Population dynamics of *Callinectes sapidus* fishery resource in Lake Maracaibo, Venezuela

Dinámica poblacional del recurso pesquero *Callinectes sapidus* en el Lago de Maracaibo, Venezuela

Dinâmica populacional do recurso pesqueiro *Callinectes sapidus* no Lago de Maracaibo, Venezuela

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Keywords:

Abstract

The blue crab, *Callinectes sapidus*, supports one of the most significant fisheries in Lake Maracaibo and western Venezuela, although several previous studies suggest signs of overexploitation. This study analyzed the population dynamics of the species as a basis for resource management, based on 46 monthly samples of landings at the main ports of Lake Maracaibo from 2010 to 2014. Monthly length-frequency data were analyzed using the FiSAT II software to estimate growth parameters (ELEFAN I), mortality (length-converted catch curve) and recruitment (cohort analysis). Natural mortality was estimated using several methods due to its complexity. The estimated growth parameters were $L_\infty = 14.67$ cm, and $K = 0.87$ yr^{-1}, with higher growth rates in males. Recruitment was continuous, with peaks during the rainy season. Total mortality was estimated at 7.74 yr^{-1}, natural mortality ranged from 0.87 to 2.05 yr^{-1}, and fishing mortality ranged from 5.79 to 6.87 yr^{-1}, showing strong fishing pressure, mainly on females. It was determined that *C. sapidus* has a short life cycle, with first entry into the fishery at 7-8 months of age and 7.0 cm, remaining until 24 months of age and 12 cm. The catch curve suggests full recruitment between 12 and 13 months of age and 8.7 cm. It is concluded that the high fishing intensity has altered the population structure and limits the adequate renewal of the stock, highlighting the need to strengthen management measures.

Resumen

El cangrejo azul, *Callinectes sapidus*, sostiene una de las pesquerías más importante del Lago de Maracaibo y del occidente de Venezuela, aunque numerosos estudios previos señalan signos de sobreexplotación. Este trabajo analizó la dinámica poblacional de la especie como base para su manejo, a partir de 46 muestreos mensuales de las capturas en los principales puertos del Lago de Maracaibo desde el 2010 al 2014. Las frecuencias de tallas mensuales se analizaron con el software FiSAT II, para estimar parámetros de crecimiento (ELEFAN I), mortalidad por pesca (curva de captura linealizada) y reclutamiento (análisis de cohortes). La mortalidad natural se estimó con varios métodos por su complejidad. Como resultado, los parámetros de crecimiento fueron $L_\infty = 14{,}67$ cm, $K = 0{,}87$ a^{-1}, con mayor crecimiento en machos. El reclutamiento fue continuo, con picos en la estación lluviosa. La mortalidad total se estimó en 7,74 a^{-1}; la mortalidad natural entre 0,87 y 2,05 a^{-1}, y la mortalidad por pesca entre 5,79 y 6,87 a^{-1}, evidenciando fuerte presión pesquera, principalmente sobre las hembras. Se determinó que *C. sapidus* posee un ciclo de vida corto ingresando a la pesquería a los 7-8 meses de edad y 7,0 cm, y permanece en esta hasta los 24 meses y 12 cm. La curva de captura mostró pleno reclutamiento entre los 12 y 13 meses de edad y 8,7 cm. Se concluye que la alta intensidad de la pesca ha modificado la estructura poblacional y limita la adecuada renovación del *stock*, destacando la necesidad de reforzar las medidas de manejo.

Palabras clave: estructura poblacional, crecimiento, tasa de mortalidad, cangrejo azul, lago tropical.

Resumo

O siri-azul, *Callinectes sapidus*, sustenta uma das pescarias mais importantes do Lago Maracaibo e do oeste da Venezuela, embora numerosos estudos anteriores apontem para sinais de superexploração. Este estudo analisou a dinâmica populacional desta espécie como base para o manejo, com base em 46 amostras mensais de capturas realizadas nos principais portos do Lago Maracaibo entre 2010 e 2014. As frequências mensais de comprimento foram analisadas utilizando o software FiSAT II para estimar os parâmetros de crescimento (ELEFAN I), mortalidade por pesca (curva de captura linearizada) e recrutamento (análise de coorte). A mortalidade natural foi estimada utilizando diversos métodos devido à sua complexidade. Os parâmetros de crescimento resultantes foram $L_\infty = 14{,}67$ cm, $K = 0{,}87$ a^{-1}, com maior crescimento nos machos. O recrutamento foi contínuo, com picos durante a estação chuvosa. A mortalidade total foi estimada em 7,74 a^{-1}; A mortalidade natural variou de 0,87 a 2,05 a^{-1}, e a mortalidade por pesca variou de 5,79 a 6,87 a^{-1}, evidenciando forte pressão pesqueira, principalmente sobre as fêmeas. Foi determinado que *C. sapidus* tem um ciclo de vida curto, entrando na pescaria aos 7-8 meses de idade e 7,0 cm, permanecendo até 24 meses e 12 cm. A curva de captura mostrou recrutamento completo entre 12 e 13 meses de idade e 8,7 cm. Conclui-se que a alta intensidade de pesca modificou a estrutura populacional e limita a renovação adequada do estoque, destacando a necessidade de fortalecer as medidas de manejo.

