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Relative Growth and Size Structure of *Achelous spinicarpus* Stimpson, 1871 Associated with Shrimp Trawling in the State of Veracruz

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Abstract: The objective was to analyse the relative growth and size structure of *Achelous spinicarpus* associated with trawling in Veracruz. The organisms came from shrimp trawls carried out in July 2013. There were 45 trawls organized in two depth intervals (B: 22 to 46 m and C: >46 m) and 14 fishing quadrants. Abundance, mean and standard deviation, by sex and depth interval, and sex ratio were determined. An ANOVA was applied to compare CW means, depth intervals and fishing quadrants. The CW-weight relationship was obtained, and growth type was also determined. Length-frequency analyses were carried out. A total of 2377 crabs were collected, 1164 males and 713 females. The overall average CW was 3.65 ± 0.7677 cm, the minimum value was 1.50 cm, and the maximum was 6.00 cm. For males, the average CW was 3.65 ± 0.8242 cm, with1.50 cm minimum value and 6.00 cm maximum value. The average CW of females was 3.64 ± 0.6164 cm, with 1.60 cm minimum value and 5.90 cm maximum value. There were no statistically significant differences in CW between males and females. However, there were significant differences between depth intervals (B and C) for the total and sex CW data. The sex ratio was 2.94:1 and 2.05:1 for depth intervals B and C, and 2.33:1 for the total data set. Growth type was allometric negative for both sexes and overall, with significant differences in slopes between sexes. There was a unimodal pattern for the two fishing depth intervals and for each sex; crabs were between 2.40 and 4.00 cm (77.64%) and between 2.56 and 5.12 (91.12%) for the B and C intervals, respectively. In males, 88.46% were between 2.40 and 4.80 cm, and 90.46% of females were between 2.72 and 4.64 cm. *Achelous spinicarpus* is an essential species in the structure of the brachyuran assemblage and in benthic communities, as well as a food resource for various species of demersal fish. Thus, the present study provides information on the population subjected to the impact of fishing activity in the area, allowing comparisons between different populations in the species' area of distribution.

Keywords: growth; size; Portunidae; *Achelous spinicarpus*

1. Introduction

The long-spined swimming crab *Achelous spinicarpus* Stimpson, 1871 is an abundant and important crab in the structure of the Western Atlantic brachyuran crab assemblage, as a dominant species and with a high frequency in the accompanying fauna of shrimp trawling. They are considered key organisms in the food web, acting as predators of several invertebrate groups and as prey for several fish species [1–8]. Bycatch in shrimp trawls is an important source of induced mortality, which may be a factor in the medium- to long-term declines of the *A. spinicarpus* population [6,9].

Long-spined swimming crabs are widely distributed in the western Atlantic, from North Carolina to Sao Paulo, Brazil, ranging from shallow areas to 550 m depth, inhabiting sand, gravel, shell and mud bottoms, and is one of the most abundant species in the Gulf of Mexico [10–15]. Information on its biology, ecology and growth is scarce. In this regard, the most outstanding are the works on morphometry and relative growth in the Gulf of Mexico by Sanvicente-Añorve [14]; Aspects of the biology in the Gulf of Salamanca, Colombia by García and Mendoza [5]; and relative growth and population structure on the coasts of Brazil by Ogawa and D'Incao [16], Pardal-Souza and Pinheiro [6,17], Silva et al. [18].

The analysis of relative growth in crustaceans aims to assess the relationship between biometric variables and has been a common practice in the study of brachyuran crab populations such as *Arenaeus cribrarius* [19], *Achelous spinimanus* [20] and *Achelous spinicarpus* [6,14]. Similarly, the analysis of size structure provides an important complement to population studies and its relationship with environmental variables to determine the state of the population at a given time [21,22]. Furthermore, weight increment and its relationship to carapace width in brachyurans can be used to analyse population changes across geographic areas and depths by determining the type of growth and structure of populations [23]. This type of analysis can be useful for studies on the life history of the species when comparing females with males or comparing different areas and depths of capture, as differences may be associated with physiological and ecological factors [24,25].

