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Growth of female crab *Romaleon setousum* (Crustacea: Decapoda) in Peruvian waters

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Summary: The crab *Romaleon setosum* holds significant commercial value for artisanal fisheries in Peru and Chile. However, critical life-history parameters necessary for stock assessments remain understudied, hindering the development of precautionary fishing strategies. Given the morphological and growth differences between sexes in *R. setosum* and the low presence of large male specimens, this study provides the first estimates of growth parameters for female *R. setosum* in Peruvian waters, employing a length-based resampling method and length-frequency analysis based on the von Bertalanffy growth function. The results reveal that accurate parameter estimates require larger sample sizes with different modal progressions. Longevity estimates align with previous studies and do not increase in specimens from higher latitudes, suggesting pronounced spatiotemporal environmental variability driven by upwelling zones and climatic events such as warmer (El Niño) and colder (La Niña) phases. These findings are essential for the effective management and sustainable exploitation of this resource, as growth parameters are fundamental inputs for both data-rich and data-limited population assessment models.

Keywords: fisheries management; length-frequency analysis; growth parameters; uncertainty.

Crecimiento de hembras de cangrejo *Romaleon setosum* (Crustácea: Decápoda) en aguas peruanas

Resumen: El cangrejo *Romaleon setosum* posee un valor comercial significativo para la pesca artesanal en Perú y Chile. Sin embargo, los parámetros críticos de su ciclo de vida, necesarios para la evaluación de stocks, siguen siendo poco estudiados, lo que dificulta el desarrollo de estrategias de pesca precautorias. Dadas las diferencias morfológicas y de crecimiento entre sexos en *R. setosum*, y la escasa presencia de machos de gran tamaño, este estudio proporciona las primeras estimaciones de los parámetros de crecimiento para hembras de *R. setosum* en aguas peruanas, empleando un método de remuestreo basado en tallas y un análisis de frecuencia de tallas basado en la función de crecimiento de von Bertalanffy. Los resultados revelan que, para obtener estimaciones precisas de los parámetros, se requieren tamaños de muestras más grandes con progresiones modales diferenciadas. Las estimaciones de longevidad coinciden con estudios previos y no aumentan en especímenes de mayores latitudes, lo que sugiere una marcada variabilidad ambiental espaciotemporal impulsada por zonas de surgencia y eventos climáticos como fases cálidas (El Niño) y frías (La Niña). Estos hallazgos son fundamentales para la gestión eficaz y la explotación sostenible de este recurso, ya que los parámetros de crecimiento son insumos esenciales tanto para los modelos de evaluación poblacional con abundantes datos, como para aquellos con datos limitados.

Palabras clave: gestión pesquera; análisis de frecuencia de tallas; parámetros de crecimiento; incertidumbre.

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INTRODUCTION

Decapod crustaceans are highly diverse, comprising over 17000 living species with varied morphology and physiology inhabiting many marine and freshwater environments (Martin and Davis 2001, De Grave et al. 2023). According to Vogt (2012), Decapoda are among the better-studied groups of animals used for human consumption, dating back to ancient times. Studies on age and longevity have been conducted for less than 2% of decapod species (Vogt 2012). Longevity estimates range from 1.3 months for *Lucifer faxoni* (Lee et al. 1992) to 72 years for *Homarus gammarus* (Sheehy et al. 1999). Most decapods, however, are thought to live between 1 and 10 years (Vogt 2012) and exhibit indeterminate growth, meaning they continue growing after reaching sexual maturity. Furthermore, longevity is influenced by latitude (higher latitude correlates with greater longevity), depth, freshwater cave habitats and temperature, which is considered the primary driver.

The limited number of studies on age and longevity in decapods can be attributed to the absence of permanent rigid structures for age determination. Consequently, age estimation relies on indirect methods, including captivity observations, mark-recapture techniques, length-frequency distribution analysis in wild populations, and the study of moulting intervals and durations (Hartnoll 2001).