Palavras-chave: estrutura populacional, crescimento, taxa de mortalidade, siri-azul, lago tropical.

Introduction

The lake of Maracaibo, in western Venezuela, is classified as a eutrophic ecosystem (Rodríguez, 2001). It is home to a rich aquatic biodiversity, including diverse fishery resources, which provide a source of food and employment for thousands of artisanal fishers. The blue crab, *Callinectes sapidus*, in the Lake of Maracaibo supports the most important artisanal fishery in western Venezuela in terms of catch volume and foreign exchange earnings, with reported landings of 14,672 tonnes and exports of 2,300 tonnes of crab meat, generating USD 22 million in 2009 (Andrade de Pasquier *et al*., 2012). In 2022, the Ministerio del Poder Popular para la Pesca y Acuicultura reported that landings had decreased to 1,332 tonnes through exportable offer catalogues.

Several studies have reported increasing fishing pressure on blue crabs (Villasmil and Mendoza, 2001), driven by high demand (Perdomo *et al*., 2010) and non-compliance with current regulations, has altered its population dynamics, reducing its biological potential and affecting its size structure (Andrade de Pasquier *et al*., 2010), which may pose a risk to the sustainability of the fishery. Given the national importance of this resource, various regulations have been established, such as closed seasons, minimum catch sizes and classification of fishing gear, in accordance with Decree No. 6,732. However, in practice, the regulations have not succeeded in preventing the capture of crabs below the legal minimum size or the use of non-selective fishing gear (Vázquez and Pascal, 2024), which affects the population dynamics of the resource (Andrade de Pasquier *et al*., 2010).

The study of population dynamics and the estimation of population parameters is an essential tool for assessing the status of blue crab resources and implementing sustainable management measures (Monteiro *et al*., 2025). The main parameters considered in fisheries management include the population growth rate and the maximum theoretical size attainable by individuals; recruitment, which determines the entry of new individuals into the exploitable fraction of the population; and the mortality rate, which estimates the intensity of exploitation (Sparre and Venema, 1995).

These parameters are obtained using standardised, reproducible and globally comparable methods, which guarantees the validity of the results (Gallego-Zerrato *et al*., 2025). Correct estimation allows the main sources of population biomass decline to be identified, including natural mortality (M) and fishing mortality (Z). Comparing these indicators over time allows the current status of the fishery and its trend to be determined. Knowledge of the population dynamics of fishery resources also provides the basis for more complex analyses, such as estimating exploitation rates and predicting future population behaviour under different scenarios.

Due to the relevance of population dynamics in fisheries management, the objective of this study was to estimate the fundamental population parameters of *C. sapidus*, such as growth (L_∞, K and t_0), recruitment and mortality in a tropical lake, in order to lay the foundations for the development of population dynamics models and stock assessments aimed at defining resource management and administration policies that are more in line with its biological, fisheries and economic reality.

Materials and methods

Study area

The Lake of Maracaibo, with an area of 13,210 km², is a body of water located in a basin fed by 135 rivers. It has a salinity gradient

that varies from higher salinity in the north to lower salinity in the south. It is characterised by being a eutrophic environment, with anticyclonic circulation and an anoxic central hypolimnetic zone. The region has two distinct seasons: rainy from May to November and dry from December to April, which influence the temperature and changes in water salinity (Rodríguez, 2001). These environmental conditions directly affect the life cycle of the species.

