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ARTICLE

Population dynamics of the swimming crabs *Callinectes* (Portunidae) components of shrimp bycatch in the eastern coast of the Gulf of California

Dinámica poblacional de jaibas *Callinectes* (Portunidae) componentes de la fauna de acompañamiento del camarón en la costa oriental del Golfo de California

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Resumen.- Se reportan por primera vez aspectos de la dinámica poblacional de 3 especies del género *Callinectes*: *C. arcuatus*, *C. bellicosus* y *C. toxotes* capturadas incidentalmente por la flota camaronera en la costa oriental del Golfo de California entre 10 y 77 m de profundidad de septiembre 2004 a marzo 2005. Se analizaron crecimiento, longevidad, patrón de reclutamiento, tasas de mortalidad y explotación para las 3 especies. Además, se realizó una comparación de tallas entre los organismos capturados por la flota camaronera y la flota ribereña. *Callinectes arcuatus* (n = 737) fue más abundante que las otras 2 especies (*C. bellicosus*, n = 291 y *C. toxotes*, n = 344). Se detectaron diferencias significativas entre las distribuciones de tallas de *C. arcuatus* y *C. bellicosus*; la flota camaronera extrae mayormente organismos de ambas especies entre 50 y 120 mm ancho de caparazón (AC), mientras que la ribereña de 75 a 155 mm. Los parámetros de crecimiento fueron moderados (L_{∞} = 160, 173 y 168 mm y K = 1,1, 1,3 y 0,9 año⁻¹ para *C. arcuatus*, *C. bellicosus* y *C. toxotes*, respectivamente), con una longevidad estimada para las 3 especies de 4 años. El patrón de reclutamiento muestra un periodo continuo, con un máximo entre mayo y agosto. La tasa de explotación no indica un grado significativo de sobreexplotación para ninguna especie. Se encontraron diferencias en parámetros de la dinámica poblacional (tallas, crecimiento) de estas especies basados en datos de capturas comerciales y los obtenidos con datos de capturas incidentales. Es importante realizar un análisis donde se incluyan los dos tipos de información para un adecuado manejo pesquero de estos recursos.

Palabras clave: *Callinectes*, dinámica poblacional, fauna de acompañamiento, Golfo de California

Abstract.- Population dynamics of 3 *Callinectes* species: *C. arcuatus*, *C. bellicosus*, and *C. toxotes* are reported for the first time as incidental shrimp bycatch samplings captured in the eastern Gulf of California in a range from 10 to 77 m in depth from September 2004 to March 2005. Growth, longevity, recruitment pattern, mortality (natural, total, and by fishing), and exploitation rate were analyzed. Also, size comparison among the organisms captured by the shrimp and artisanal fishing fleets was calculated. *Callinectes arcuatus* (n = 737) was more abundant than the other two (*C. bellicosus*, n = 291 and *C. toxotes*, n = 344). Significant differences were shown between size distribution of *C. arcuatus* and *C. bellicosus* captured by the 2 fleets; the shrimp fleet extracted mainly organisms in sizes ranging from 50 to 120 mm in carapace width (CW), while the artisanal fleet extracted sizes from 75 to 155 mm in CW from both species. Growth parameters were moderate (L_{∞} = 160, 173, and 168 mm; K = 1.1, 1.3 and 0.9 year⁻¹ for *C. arcuatus*, *C. bellicosus*, and *C. toxotes*, respectively), estimating a 4-year longevity for the 3 species. The reproductive recruitment pattern showed a continuous period with a peak from May to August. The exploitation rate did not show a significant degree of overexploitation for any of the species. There are some differences in the parameters of population dynamics (sizes, growth) of this species based on data from commercial captures and those obtained with data of incidental captures. It is important to perform an analysis including both types of information for an adequate fishery management of these resources.

Key words: *Callinectes*, population dynamics, bycatch fauna, Gulf of California

INTRODUCTION

Swimming crab species of the genus *Callinectes* Stimpson, 1860 are distributed along the Neotropical Atlantic, Eastern Tropical Pacific, and the Tropical West Africa coast (Williams 1974). Fischer & Wolff (2006) mention the existence of 14 *Callinectes* species in both American coasts, of which 11 are registered in tropical and subtropical waters.

