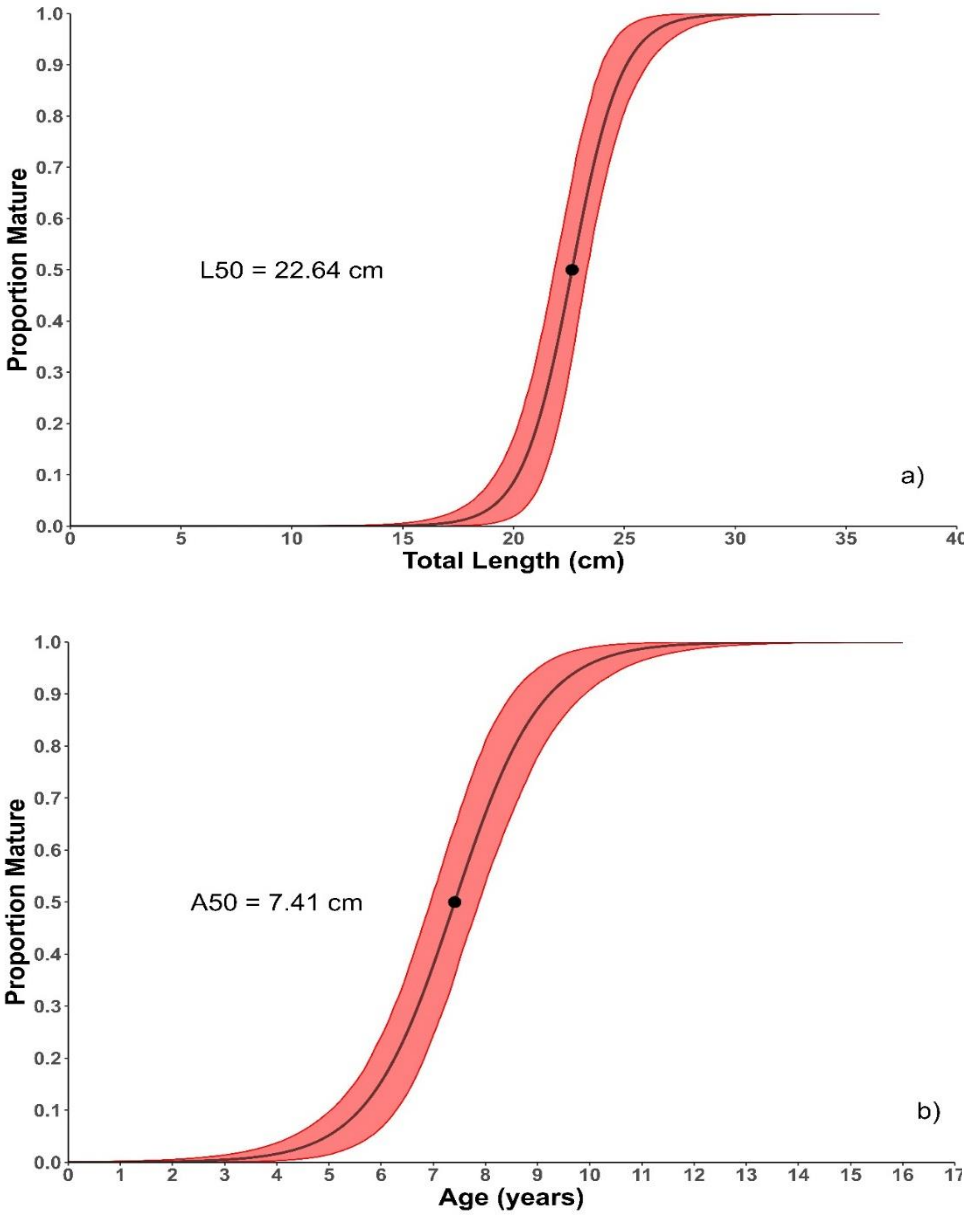

Fig.5. Size at maturity curves (a) and age at sexual maturity (b) for combined sexes of *Pontinus sierra.*