Sampling and data collection

For population dynamics analyses, commercial catches of *C. sapidus* extracted with traps and longlines were used, collecting data on sex and carapace width (CW), excluding lateral spines. A precision vernier caliper with a resolution of 0.1 cm was used for the measurements. A total of 46 monthly samples were collected between May 2010 and August 2014 at the three main landing ports of the Lake of Maracaibo (Figure 1). This formed the most complete and rigorous database available to date.
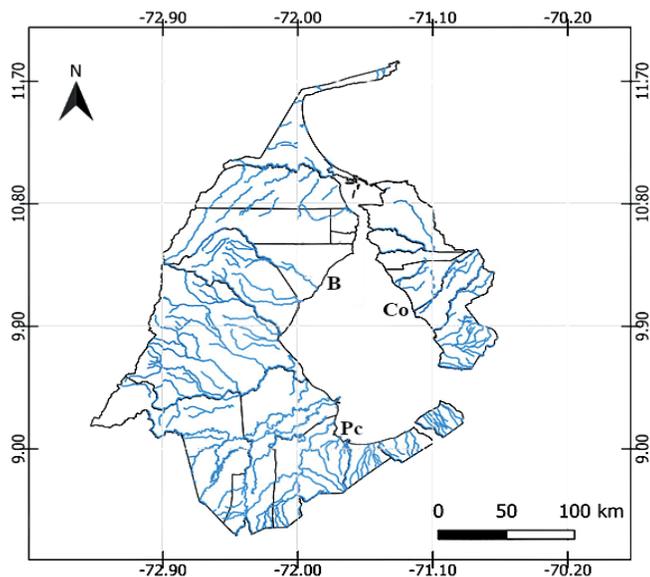

Figure 1. The Lake of Maracaibo system and the three main landing ports for blue crab (*Callinectes sapidus*). B: Barranquitas; Pc: Puerto Concha; Co: Caño La O.

Estimation of growth parameters

Monthly size frequency distributions were constructed in 0.5 cm classes to estimate growth parameters. The von Bertalanffy model (1934) is one of the most widely used representations to describe individual growth in decapod crustacean populations, using the size structure of catches (Sparre and Venema, 1995). von Bertalanffy's general equation for length growth is as follows: $L_{(t)} = L_\infty * (1 - exp^{-k*(t-t_0)})$; where: t = age in years; t_0 = theoretical age in years at zero length; Lt = total length at age t in cm; L_∞ = asymptotic length; K = curvature parameter per year.

The growth parameters L_∞, K and to were estimated by analysing monthly size distributions using the ELEFAN I routine of the FAO-ICLARM Stock Assessment Tools (FiSAT II, 2005) programme. The parameters and growth curve were estimated based on the maximum value of the goodness-of-fit index (Rn). From these parameters, the growth index Phi prima (Ø') was calculated for *C. sapidus* and comparisons were made with Ø' values reported for the species, according to the expression: $\emptyset' = \log_{10} K + 2 \log_{10} L_\infty$. To identify cohorts or groups of crabs of the same age, the monthly size

composition was used, which was analysed using the Bhattacharya's method (1967).

The existence of differences in carapace width between sexes was determined using the Mann-Whitney test, after verifying the distribution of the data with the Kolmogorov-Smirnov test and the homogeneity of variance with the Levene test in Statgraphics Centurion XVI ($\alpha = 0.05$).

Estimation of mortality rate

Total mortality (Z) was estimated from the linearised catch curve converted to sizes in Pauly's equation, previously applied in other studies in the area (Villasmil *et al*., 1997). This is a linear equation in which:

$$\frac{\ln C\,(L_1, L_2)}{t\,(L_1, L_2)} = C - Z * t\left(\frac{(L_1 + L_2)}{2}\right)$$

The most commonly used methods for estimating M in decapod crustaceans include: $M = \frac{2,996}{Lv}$.

Taylor method (1960), based on longevity (Lv) with the relationship

Rikhter and Efanov method (1976), which associate M with the age of mass maturation (Tm) of the population using: $M = \left(\frac{1,521}{Tm^{0,72}}\right) - 0,155$

Pauly method (1980), who relates M to growth parameters and average water temperature (T, in °C).

$$\log M = -0,0066 - 0,279 * \log(L_\infty) + 0,6543 * \log(K) + 0,4634 * \log(T)$$

To determine the age of mass maturation (Tm), cumulative frequency distributions of sizes were used and subsequently converted to age using the inverse von Bertalanffy equation. The average water temperature used to estimate mortality was taken from regional literature, with a value of 29 °C (Rodríguez, 2001).