These crabs inhabit the coastal areas and depend on lagoon and estuary systems. They have a complex life cycle comprising planktonic, nekctic, and benthic stages, which take place in these systems and close to the marine area (Ramírez-Félix *et al.* 2003). Swimming crabs have a priority role in the trophic web and are characterized by great recruitment, sexual maturity at an early age, accelerated growth, high rates of natural mortality, and a short life cycle (Van Engel 1990).

Ecology, life cycle, and population dynamics of these crabs in the eastern Pacific are poorly understood. Lack of knowledge on these resources that constitute the basis of important commercial fisheries in several regions of the eastern Pacific has practical implications. One example is the crab fishery that has been performed in Mexico for more than 20 years and is one of the most important as to generating jobs and currency. In 2010, this fishery had a value of 239 million pesos, representing 2.21% of the fishery production value in the country (SAGARPA-CONAPESCA 2011). The production of this resource was 20,262 ton live weight, of which 10,758 ton corresponded to the Pacific coast and 9,505 ton to the Gulf of Mexico and the Caribbean Sea. From the Pacific side, the production of the Gulf of California that stands out is a contribution of the states of Sinaloa (6,107 ton) and Sonora (4,073 ton) (SAGARPA-CONAPESCA 2011). The captures in the Gulf of California are composed mainly of 3 species: green crab (*Callinectes bellicosus*) that stands out for its larger volumes compared with the blue (*C. arcuatus*) and the giant (*C. toxotes*) swimming crabs.

To capture these species off the Gulf coastline states, 2 types of fishing gear are used: (1) hoops - metal structures with a woolen cloth mesh (Sinaloa and Nayarit); and (2) metal fishing traps - cube-shaped, hexagonal metal mesh plastic-coated, with 2 entrances and a cylinder in the middle for bait (rest of the Gulf) (Ramírez-Félix *et al.* 2003, DOF 2006)¹.

Works performed on *Callinectes* crabs in the Gulf of California have dealt mainly on size, longevity, and growth (Nevárez-Martínez *et al.* 2003, Hernández & Arreola-Lizárraga 2007, Reyes-Benítez *et al.* 2007, Rodríguez-Domínguez *et al.* 2012), reproductive period (Paul 1982a, Nevárez-Martínez *et al.* 2003), abundances and seasonal capture (Villarreal-Chávez 1992, Escamilla-Montes 1998, Molina-Ocampo *et al.* 2006), ecology (Arreola-Lizárraga *et al.* 2003, Ramírez-Félix *et al.* 2003, Molina-Ocampo *et al.* 2006), and population genetics (Ramírez-Félix *et al.* 2003, Pfeiler *et al.* 2005). These works have focused exclusively on analyzing the information obtained in commercial captures of artisanal fishery without knowing how the population fraction found in deeper areas is integrated.

Considering that a migration from shallow waters to open seas occur in *Callinectes* spp. (with reproductive purposes) (Molina-Ocampo *et al.* 2006), away from where the commercial captures of artisanal fishery are obtained and due to the high selectivity of the capture methods used (traps), it is possible to consider the hypothesis that a portion of the population is not available for artisanal fishery. Therefore, some aspects of the population dynamics (mortality, growth, exploitation, etc.) have been partially addressed in the works cited above, but knowing all the parts of the population dynamics of these resources is imperative for proper fishery management.

From an economic and ecological point of view, *Callinectes* crabs are important in the Mexican Pacific and specifically in the Gulf of California. However, some aspects are still unknown, such as mortality rates, exploitation level, and sizes, among other aspects of these species incidentally captured in shrimp trawling. Therefore, the objective of this work was to study the population dynamics of *C. arcuatus*, *C. bellicosus*, and *C. toxotes* in the eastern Gulf of California where mortality rates and exploitation level of these 3 species captured incidentally by shrimp trawling fleet at depths from 10 to 77 m are assessed for the first time.

MATERIALS AND METHODS

STUDY AREA AND SAMPLING DESIGN

The study area comprises the eastern portion of the Gulf of California between 21°13'37"N, 105°16'06"W, and

¹DOF. 2006. Norma Oficial Mexicana NOM-039- PESC-2003, Pesca responsable de jaiba en aguas de jurisdicción federal del litoral del Océano Pacífico. Especificaciones para su aprovechamiento. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, México, 9 pp.