Trawling areas present seabed modifications, which have repercussions on species richness, distribution patterns and abundance of the organisms that inhabit them, as well as on some population parameters such as size, growth type and sex ratio [7,15]. Thus, the main objective of this research was to evaluate the growth rate, sex ratio and size-frequency distribution of *A. spinicarpus*, obtained as a shrimp accompanying fauna, in the south-central portion of the coast of Veracruz, given that it is a region where the shrimp fishery occurs and where *A. spinicarpus* is a dominant species in the association of species that make up the trawl fishery, in addition to its importance in the food chain and community structure of the seabed. Therefore, studies of this type provide information on the dynamics of the population subject to the impact of fishing activity in the area and allow for comparative studies between different populations in the species' area of distribution.

2. Materials and Methods

Crabs were obtained from the shrimp accompanying fauna (SAF). The trawl area was located on the continental shelf of the southwestern section of the Gulf of Mexico, extending from the port of Alvarado (18°47′42.94″ N, 95°44′43.87″ W) to the port of Coatzacoalcos (18°10′50.16″ N, 94°25′11.51″ W), both in the state of Veracruz (Figure 1). The shrimp trawl zone where the catches were obtained is characterized by the discharge of several coastal lagoons and estuaries, the Alvarado lagoon system and the Papaloapan River predominate. This deltaic system plays an important role in contributing terrigenous elements and organic matter to the continental shelf [26–28]. The type of bottom and sediment in the fishing zone is dominated by flat bottoms made up mostly of mud and sand, due to discharges from the lagoon and estuarine systems. The fishing zone presents irregular bottoms with the presence of consolidated sediments and rocky bottoms with materials of alluvial and marine coastal origin [29,30].

The climate of the area is described, according to García [31], as warm subhumid with rainfall between June and September and an average annual temperature of 26.4 °C. According to Carrillo et al. [32] the climatic pattern is defined by three seasons: the dry season (March to June), the rainy season (July to September) and the cold fronts (October to March).

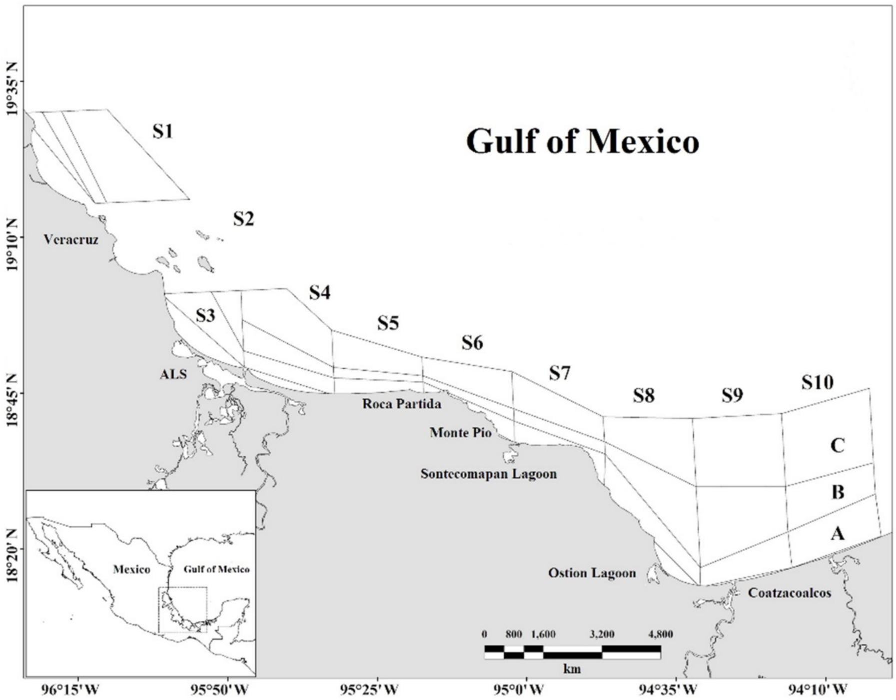

Figure 1. Study area, taken from Morán-Silva et al. (2021).