Once Z and M were known, fishing mortality (F) was calculated using the relationship: $Z = M + F$; where $F = Z - M$. Since Z and M were estimated using three different methods, a matrix of F values was constructed, with Z and M as inputs, in order to obtain an F value for each possible combination.

Estimation of recruitment

Recruitment was determined from the decomposition of frequency distributions over time, using the back-calculation algorithms included in FiSAT II, which allowed the seasonality and intensity of the entry of new individuals into the exploitable fraction of the crab population in the Lake of Maracaibo to be described.

Results and discussion

Growth

Size-frequency distributions showed that males reached larger sizes than females. The size range for females ranged from 5.0 to 11.5 cm, and for males from 5.0 to 13.5 cm (Table 1).

Given the non-normal distribution of the data (Kolmogorov-Smirnov test, $p < 0.05$), the non-parametric Mann-Whitney test was applied to compare carapace width between sexes. Males had significantly higher values than females ($W = 1.41 \times 10^8$; $p < 0.0001$), with medians for males of 8.86 cm (IQR: 8.11–9.56 cm) and for females of 8.73 cm (IQR: 8.11–9.23 cm). However, the difference between the medians was small (0.13 cm), suggesting mild sexual dimorphism, likely amplified by the large sample size.

The estimated population growth parameters for the grouped sexes showed values of $L_\infty = 14.67$ cm and $K = 0.87$ yr[-1]. For females, $L_\infty = 14.36$ cm and $K = 0.80$ yr[-1] were obtained, while for males the

Table 1. Frequency distribution of *Callinectes sapidus* sizes for grouped sexes, females and males in the Lake of Maracaibo from 2010 to 2014.

Size	Sexes grouped	Females	Males
5.0	2	1	1
5.5	10	6	4
6.0	87	34	53
6.5	323	144	179
7.0	838	411	427
7.5	2,128	1,022	1,108
8.0	3,632	1,657	1,973
8.5	4,977	2,482	2,495
9.0	5,973	3,472	2,501
9.5	5,338	3,095	2,243
10.0	3,184	1,466	1,719
10.5	1,481	454	1,027
11.0	532	59	473
11.5	172	4	168
12.0	40	0	40
12.5	8	0	8
13.0	2	0	2
13.5	1	0	1
Total	**28,728**	**14,307**	**14,422**

values were $L_\infty = 14.75$ cm and $K = 0.82$ a^{-1}. These results showed slightly higher growth in males of *C. sapidus* (Figure 2).
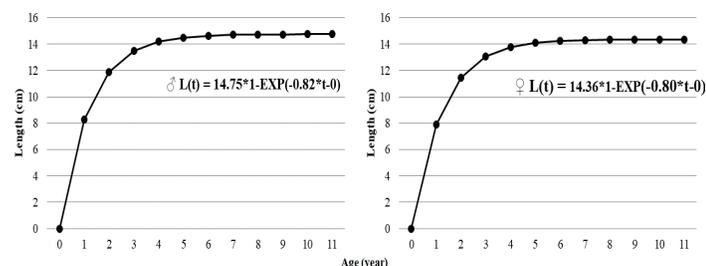
Figure 2. Growth curve for males (♂) and females (♀) of *Callinectes sapidus* in the Lake of Maracaibo, obtained using the von Bertalanffy growth equation.

The asymptotic length of females was lower, in line with previous studies in the region (Andrade de Pasquier *et al*., 2012). This sexual dimorphism represents an ecological strategy that confers adaptive advantages for the reproduction of the species. Males, reaching larger sizes and possessing larger bodies, can defend territories and compete for females, which influences sexual selection processes and the genetic structure of the population. At the population level, this differentiation reduces intraspecific competition between sexes by decreasing pressure on the same resources, which favours ecological partitioning (Marchessaux *et al*., 2023).

The growth parameters obtained for the total population allowed us to calculate a growth performance index of Ø´ = 2.27, a value that falls within the range reported for species of the same genus. Likewise, the estimates of L_∞ and K were comparable to those observed in populations of related taxa (Table 2). Consequently, the estimated growth parameters are considered consistent and adequate for stock assessment and application in fisheries management measures.

Table 2. Comparison of growth parameters for *Callinectes sapidus*.