Figure 1. Sampling stations during the 2004-2005 shrimp fishing season in the Gulf of California and main sites where crab capture is recorded / Estaciones de muestreo durante la temporada de pesca camaronera 2004-2005 en el Golfo de California y principales lugares donde se registra la captura de jaiba

31°24'35"N, 114°22'51"W, throughout the continental shelf covering the states of Sonora, Sinaloa, and Nayarit (Fig. 1).

The samplings were performed through the 'Onboard Observers' program integrated by 10 technicians, each one on board a shrimp fishing ship from the state of Sonora, México during the 2004-2005 shrimp season that started in August 2004 and finished in March 2005. These ships trawled variable depths (10 to 77 m) in a station network located mainly in the fishing areas of commercial shrimp fleet at a speed of $\sim 5.5 \text{ km h}^{-1}$ (Fig. 1) from 3 to 5 h. The fishing gear utilized was mixed nets, operating one per band at both sides of the ship; mesh size was 5.71 cm in the net body and 3.81 cm in the bag, the official minimum size permitted. Each haul produced approximately 20 kg of samples without selection; sampling size was determined following standard criteria (Box *et al.* 2008). The samples were tagged with the proper data of the throw and frozen for later analysis.

Identification and processing of the biological material were performed in the Fisheries Laboratory of Centro de Investigaciones Biológicas del Noroeste (CIBNOR, S.C.) at Guaymas, Sonora. Samples were separated by groups of organisms, and crabs were taxonomically identified using Rathbun (1930) and Hendrickx (1984, 1995) keys.

BIOMETRICS, BIOMETRICAL RELATIONS, AND SEX PROPORTION

Each identified specimen was measured in carapace width (CW), which is the distance between the antero-lateral spines with a 0.1-mm precision vernier besides recording its total weight (W) and sex. The existing relationship between the number of females and males in each one of the species and their weight/length relationship were determined by using the potential model $W = a (CW)^b$ where W is the organism's total weight in grams; CW is the carapace width in millimeters; *a* is a regression constant; and *b* is the regression coefficient. The

regression coefficient was statistically evaluated by the Student's t-test (Zar 1999) to determine the growth type the species showed: if $b = 3$, growth is isometric, and if $b \neq 3$, growth is allometric (Ricker 1975).

SPECIES LATITUDINAL AND BATHYMETRIC DISTRIBUTION

The graphic latitudinal and bathymetric distribution of the 3 crab species were obtained with information of the geographical coordinates and depth where each tow was performed.

SIZE STRUCTURE, GROWTH, AND LONGEVITY

Size structures were obtained monthly in 5 mm-CW intervals of the 3 species and were used to estimate growth adjusted to the von Bertalanffy seasonal model

$$L_t = L_\infty \left[1 - e^{\left(-k(t-t_0) + C(K/2\pi) \sin 2\pi(t-ts) \right)} \right]$$

where L_t is carapace width (CW) at time t ; L_∞ is the organism's asymptotic size; K is growth coefficient (annual); C is growth amplitude; WP is winter point ($= ts + 0.5$), time when growth is minimum; ts is summer point ($=$ maximum growth rate); t_0 is time when the organism has size zero.

The L_∞ seed values were calculated using the Powell-Wetherall method (Powell 1979, Wetherall *et al.* 1987) and K by the New Shepherd's Length Composition Analysis, NSLCA (Shepherd 1987, Pauly & Arreguín-Sánchez 1995) method. The final parameters were estimated by the size frequency electronic analysis (ELEFAN I). The third parameter equation value (t_0) was obtained by using the empirical equation proposed by Pauly (1980): $\log(-t_0) = -0.3922 - (0.2752 * \log L_\infty) - (1.038k * \log K)$. The von Bertalanffy equation was used to obtain the growth curves of the 3 crab species. With the purpose of evaluating significant differences in growth between the three species, the growth performance index ϕ' (Pauly & Munro 1984) was determined following the equation:

$$\phi' = \log_{10} K + \log_{10} L_\infty$$

Longevity was estimated by the equation proposed by Taylor (1962): $t_{max} = 3/K + t_0$; where t_{max} is longevity, K growth coefficient, and t_0 is hypothetical time when the organism has size zero.