The crabs were obtained as part of the shrimp accompanying fauna capture, as a result of 45 trawls carried out in 20 fishing days in the month of July 2013, rainy season, combined with the research cruises of the Regional Center for Fisheries Research Veracruz-INAPESCA (CRIP Veracruz-INAPESCA). The depth strata were defined by the captain of the ship, who, according to his experience in the capture area, decides the course of the ship and the towing areas, trying to cover most of the quadrants described. The catches were made within the quadrants established by the National Fisheries Institute [33], covering 14 quadrants and two depth intervals: B (22 to 46 m) and C (>46 m) arranged in a northeast-southeast axis on the south-central coast of the state of Veracruz according to Morán-Silva et al. [15] (Figure 1).

The catch of 45 trawls located in 14 fishing quadrants was analyzed, corresponding to the interval B the quadrants S1B, S3B, S4B, S5B, S6B, S7B, S9B and S10B; and for interval C the quadrants S3C, S4C, S5C, S6C, S7C and S8C (Figure 1). The crabs were caught during commercial fishing operations: night trawls, with an average duration of 4 h and speed of 3 knots per hour, using a 20 m Japanese type trawl, with a 9 m aperture and a 1.75 mesh size.

Crabs were obtained from a 4 kg sample of discarded fauna taken from each trawl [15]. The collected organisms were washed, placed in polyethylene bags and frozen. The organisms were identified in the laboratory using the criteria described by Williams [11], Felder [34] and Hernández-Aguilera and Sosa-Hernández [35]. Sex was obtained for each organism from the shape of the abdomen and telson [36]. For each organism, weight (W) was recorded with a digital scale and carapace width (CW) from the base of the anterolateral spines, with vernier calipers accurate to 0.1 mm.

The Shapiro-Wilk normality test was applied to evaluate each data set [37]. Abundance, mean and standard deviation by sex and depth interval were then determined. An analysis of variance (ANOVA) was applied to compare means of carapace width by sex, depth intervals and fishing quadrants [37].

The width-weight relationship (CW-W) was obtained for the total number of individuals and for each sex, through the potential model [38], taking CW as an independent variable (x) to determine the allometry of the growth type (b) through the model:

$$W = aCW^b$$

where:

W = Weight

CW = Carapace Width

b = slope (degree of allometry)

Allometric growth rate by sex was determined based on the value of slope (b), and a *t*-Student test (α = 0.05) was used to evaluate the observed values of slope (b) and to establish differences in growth between sexes [37].

The overall sex ratio was determined by depth intervals and fishing quadrants and a *chi-square* test (α = 0.05) was used to compare statistically the observed sex ratios with theorical 1:1 ratio to confirm the bias towards males [37].

For the size-frequency analysis of the total number of organisms and by sex, the kernel density estimator (KDEs) with Gaussian function was used, using the programs written by Salgado-Ugarte et al. [39–41]. These include the efficient algorithms of the average shifted histograms (M = 10) and the weighted average of the rounded points. Similarly, the Silverman [42] smoothed bootstrap test was applied with 200 repetitions in addition to the Silverman's rule of thumb or optimal bandwidth using specific programs presented in Salgado-Ugarte [43] and Salgado-Ugarte et al. [44] with the statistical package Stata 9.1 [45]. All of the above were used to determine the length class interval and for its subsequent verification of the modal peaks, following the criteria of representativeness of the population proposed by Gómez-Marquez et al. [46].

3. Results

A total of 2377 crabs were collected, of which 1164 were males and 713 were females, where 890 crabs corresponded to depth interval B and 1487 to interval C. The overall average carapace width (CW) was 3.65 ± 0.7677 cm, with a minimum value of 1.50 cm and a maximum value of 6.00 cm. For males, the average CW was 3.65 ± 0.8242 cm, with a minimum value of 1.50 cm and a maximum value of 6.00 cm. For females, the average CW was 3.64 ± 0.6164 cm, with 1.60 cm as the minimum value and 5.90 cm as the maximum value (Table 1). There were no statistically significant differences in size between males and females ($t_{(0.05;\, g.l. = 2375)} = 1.96$, $p = 0.7642$). There were, however, differences between the two depth intervals (B and C) for the total CW data set ($t_{(0.05;\, g.l. = 2375)} = 1.96$, $p < 0.001$). Similarly, for males there were significant differences in carapace width (CW) between depth intervals ($t_{(0.05;\, g.l. = 1662)} = 1.96$, $p < 0.001$); the same was true for females ($t_{(0.05;\, g.l. = 711)} = 1.96$, $p < 0.001$). Mean CW values and standard deviation by sex, depth interval and quadrant are presented in Table 1.