Author	Year	Location	Sex	L_∞	K	Ø'
Villasmil *et al.*	1997	Lake of Maracaibo (VEN)	M	15.0	1.75	2.595
			F	14.7	1.55	2.525
Ju *et al.*	2001	Chesapeake Bay, USA	B	24.0	1.09	2.760
Rosas-Correa and De Jesús-Navarrete	2008	Chetumal Bay (MEX)	B	23.1	0.51	2.220
Andrade *et al.*	2011	Lake of Maracaibo (VEN)	B	16.8	0.84	2.375
Sumer *et al.*	2013	Beymelek Lake (TUR)	M	23.0	0.86	2.658
			F	18.1	1.06	2.541
Türeli *et al.*	2016	Yumurtalik Cove (TUR)	B	20.1	0.81	2.515
			M	20.9	0.50	2.315
			F	20.6	0.74	2.499
Rodríguez-Castro *et al.*	2016	Tamaulipas (MEX)	B	18.2	0.62	2.313
Mehanna *et al.*	2019	Bardawil Lake (EGY)	B	9.96	1.42	2.149
			M	9.71	1.53	2.159
			F	10.11	1.45	2.171
Presente estudio	2025	Lake of Maracaibo (VEN)	B	14.67	0.87	2.272
			M	14.75	0.82	2.251
			F	14.37	0.80	2.218

B = Both sexes, M = Males, F = Females

Mortality

The total mortality rate (Z), estimated using the Pauly method, was 7.74 yr^{-1} for both sexes combined, 6.85 yr^{-1} for males and 9.37 yr^{-1} for females (Figure 3). This difference shows that females are more vulnerable to fishing pressure than males of the same age. On average, males and females were exposed to total mortality at a size of 8.8 and 8.7 cm, respectively, and at an age of 12-13 months. These results indicate that full exploitation of the resource occurs at sizes and ages close to first sexual maturity, when individuals begin their reproductive migration for spawning.
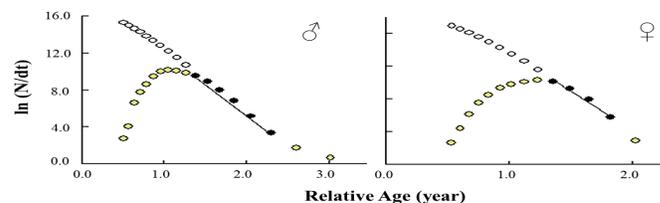
Figure 3. Estimated total mortality curve (Z) for males (♂) and females (♀) of *Callinectes sapidus*, obtained using the capture curve method, in the Lake of Maracaibo.

Natural mortality (M) estimated using the Taylor method was 0.87 yr^{-1} for both sexes combined, 0.82 yr^{-1} for females and 0.80 yr^{-1} for males. The Tm of the population was 1.05 years on average, 1.17 years for females and 1.11 years for males. The Rikhter and Efanov method yielded values of 1.20 yr^{-1} for the population, 1.25 a^{-1} for females, and 1.31 yr^{-1} for males. The Pauly method estimated higher values, 2.05 yr^{-1} for the population, 1.95 yr^{-1} for females and 1.97 yr^{-1} for males (Table 3).

Table 3. Annual estimates of total mortality (Z), natural mortality (M) and fishing mortality (F) obtained for *Callinectes sapidus* in different fisheries worldwide.

Sex	Z	M Min – Max	F Min – Max	Source
B	7.74	0.87 – 2.05	5.79 – 6.87	
M	6.85	0.80 – 1.97	4.99 – 6.05	Actual
F	9.37	0.82 – 1.95	7.50 – 8.55	
B	7.53	1.83	5.66	Andrade *et al.* (2011)
B		2.5		
M	9.7		7.2	Villasmil *et al.* (1997)
F	9.2		6.7	
B	0.85	0.66	0.19	Rosas-Correa and De Jesús-Navarrete (2008)
B	6.35	2.57	3.78	
M	5.19	2.31	2.88	Mehanna *et al.* (2019)
F	6.21	2.51	3.70	

B = Both sexes, M = Males, F = Females.

Natural mortality is an extremely critical parameter in population dynamics studies and difficult to obtain by direct methods; therefore, any applicable method represents a valid criterion for comparing estimates of natural mortality (Sparre and Venema, 1995). The M values obtained in this study, although slightly higher than those reported previously (Andrade *et al.*, 2011), remain within the estimated range (Table 3). However, fast-growing species such as *C. sapidus* have high M rates in the early stages of life (Vogt, 2019), which can compromise the renewal of the fish stock by reducing the reproductive biomass.