The most used method for studying crustacean growth, especially in commercially important but data-limited fisheries, is size-frequency analysis. This approach assumes that significant and persistent modes progressing over time represent individual year classes. This assumption holds true for species at higher latitudes, where seasonal reproduction generates one modal group annually. However, subtropical species, which reproduce and grow year-round, often lack clearly defined cohorts (Urban 2001).

Length-frequency analysis, powered by computational tools such as ELEFAN (Pauly 2013), has improved growth estimation in fisheries (Bradley et al. 2017). ELEFAN calculates the von Bertalanffy (1938) growth coefficient (K), constraining or fixing the asymptotic length (L_∞) based on maximum observed lengths or methods such as Powell-Wetherall. However, the inverse relationship between K and L_∞ creates challenges, such as overestimating L_∞ when K is underestimated, and vice versa (Schwamborn et al. 2019).

Advances such as ELEFAN-SA and ELEFAN-GA (Mildenberger et al. 2017) improve parameter optimization, although they can be trapped in local maxima and lack confidence in their estimates. Resampling methods (Schwamborn et al. 2019) address this limitation by providing confidence intervals for the fit of the von Bertalanffy growth function.

The marine invertebrate fishery in Peru is primarily artisanal, targeting various species along the coast. Molluscs represent the most significant group in terms of landing volume and species diversity, followed by crustaceans, including shrimps and crabs such as *Romaleon setosum*. Many of these species lack stock assessments due to insufficient estimates of key population dynamics parameters, such as growth. This issue, compounded by increased commercial harvesting, has led to overexploitation of some species, underscoring the need for sustainable management measures. Determining growth, longevity and mortality parameters is crucial to addressing these challenges.

Growth parameters are essential for understanding the biology and productivity of organisms. Growth rates indicate the time required to reach a commercially viable size, providing critical insights for management strategies and population dynamics modelling. This information supports sustainable fisheries management and the development of conservation measures. Given the abundance of *R. setosum* in the cold upwelling regions of the Humboldt Current (Fischer and Thatje 2016), ranging from Guayaquil, Ecuador, to the Taitao Peninsula, Chile (Garth 1959), and its economic importance in Peruvian artisanal fisheries, it is imperative to address the lack of stock assessments. Limited studies on this species, such as those by Merino (1995) and Argumedo (2012), highlight this gap and indicate that males reach larger sizes than females. This has made males more attractive for trade, resulting in a low presence of large male specimens (skewed size structures) which hinders accurate growth determination for males using size data. Therefore, it is imperative to obtain growth estimates to assess reproductive potential. This study aims to estimate growth parameters for female *R. setosum* in Peruvian waters using a size-based approach, providing essential data for evaluating the population status of this species.

MATERIAL AND METHODS

Study area

The present study was carried out in the regions of Lima, Ica and Moquegua, which are the areas where the highest volumes of landings of *R. setosum* are recorded (Fig. 1).

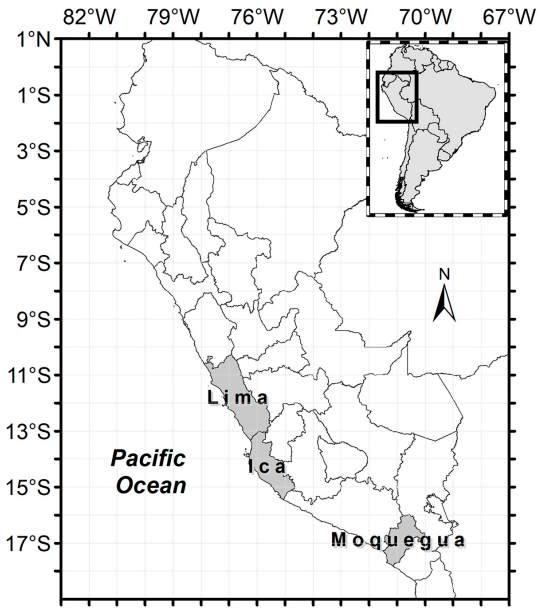

Fig. 1. – Main zones of artisanal fishing for *Romaleon setosum* in Peruvian waters.