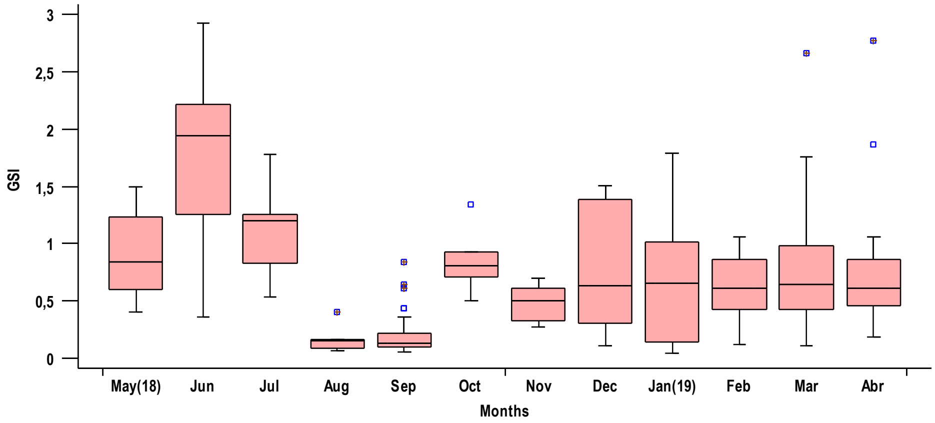

Fig.6. Monthly variation of GSI for combined sexes of *Pontinus sierra* during the study months.

DISCUSSION

The maximum size recorded for *Pontinus sierra* in the present study exceeds that reported by Jiménez Prado and Beárez (2004), who recorded 28 cm TL for continental Ecuador, and Poss (1995), who reported 18.6cm TL for the eastern Pacific. This disparity can be attributed to the fact that those studies represent initial records. However, Nieto Díaz (2014) reported a higher average size of 22.37 cm in Anconcito, Ecuador. Despite similar fisheries operations and the use of the same fishing gear, the Anconcito fleet extends to Isla de La Plata in Manabí, the customary zone for artisanal fishermen from Las Piñas. This expanded fishing range may result in increased fishing pressure affecting the size of the resource (Duarte et al. 2006; Pauly et al. 2002).

Regarding the *Pontinus* genus in Ecuador, notable work has been conducted by Jarrin et al. (2018) on *P. clemensi* in the Galápagos Islands, reporting average sizes of 38.25 cm and 41.22 cm TL for females and males, respectively, with a maximum size of 67 cm TL, surpassing the findings of the present study. Franco-Fuentes et al. (2023) also reported a wider size range with a maximum of 60 cm TL in the Galápagos Marine Reserve. The differences observed can be attributed to several factors, such as species differences, and the fact that the research was conducted in a protected area of the Galápagos, where fishing activities are regulated or prohibited. Consequently, species in these areas may not experience fishing pressure, allowing them to live and grow to larger sizes.

Jarrin et al. (2018) also indicated that significant size differences where males are larger than females seem to be common in species of the genus *Pontinus*, as reported by Estácio and Krug (2001) and Abellán et al. (2001) for *P. kuhlii* and *P. clemensi* in the Atlantic. This trend was observed even in some species within the same family, as reported by López et al. (2020) and Mesa et al. (2005) for *Pterois volitans* and *Scorpaena maderensis* in the Atlantic and Mediterranean, respectively. These differences could be attributed to factors such as sexual dimorphism (Marcinkevicius 2020), and variations in growth, age, and lifespan.

The negative allometric growth in *P. sierra* could be attributed to various factors, such as variations in body configuration, internal organ development, or adjustments in tissue proportions (Yee-Duarte et al. 2018). Furthermore, the morphological characteristic of species within the genus *Pontinus* or the allocation of energy towards reproductive processes due to a prolonged reproductive period could contribute to this phenomenon.

Regarding reproduction, Jarrin et al. (2018) reported a skewed sex ratio in favor of females. Martín-Vivaldi and Cabrero (2003) stated that in certain species, females have a higher fecundity capacity, allowing them to produce more eggs. This can lead to a bias in the sex ratio in favor of females, thus ensuring a higher reproduction rate. Most fish maintain a balanced sex ratio; however, this ratio can vary each year (Castillo Alva 2012), due to factors such as environmental changes (Rodríguez-Pulido et al. 2018).

Pontinus sierra exhibits a reproductive cycle that appears to remain constant throughout the year, with peaks in May, June, and July. This condition allows us to determine whether the fish population is in a resting, maturing, spawning, or post-spawning phase (Vega Calderon 2019). However, despite a decrease in August and September, few mature individuals were observed during these months. This may be influenced by adaptation to their environment, food availability (Chura et al. 2021), as well as their size and age. In certain situations, larger and older fish may have a more prolonged reproductive period compared to younger ones (Ramos-Santiago et al. 2006).