Table 1. Total number of crabs (*n*), sex ratio (M:F), Mean value and standard deviation (Mean ± S.D.), Minimum value (Min), Maximum value (Max) and number of crabs for carapace width (CW) and weight (W) for total crabs (General), by sex, trawl depth intervals (Interval B and C) for *Achelous spinicarpus*.

			CW (cm)			**W (g)**		
	n	**M:F**	**Mean ± S.D.**	**Min**	**Max**	**Mean ± S.D.**	**Min**	**Max**
General	2377	2.33:1	3.65 ± 0.7677	1.50	6.00	3.84 ± 2.0771	0.4	17.5
Males	1664		3.65 ± 0.8243	1.50	6.00	3.89 ± 2.262	0.4	17.5
Females	713		3.64 ± 0.6164	1.60	5.90	3.74 ± 1.559	0.7	11.3
Depth								
Interval B	890	2.94:1	3.46 ± 0.7217	1.50	5.80	3.50 ± 1.9477	0.6	15.4
Males	664		3.45 ± 0.7649	1.50	5.80	3.48 ± 2.0704	0.6	15.4
Females	226		3.48 ± 0.5788	2.00	5.10	3.34 ± 1.5247	0.8	10
Interval C	1487	2.05:1	3.76 ± 0.7738	1.60	6.00	4.04 ± 2.1253	0.4	17.5
Males	1000		3.78 ± 0.8376	1.70	6.00	4.16 ± 2.3434	0.4	17.5
Females	487		3.71 ± 0.6213	1.60	5.90	3.81 ± 1.5644	0.7	11.3

Sex ratios (M:F) obtained for depth intervals B and C were 2.94:1 and 2.05:1, respectively, and the sex ratio was 2.33:1 for the entire data set (Table 1), with the highest value corresponding to depth interval B. With respect to the fishing quadrants, quadrant S4B was the highest with 8.57:1; the lowest was quadrant S6B with 1.34:1 (Figure 2), in all cases highlighting that the abundance of males was higher than that of females ($p < 0.001$), except for quadrant S1B ($p > 0.073$) and quadrant S6B ($p > 0.072$).

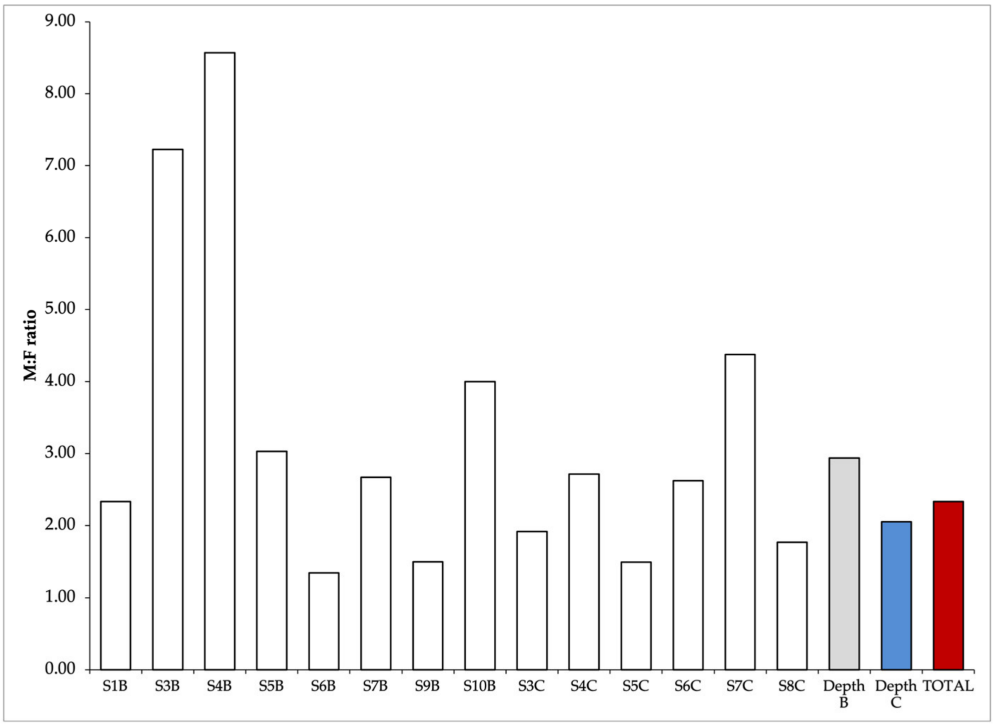

Figure 2. M:F ratio obtained by fishing quadrant, depth interval and total for *Achelous spinicarpus*.