Sampling and information processing

The data were obtained from biological and biometric sampling conducted under the project "Monitoring of Marine Invertebrate Fisheries" of the Instituto del Mar del Peru (IMARPE), following the protocol proposed by Espinoza et al. (2016). The crabs for biometric and biological sampling were collected at the landing sites on a biweekly frequency and taken to the IMARPE laboratories for processing. During sampling, after the removal of epibionts, the width of the cephalothorax (distance between the right and left ends of the last anterolateral spine on each side of the shell) was measured to the nearest millimetre using a digital caliper. The width of the cephalothorax was recorded on the respective forms, which included information on date, area, fishing gear, catch, vessel name and other relevant details. The monthly length-frequency of female specimens used in the analysis corresponds to the periods of 2010-2011 for the Lima region, 2014-2015 for Ica and 2018-2019 for Moquegua.

Growth parameters estimation

Growth was estimated only for females due to the low presence of large male specimens. To estimate the growth parameters, the ELEFAN method implemented in the R package TropFishR (Mildenberger et al. 2017) was used, which includes improved versions of the functions of the FAO-ICLARM II stock assessment tools (FISAT II) (Gayanilo et al. 2005). This method estimates parameters of the von Bertalanffy growth function from the progression of modes observed in length frequencies over time (Pauly 1980). Total length measurements (cephalothorax width) grouped into 6 mm class intervals were used, as this reduces the possibility of confusing a moult with an annual mode in the histograms (Wolff and Soto 1992). The seasonally oscillating von Bertalanffy growth function was used (Pauly and Gaschutz 1979, Somers 1988):

$$L_t = L_\infty(1 - \exp - (K(t - t_0) + (\frac{C*K}{2\pi})sin(2\pi(t - t_s)))$$

where L_t is the length at time t, L_∞ is the asymptotic length, K is the growth coefficient, t_0 is an estimated parameter that represents the age when the individual's length is zero, C is a constant that indicates the amplitude of the growth oscillation, typically ranging from 0 to 1, and ts defines the time of year when the sine wave oscillation begins (i.e. turns positive).

For the estimation of the parameters using the ELEFAN routine in TropFishR, a moving average of five size intervals was used, a configuration also employed in FISAT II (Taylor and Mildenberger 2017). Likewise, the ELEFAN_GA genetic search algorithm (Mildenberger et al. 2017) was used to fit the growth models to the monthly length-frequency distributions. It is important to note that an additional output of the ELEFAN of TropFishR is the t_{anchor} parameter, which represents the fraction of the year when the annually repeated growth curves intersect at a length equal to zero.

The growth parameters estimated in this study with those estimated in other studies in Peru and Chile were compared using the growth index phi prime ($\phi' = \log_{10}K + 2\log_{10}L_\infty$) proposed by Munro and Pauly (1983). Following the criterion of Sparre and Venema (1997), the coefficient of variation of ϕ' should not exceed 4% to consider the results statistically similar.

Uncertainty in growth

To assess the sources of uncertainty in the length-based estimates of body growth, we used the ELEFAN-GA-boot function from the fishboot R package (Schwamborn et al. 2018), which is a bootstrapped version of the ELEFAN-GA curve-fitting function from TropFishR. A total of 1000 simulations were performed using the following configuration: popSize = 60, pmutation = 0.2, maxiter = 50, run = 10.

It should be noted that one of the settings proposed by Schwamborn et al. (2019) was considered, along with a large search space for the parameters K (0.01–1), t_{anchor} (0–1), C (0–1) and t_s (0–1). Regarding the asymptotic length, nine search spaces were established, L_∞=145-600, 145-550, 145-500, 145-450, 145-400, 145-350, 145-300, 145-250 and 145-200, to simulate different magnitudes of variability.