There are no records of sexual maturity size for the same species for comparison. However, in species of the same genus with similar size ranges, it is smaller than that reported by Isidro (1996) with 25 cm TL for *P. kuhlii* in the Azores Archipelago in the Atlantic and similar to that reported by Barboza (2019) with 22.9 cm TL for *P. nigropunctatus* in São Paulo, Brazil, and by Estácio and Krug (2001) with 22.6 cm and 29.9 cm TL for females and males of *P. kuhlii*, respectively.

These variations in sexual maturity size and reproductive activity can be attributed to environmental factors such as water temperature, habitat quality, and food availability, which can influence the growth and sexual maturity of fish (Rodríguez-Pulido et al. 2018). Additionally, species of the same genus exhibit genetic variations that influence their growth and sexual maturity, related to adaptation to different environments and living conditions (FAO/PNUMA 1984).

The results indicate that *P. sierra* could have a longevity of at least 16 years, a figure similar to the age reported by Jarrin et al. (2018) for *P. clemensi* in the Galápagos, where an age range of 9 to 17 years was observed. In the same study, the logistic model was shown to be the most suitable using frequentist methods, with a value of K=0.31. Abellán et al. (2001) also reported ages of 6 to 18 years for *P. khulii* in the Canary Islands, although with a K=0 value according to the frequentist von Bertalanffy model. On the other hand, Jakes-Cota et al. (2020) found ages of up to 10 and 15 years for males and females, respectively, with K=0 values for *Scorpaena mystes* in the Gulf of California, Mexico, using the frequentist VB model.

Similarities in age range among species are evident. According to the K value obtained in this study, *P. sierra*, like other demersal species in deep waters, exhibits slow growth and begins reproducing later in life (Moser 1996). However, a variation in the K value compared with other studies could be attributed to the significant presence of juveniles in this analysis. This could indicate that species like *P. sierra* captured in Las Piñas, Ecuador, are compelled to reach sexual maturity at smaller sizes and younger ages, suggesting vulnerability to fishing exploitation (Ba et al. 2015).

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مقاله کامل

ویژگی‌های سن، رشد و تولیدمثل *Pontinus sierra* صید شده توسط ماهیگیران صنعتی در اکوادور

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چکیده: این مطالعه ویژگی‌های سن، رشد و تولیدمثل *Pontinus sierra* را که توسط ناوگان ماهیگیری صنعتی در خلیج ماهیگیری لاس پیناس، منابی، اکوادور، از مه ۲۰۱۸ تا آوریل ۲۰۱۹، با تجزیه و تحلیل ۲۵۳ نمونه گرفته شده است، ارزیابی کرد. نمونه‌ها به آزمایشگاه زیست‌شناسی دانشکده علوم دریایی در دانشگاه لایکا Eloy Alfaro de Manabí منتقل شدند، جایی که آنالیزهای مورفومتریک مربوطه انجام شد. رابطه طول وزن برقرار شد ($W=0.02TL^{2.69}$)، که نشان‌دهنده رشد آلومتریک منفی است. تجزیه و تحلیل اتولیت تا ۱۶ گروه سنی را شناسایی کرد و در بین سه خوانش، APE=۱/۷، CV=۵/۶۴ سازگار بود. تحلیل چند مدل بیزی مدل ون برتالانفی را به‌عنوان بهترین تناسب (Looic=۶۳۹/۴۰)، با پارامترهای رشد L∞=۴۳/۴۴ سانتی‌متر طول کل، K=۰/۱ انتخاب کرد. میانگین اندازه و سن بلوغ جنسی به ترتیب ۲۲/۶۴ سانتی‌متر LT و ۷/۴۱ سانتی‌متر بود. پویایی تولیدمثلی، با استفاده از شاخص گنادوسوماتیک (GSI) ارزیابی شد، فعالیت تولیدمثلی تفاوت معنی‌داری را در طول دوره مطالعه نشان داد (K-W=۰/۸۹ ؛*P*<۰/۰۵). *P. sierra* رشد نسبتاً آهسته‌ای را نشان می‌دهد و گونه‌ای طول عمر بالا با تولیدمثل مداوم است. این یافته‌ها اطلاعات مهمی را برای مدیریت پایدار این منبع مهم ماهیگیری در منطقه فراهم می‌کند.

کلمات‌کلیدی: سن، رشد، تولیدمثل، اتولیت.