There is a close relationship between M and the age of first sexual maturity (Rikhter and Efanov, 1976). In *C. sapidus*, first sexual maturation occurs between 7 and 8 months of age, reflecting compensatory mechanisms associated with early sexual maturity in response to high M rates. This characteristic should be considered in fisheries management, favouring resource conservation and encouraging the use of selective fishing gear that allows individuals younger than this age to escape.

Fishing mortality (F) was estimated at 6.33 yr^{-1} for both sexes, 8.02 yr^{-1} for females and 5.52 yr^{-1} for males. In some cases, these values exceed those reported for other stocks of the genus *Callinectes* and even previous estimates in the region (Table 3). This increase in the exploitation rate suggests a recent intensification of fishing pressure compared to previous analyses, a change that could be negatively impacting the population structure and fishery yield.

Recruitment

Modal progression analysis identified one cohort for females, with an average size of 8.40 ± 0.84 cm SD, and four cohorts for males, with average sizes of: I = 7.16 ± 0.54 cm SD, II = 8.71 ± 0.77 cm SD, III = 10.09 ± 0.68 cm SD, and IV = 11.26 ± 0.49 cm SD (Figure 4). The difference in the number of cohorts may be associated with the differential distribution of the population, considering that males remain in the lake throughout their life cycle, while females migrate to permanent closed areas (Tankersley *et al.*, 1998).
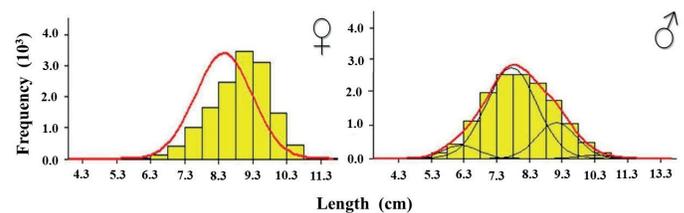

Figure 4. Modal distribution of *Callinectes sapidus* cohorts, derived from Battacharya's analysis for males (♂) and females (♀) in the Lake of Maracaibo.

Monitoring of monthly trends showed constant recruitment to the fishery throughout the year. However, two main peaks associated with the rainy season were identified; the first occurred between June and July and the second in October and November. This pattern coincides with that described for most crustaceans in tropical environments (Oliveira-Filho *et al.*, 2025) and with previous records for the Lake of Maracaibo (Andrade de Pasquier, 1999). When comparing these results with previous studies, it is confirmed that blue crab fisheries are highly dependent on the continuous influx of juveniles and are particularly vulnerable to overfishing of females.

The high temperatures characteristic of tropical water bodies increase the metabolic rate, maintaining continuous oogenesis (Azra *et al.*, 2020). However, local seasonality influences reproductive dynamics and metabolic rate, in accordance with reports by Selfati *et al.* (2025) and Young and Elliott (2020). The high variability observed in recruitment in the Lake of Maracaibo justifies the implementation of dynamic and precautionary management measures aimed at protecting recruitment periods, ensuring effective minimum sizes, and maintaining reproductive biomass.

Conclusions

The population dynamics of C. *sapidus* in the Lake of Maracaibo were characterised by a short life cycle and rapid growth, with slight differences between sexes. Males showed slightly higher growth parameters, reaching greater asymptotic lengths and growth rates than females. The population entered the fishery at an early age, between 7 and 8 months, and was fully exploited between 12 and 13 months, when individuals reached sizes close to 8.7-8.8 cm. This pattern coincided with the onset of reproductive displacement, indicating that a significant fraction of the stock was captured at stages close to sexual maturity, posing a risk to population renewal. Individuals ceased to be part of the stock at 24 months and with sizes greater than 12.0 cm. The growth parameters of C. *sapidus* showed variations with respect to previous assessments, evidenced by a decrease in the asymptotic length of the population.

Total mortality estimates showed high values, particularly in females, which had higher rates than males. Likewise, fishing mortality reached high levels in both sexes, exceeding previous records for the region and for other stocks of the genus *Callinectes*, indicating a recent increase in fishing pressure.

Recruitment remained continuous throughout the year, with two peaks associated with the rainy season, confirming the fishery's high dependence on annual recruitment and the constant influx of juveniles. The combination of high mortality rates, early exploitation and continuous recruitment suggests that the stock is highly vulnerable to overfishing, especially in females.

Overall, the estimated growth, mortality and recruitment parameters are considered consistent and adequate for the assessment of the *C. sapidus* stock in the Lake of Maracaibo, and constitute a solid basis for the design and implementation of management measures aimed at the sustainability of the resource.

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