In addition, the empirical equation proposed by Froese and Binohlan (2000) was considered as an additional search space:

$$log_{10}(L_\infty) = 0.044 + 0.9841 * log_{10}(L_{max}) \pm 0.0741$$

which estimates a range of L_∞ from the maximum size (L_{max}) observed in the fishery. For this scenario, L_{max} was considered to be 172 mm of cephalothorax width of a female specimen recorded in the Callao area (Argumedo, 2012), and a total of 2000 simulations were carried out. Then, 95% confidence intervals were estimated from the percentiles of the L_∞, K and C distributions, as well as the first (P_{25}) and third (P_{75}) percentiles of the parameters.

RESULTS

The simulations conducted considered different search spaces for L_∞, while maintaining the search space for the growth coefficient (K) consistent for each region (Fig. 2) and showed lower uncertainty as the search space of L_∞ was reduced. That is, when the search ranges were narrower, the behaviour of the growth parameters L_∞ and K resembled an asymmetric distribution with 50% of the estimated values concentrated near the peak of maximum density of their distribution.

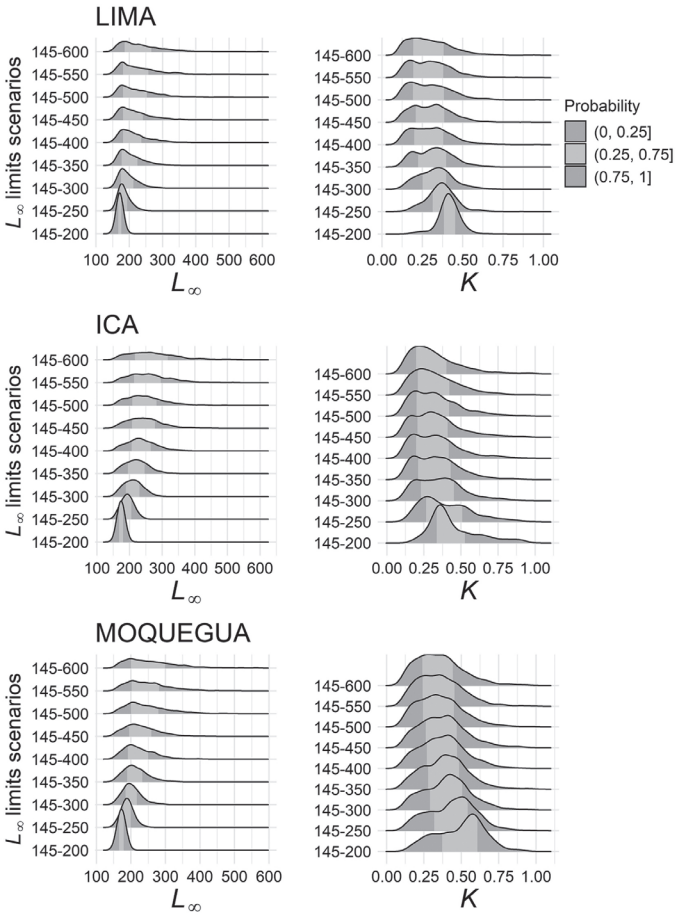

Fig. 2. – Frequency distribution of the estimated parameters through the seasonally oscillating von Bertalanffy growth function under different search spaces for the L_∞ with a K ranging from 0.01 to 1 for each region.