The correlation coefficients were statistically significant ($p < 0.001$), while the growth rate obtained through the CW and W ratios were negative allometric for both sexes and overall, with significant differences in the slopes between both sexes ($t_{(0.05;\ g.l.\ =\ 2375)} = 1.96$, $p < 0.05$) (Table 2; Figure 3).

Table 2. Parameters of the relationship between carapace width (CW) and weight (W) for *Achelous spinicarpus*, overall and by sex, number of crabs (*n*), ordinate to the origin (a), slope (b), standard error of slope (SE) and correlation coefficient (R^2).

	n	Equation $W = aCW^b$	a	b	SE (b)	R^2
General	2377	$W = 0.1507CW^{2.4132}$	0.1507	2.4132	0.5379	0.5421
Males	1664	$W = 0.1473CW^{2.4523}$	0.1473	2.4523	0.5221	0.6672
Females	713	$W = 0.1470CW^{2.4421}$	0.1470	2.4421	0.3674	0.5956

With respect to the size-frequency analysis (CW), the interval obtained was 0.16 cm, presenting a unimodal pattern for the two fishing depth intervals and for each sex; most of the crabs for the depth interval B were located between the sizes of 2.40 to 4.00 cm (77.64%) and for depth interval C between 2.56 and 5.12 (91.12%), while for males 88.46% were between 2.40 and 4.80 cm, and 90.46% of females were between 2.72 and 4.64 cm (Figure 4).