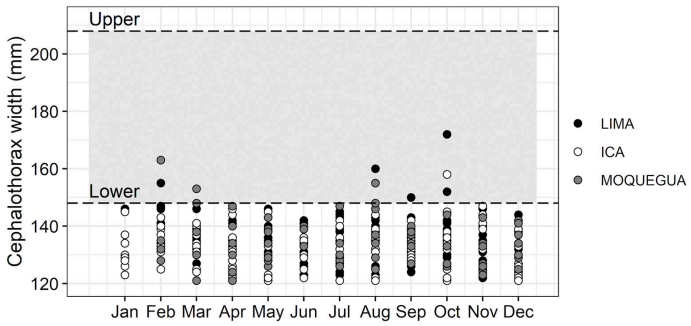

Fig. 3. – Maximum monthly width of the cephalothorax recorded during the period 2000–2019 for female specimens of *R. setosum* (dots). The dashed horizontal lines and grey area represent the limits of L_∞ estimated using the empirical equation proposed by Froese and Binohlan (2000). X-axis indicates the months of the year: Jan, January; Feb, February; Mar, March; Apr, April; May, May; Jun, June; Jul, July; Aug, August; Sep, September; Oct, October; Nov, November; Dec, December.

Figure 3 shows the search space when the empirical equation proposed by Froese and Binohlan (2000) was used to estimate a range of L_∞ from the maximum length observed in the fishery. These results are like the search space with a range of 145–200, which showed less uncertainty in the estimates of L_∞ and K (Fig. 2).

In addition, the simulations conducted using a search space of L_∞ with the empirical equation of Froese and Binohlan (2000) showed scenarios with greater uncertainty in Ica and Ilo than in Lima. However, the combinations of the individual values of L_∞ and K were concentrated within 25% of the density of these combinations, with the maximum density peak of the parameters L_∞ and K recorded (Fig. 4 and Table 1). Likewise, Figure 4 shows the estimated growth curves derived from the monthly size frequencies of female specimens for each region. It is observed that the values of the estimated growth parameters at the maximum density peak, obtained from the different adjustments of the von Bertalanffy growth function curve to the re-sampled monthly length-frequency distributions, are considered appropriate because of the alignment with the temporal succession of observed modal groups.

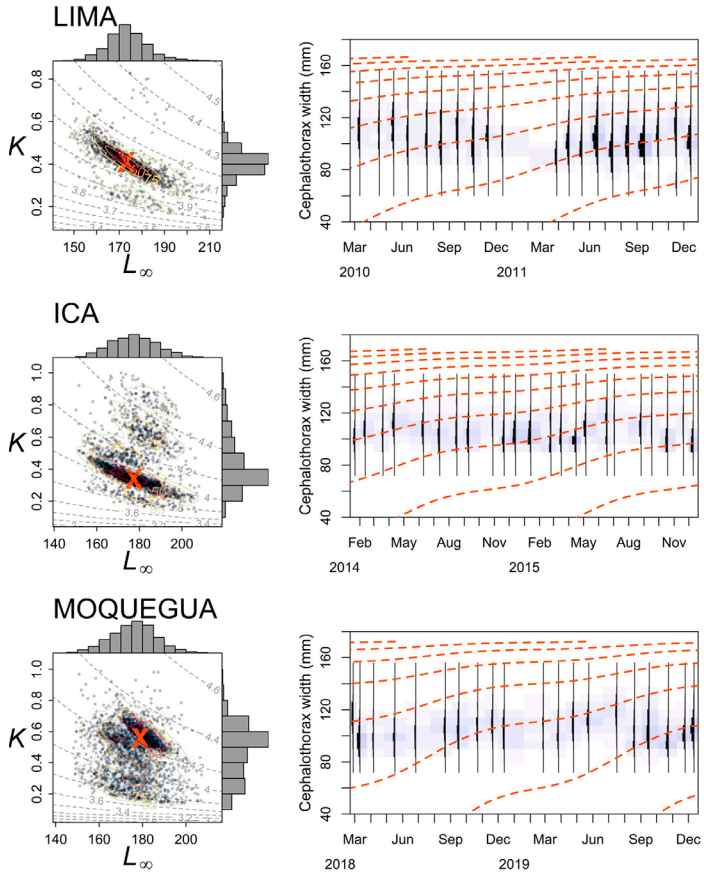

Fig. 4. – Left panel: scatterplot of L∞ vs K with a 95% percentile contour (bivariate kernel distribution). Each point represents a result obtained by an optimized fit. Grey lines: ϕ' isolines. Red "X": location of the mode (maximum peak of density). Right panel: size-frequency distribution of female *R. setosum* specimens for each region with estimated growth curve (dashed line). X-axis indicates the months of the year: Jan, January; Feb, February; Mar, March; Apr, April; May, May; Jun, June; Jul, July; Aug, August; Sep, September; Oct, October; Nov, November; Dec, December.

Table 1. – Growth parameters of the von Bertalanffy equation for female specimens of *Romaleon setosum* using a search space of L_∞ based on the empirical equation of Froese and Binohlan (2000), compared with estimated values from studies of the same species.

Zone	Parameters	Mode Value (mm)	Method	Reference
Lima, Peru	L_∞	173.18	VBGF	This study
	K	0.41		
	C	0.39		
	ϕ'	4.08		
Ica, Peru	L_∞	177.43	VBGF	This study
	K	0.34		
	C	0.56		
	ϕ'	4.04		
Moquegua, Peru	L_∞	178.96	VBGF	This study
	K	0.56		
	C	0.61		
	ϕ'	4.26		
Callao, Lima, Peru	L_∞	194.14	VBGF	Argumedo (2012)
	K	0.52		
	C	0.28		
	ϕ'	4.29		
Guaynuna Bay, Ancash, Peru	L_∞	131	VBGF (without oscillation)	Merino (1995)
	K	0.47		
	C	-		
	ϕ'	3.91		
La Herradura Bay, Region IV, Chile	L_∞	160.5	VBGF	Wolff and Soto (1992)
	K	0.57		
	C	0.4		
	ϕ'	4.17		

The estimated values of the parameters L_∞, K, C and growth index (ϕ') across regions and from other studies carried out in Peru and Chile are shown in Table 1. Differences were observed between the estimated growth parameters. However, when the ϕ' values from research conducted in Peru and Chile were compared (Table 1), a coefficient of variation value of ~3.5% was obtained, which did not exceed 4%. Therefore, it can be assumed that the results obtained are statistically similar. Additionally, Table 2 provides estimated values, confidence intervals and percentiles for the growth parameters of *R. setosum*, offering valuable data for future stock assessments.

Table 2. – Growth parameters of the von Bertalanffy equation estimated for female specimens of Romaleon setosum. CI, confidence interval; P_{25}, 25th percentile, P_{75}, 75th percentile.

Zone	Parameters	Mode Value (mm)	CI Lower	CI Upper	P_{25}	P_{75}
Lima (12.05°S 77.14°W)	L_∞	173.18	155.8	192.1	167.03	177.89
	K	0.41	0.24	0.55	0.36	0.44
	C	0.39	0.07	0.78	0.29	0.53
Ica (13.73°S 76.23°W)	L_∞	177.43	157.41	198.19	169.50	184.41
	K	0.34	0.17	0.8	0.27	0.61
	C	0.56	0.31	0.97	0.49	0.70
Moquegua (17.64°S 71.35°W)	L_∞	178.96	154.6	196.77	170.53	183.84
	K	0.56	0.15	0.71	0.28	0.65
	C	0.61	0.23	0.96	0.44	0.69

DISCUSSION

Determining the growth parameters of *R. setosum* is essential for understanding and modelling its population dynamics. Despite its economic significance as the most important crustacean in Peruvian waters after shrimp,

studies on its growth have been limited. Most prior research has utilized size analysis with the ELEFAN software following Pauly's (1987) methodology, which typically involves fixing the asymptotic length (L_∞) while focusing on optimizing the growth coefficient (K). However, as Schwamborn et al. (2019) noted, this approach can lead to errors, with K being over- or underestimated depending on inaccuracies in L_∞. To mitigate these errors, newer methods have been developed that simultaneously optimize all growth parameters, such as response surface analysis and the algorithms ELEFAN-SA and ELEFAN-GA. While these methods reduce parameter estimation bias, they remain prone to local maxima effects, making it challenging to achieve optimal solutions (Schwamborn 2018).