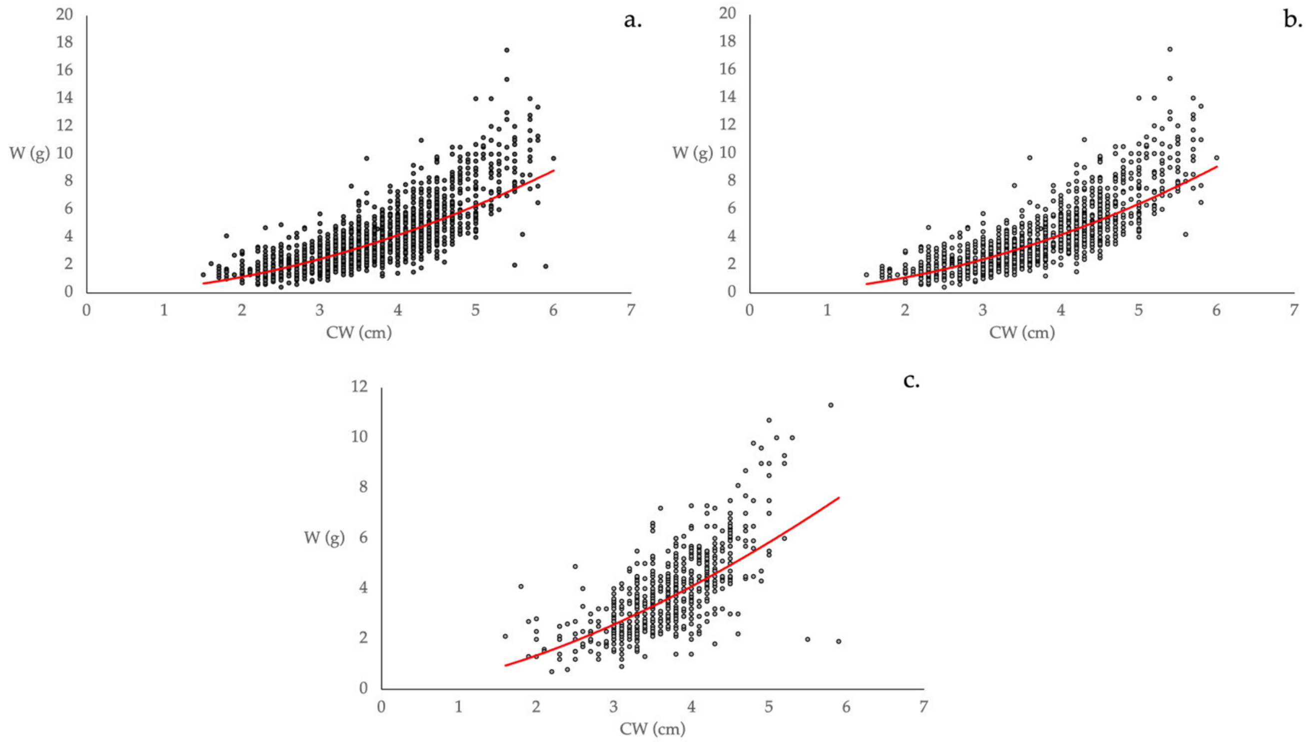

Figure 3. Scatter plot of points corresponding to the CW (carapace width) and W (weight) ratio, for *Achelous spinicarpus*. (**a**) total number of crabs, (**b**) males and (**c**) females.

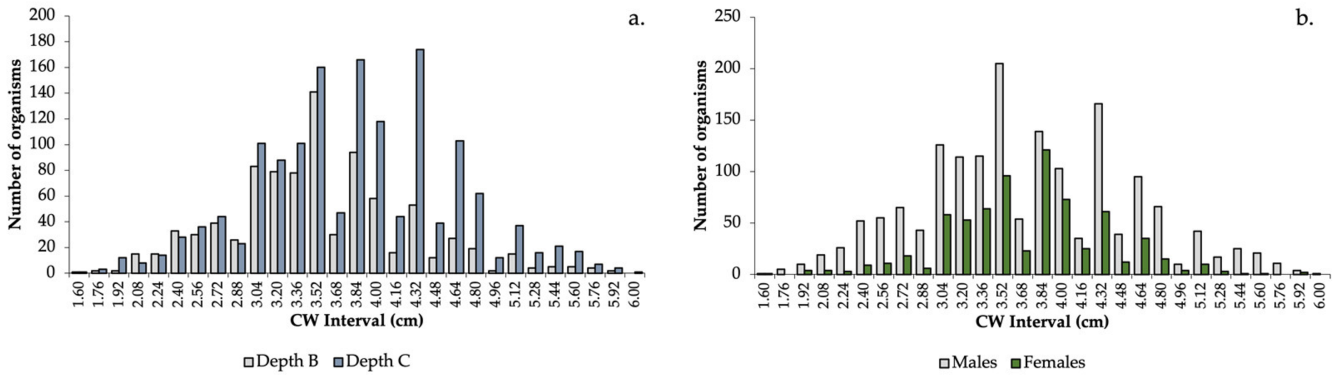

Figure 4. Length frequency histogram obtained by depth (**a**) and sex (**b**) intervals for *Achelous spinicarpus*.

4. Discussion

Most studies on decapod crustaceans in the Gulf of Mexico have focused on commercially important species [47]. The studies are associated with the shrimp trawl fishery because brachyuran crabs form part of the shrimp's accompanying and discarded fauna, as they share the same habitat. This habitat is characterized by soft-bottom areas associated with coastal zones with the presence of lagoon and estuarine systems; they are also habitats used by these organisms as breeding and nursery areas [15,48,49].

Achelous spinicarpus was found in both depth ranges in the present study; however, most organisms were found at depths greater than 46 m, areas with less influence from the discharge of the lagoon systems in the area. This contrasts with that reported by Lima et al. [50] for the Ubatuba region, where *A. spinicarpus* was found in the 25 to 40 m depth range and was more abundant at 35 m. However, the distribution coincides with that reported by Pires [51], who recorded the highest abundances at depths of 50 m.

No differences were found between depth intervals for maximum carapace width in *A. spinicarpus*, which may be a consequence of the influence of discharges from lagoon systems throughout the sampling area, as mentioned by Hajjej and Jarboui [22]. The variation in carapace width recorded in the present study is consistent with that observed by Holthuis [52] in different populations ranging from Florida to French Guiana and observations by Sanvicente-Añorve et al. [14] in the southeastern Gulf of Mexico.