Additionally, Schwamborn (2018) highlights the importance of accounting for data uncertainty when estimating growth parameters. This challenge is especially relevant in cases with limited sample sizes, where modal progressions in length-frequency data are unclear.

In the present study, the sources of uncertainty in parameter estimation were addressed through resampling. This approach generated confidence intervals that represent the uncertainty from various sources such as the number of sampling months and the size range. Uncertainties were minimal in the Lima region, where sample sizes were larger and modal progressions were clearer. Other ways to deal with uncertainty in parameter estimation in data-limited fisheries include evaluating multiple L_∞ and K scenarios using expert knowledge, despite the subjectivity that this may involve (Miyagawa et al. 2023). Empirical equations such as those proposed by Froese and Binohlan (2000) can also be used to establish reasonable ranges for L_∞.

The growth parameters estimated in this study indicate that the cephalothorax width of females at the end of their first year is 58.2 mm in Lima, 51.1 mm in Ica, and 76.4 mm in Moquegua. These values align with estimates by Merino (1995) and Argumedo (2012), which range from 49.1 mm to 87.5 mm (Fig. 5). By the third year, females reach sizes of 113–145 mm (this study) and 99–166 mm (previous studies).

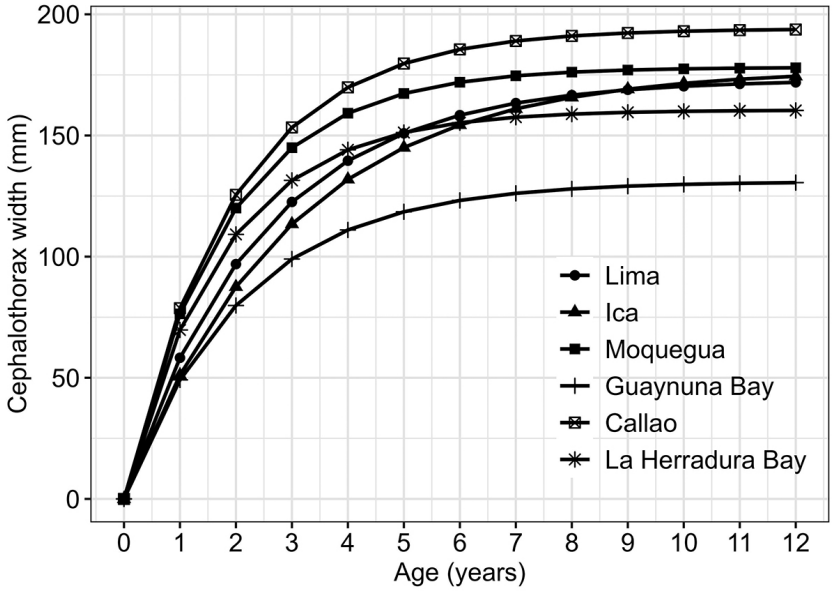

Fig. 5. – Estimated length at age of *R. setosum* females based on growth parameters estimated in this study (Lima, 12°S, Ica, 14°S; Moquegua, 17°S) and previous studies (Guaynuna Bay, 09°S; Callao, 12°S; La Herradura Bay, 29°S).

Growth estimates across regions (Lima, Ica and Moquegua) were comparable and aligned with findings by Wolff and Soto (1992) in Chile. However, discrepancies with Merino (1995) and Argumedo (2012), who reported slower and faster growth, respectively, could be attributed to methodological differences, such as reliance on maximum fishery sizes to set L_∞ (Sparre and Venema 1997), the use of Kscan routines (Gayanilo et al. 2005), or regional variations in life-history traits influenced by latitude, reproductive performance and exploitation rates (Brante et al. 2004, Fischer and Thatje 2008, 2016).

Differences in growth oscillation constants were also found between regions found in this work and previous studies. These differences are likely due to abiotic factors such as temperature fluctuations, light availability, food supply and individual life histories, including moulting cycles (Liu et al. 2021).

R. setosum is adapted to the cold, nutrient-rich conditions of the Humboldt Current, allowing it to inhabit a wide geographic range along the southeastern Pacific coast, from 2°S in Peru to 46°S in Chile (Fischer and Thatje 2008). In this extensive area, latitudinal variations in the life cycle influenced by biotic and abiotic factors are expected, affecting physiology, reproductive cycles, sizes at maturity, reproductive performance and longevity (Hemmi 1993, Hochachka and Somero 2002, Orton 1920 in Fischer 2009). For example, Longhurst and Pauly (1987) noted that populations at high latitudes tend to have larger asymptotic sizes (L_∞) and lower K values, indicating slower growth. In the Humboldt Current, males are larger than females (Wolff and Soto 1992, Merino 1995, Argumedo 2012). However, the results of this study show that neither L_∞ nor longevity increase consistently at higher latitudes (Fig. 6). This is probably due

to interruptions in the latitudinal temperature gradient caused by local upwelling regimes (Fischer 2009), as well as tolerance to interannual thermal variability driven by the El Niño-Southern Oscillation (Fischer 2009). Therefore, latitudinal differences in life cycle traits should be analysed alongside other abiotic and biotic covariates.

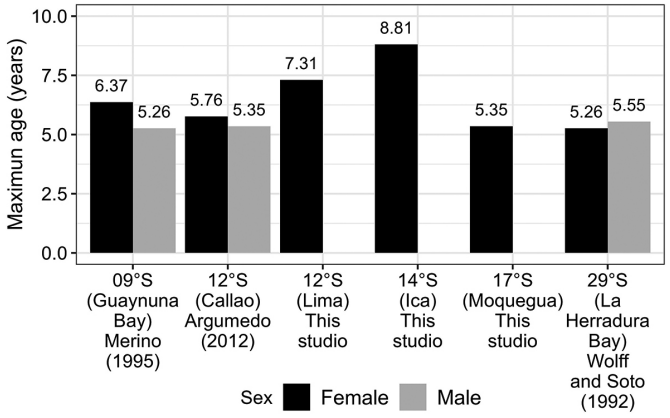

Fig. 6. – Age estimates at 95% of the infinite length (L_∞) for females and males of *R. setosum* by zones or study areas, based on estimates of growth parameters in this study and previous studies.

The methodology employed in this study effectively incorporates uncertainty related to sample size, an aspect often overlooked in previous research on *R. setosum* in Peru and Chile. This contributes to more reliable growth parameter estimates, supporting future analyses such as mortality assessments, population evaluations and simulations (Schwamborn et al. 2019). With many artisanal fisheries lacking the data needed for standard stock assessments, alternative approaches, including limited-data methods such as spawning potential ratio, are gaining traction worldwide (Miyagawa et al. 2023). These methods require precise growth parameter estimates, particularly for females.

This is the first study to use resampling methods to estimate growth parameters for *R. setosum*. The estimated parameters can be used in traditional assessment models to determine how fast a species can grow and therefore predict whether abundance levels of a stock are below or above biological reference levels after a certain time under specific levels of fishing mortality. Therefore, the growth parameters estimated for *R. setosum* in this study will allow 1) the implementation of models to determine its population status in Peruvian waters, and 2) performance projections under different fishing mortality scenarios, contributing to future management measures aimed at reducing fishing pressure on the population. However, future studies should include broader size ranges over multiple years, encompassing both favourable and unfavourable environmental conditions, to better assess potential impacts on growth dynamics.

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DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

AUTHORSHIP CONTRIBUTION STATEMENT

Miguel Pérez-Huaripata: Conceptualization, Formal analysis, Writing – original draft, Writing – review and editing. **Juan Arguelles:** Supervision, Writing – review and editing. **Edgar Argumedo:** Formal analysis, review and editing. **Sven Thatje:** Writing, review and editing the final draft.

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