In disagreement with other species in the family Portunidae, where females mature earlier than males, showing marked sexual dimorphism [53,54], *Achelous spinicarpus*, did not differ in carapace width between sexes, which may indicate the absence of a marked sexual dimorphism and is in agreement with Pardal-Souza and Pinheiro [17] and Silva et al. [18], who mention that some portunids, as is the case of *A. spinicarpus*, show a similar maturation size between sexes. Therefore, it should be considered that by failing to trawl in areas shallower than 20 m depth, juvenile and smaller organisms will not be caught, as these can only be found in the adjacent coastal area [55].

The carapace width sizes in the present study were smaller than those reported by Sanvicente-Añorve et al. [14] in the southeastern Gulf of Mexico, as well as the size distribution, as most of the organisms were between 2.40 to 4.80 cm in males and 2.72 to 4.64 cm in females, contrasting with the 4.00 to 5.00 intervals reported. Similarly, García-Montes et al. [12] reported for the Gulf of Mexico that most of the organisms caught were in the 4.00 to 5.00 cm size class. The sizes described in the present work suggest that the population studied was mostly composed of immature organisms. This takes into account that crabs are recruited to the adult population at around 1.30 cm for the southeastern Gulf of Mexico [14] and 3.70 and 3.20 cm for males and females, respectively, in Brazil [56], the fact that no ovigerous females were found at the time of capture and the effect of the selectivity of the fishing gear.

In addition to the above, it should be noted that no significant differences were found in the average carapace width between males and females, but there were differences in the average weight by sex, indicating that males are slightly more robust than females, a common situation among portunids. This is a result of the differential allocation of energy to somatic growth in males, while females divert much of their energy to gonadal maturation and egg production [16,17,57].

Another point to consider is the fact that a greater presence of males was recorded, both in depth intervals and fishing quadrants, which is consistent with that reported by Ogawa and D'Incao [16], Silva et al. [18] and De-Carli [25] in Brazil and Garcia-Mendoza [5] for Colombia. This is related to the division of habitat by sex, where there is a spatial segmentation in the sex ratio, with females migrating to areas of higher salinity, depth and lower temperature, suitable for egg hatching [48,58].

On the other hand, and according to the growth parameters, *Achelous spinicarpus* showed an allometric negative type of growth in general and by sex, characterized by rapid growth from the intermediate stage onwards. This contrasts with the growth described by Mendoza-Castro [59] in the Gulf of Salamanca, Colombia, who described the growth of *A. spinicarpus* as isometric and with Sanvicente-Añorve et al. [14] who reported isometric growth for this species in the southeastern Gulf of Mexico.

The slope values (b) obtained from the equations of the carapace width and weight relationship for *A. spinicarpus* were below 2.5, which may be an effect of the selectivity of the fishing gear that allows the capture of crabs of a certain size, as well as of the trawling areas and climatic seasonality that did not allow the capture of a greater variety of sizes [23]. The growth and longevity of some decapods, in the case of *A. spinicarpus*, clearly depend on the latitude and local environmental conditions, as suggested by Sanvicente-Añorve et al. [14].

The analysis of the distribution of length class frequencies showed a unimodal pattern, both for the total data set and for both sexes, which contrasts with what was found in the region of Ubatuba and Caraguatatuba, Brazil [18] where bimodal and polymodal patterns were reported, respectively. The unimodal pattern may be the result of sampling and seasonality because the crabs were only sampled during the rainy season, taking into account that the presence of bimodal and polymodal patterns are a consequence of recruitment pulses, differential mortality or differences in the behavior of crabs, resulting from sex segregation and reproductive processes [60]. Similarly, differences may be due to the location of haul-out areas, considering that some portunid species move for feeding or reproduction, giving rise to segregated population portions [25,61,62]. Thus, reproduction must be synchronised with environmental conditions. An example of this is the case of *Callinectes ornatus* (Ordway, 1863) whose females migrate to areas further from the coast to disperse their larvae, while a few males with developed gonads follow them and others remain near the coast in shadier areas, to ensure mating with primiparous females [50].

Finally, it should be considered that *A. spinicarpus*, as one of the species with a high frequency and relative abundance [3,15,56,63], is an essential species in the structure of the brachyuran assemblage and in benthic communities, as well as a food resource for several species of demersal fish [8,64–66].

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