RECRUITMENT PATTERN

To obtain the recruitment pattern (faithful estimate of possible birth dates of the organisms in the captures) the method ELEFAN II (Electronic Length Frequency Analysis II) (Gayanilo *et al.* 1995) was used. This method shows the longitude frequencies in the captures backwards along the time axis, thus obtaining their likely birth dates.

MORTALITY (NATURAL, BY FISHING, TOTAL) AND EXPLOITATION RATE

Natural mortality (M) was estimated using Pauly's (1984) empirical equation:

$$\ln M = -(0.01529) - 0.279 * \ln(L_\infty) \dots \\ \dots + 0.6543 * \ln(K) + 0.463 * \ln(T)$$

where L_∞ (mm) and K (annual) von Bertalanffy are equation parameters, and T is the annual mean temperature of the habitat measured in °C (22°C). The instant total mortality coefficient (Z) for each species was estimated by the lineal curve method converted to longitude: $\log(Ni/\Delta ti) = a + b * ti$ where Ni is the number of organisms in longitude i ; Δti is the necessary time for the organism to grow in longitude i from one class to the other; t is the relative age in which the class longitude mean i is reached; and b is an estimate of Z (Gayanilo *et al.* 1995).

The difference between the instant total mortality coefficient (Z) and that of natural mortality (M) is mortality by fishing (F): $F = Z - M$. While exploitation rate (E) was estimated as: $E = F/Z$ where values higher than 0.5 reflect overexploitation, and lower ones reflect under-exploitation (Sparre & Venema 1995).

COMPARING SIZES (COMMERCIAL FLEET/ARTISANAL FISHING)

We obtained data of biological samplings of *Callinectes* spp. crabs by artisanal fishing in 3 coast sites off Sonora (Bahía Lobos, Bahía Kino, and Las Guásimas). In these sites (Fig. 1), crabs were captured with *Chesapeake* type metal traps (60 x 60 x 40 cm) made with 5.7 x 3.1-cm hexagonal plastic-coated metal mesh with 2 entrances, one or 2 internal chambers, and a bait box in the center of the bottom chamber. Size structures from 2004 to 2005 were obtained, which helped to perform a comparison between the sizes obtained by the shrimp trawl fleet and artisanal fishing. To show significant differences among

frequency distributions, Pearson's Chi-Square Test χ^2 was applied to measure a goodness of fit between the observed and expected values (Zar 1999):

$$\chi^2 = \sum_{i=1}^k \frac{(oi - ei)^2}{ei}$$

where oi is size frequency of commercial fishing specimens and ei is that of artisanal fishing specimens.

RESULTS

During 32 monitored trips on board 13 ships from the shrimp fleet based in Guaymas, Sonora, 343 collected samples were analyzed. Their total weight was 2,331 kg with more than 16,900 specimens collected. Fish (69%) were the most abundant group of the capture, followed by crustaceans (14%), mollusks (14%), and echinoderms (3%).

Of the crustaceans, *Callinectes* contributed with 1,376 samples, which belonged to 5 species: *C. arcuatus* (n = 737), *C. bellicosus* (n = 291), *C. toxotes* (n = 344), *C. robustus* (n = 1), and *C. ruber* (n = 3). The following population parameter analyses were only performed for the first 3 species because of the low number of organisms obtained in the 2 last ones.

BIOMETRIC RELATIONSHIPS AND SEX PROPORTION

The relationship CW/weight of the 3 species (females and males) showed negative allometric growth according to the regression parameters. For *C. arcuatus* $a = 0.00020$, $b = 2.78$, $r = 0.946$, $P < 0.05$; for *C. bellicosus* $a = 0.00021$, $b = 2.81$, $r = 0.947$, $P < 0.05$; and for *C. toxotes* $a = 0.00083$, $b = 2.45$, $r = 0.973$, $P < 0.05$ (Fig. 2).

From these 3 species 1,293 sexed organisms were obtained (Table 1), finding always a greater proportion of females in relation to males throughout the study period: *C. arcuatus* (5:1), *C. bellicosus* (2:1), and *C. toxotes* (6:1).

LATITUDINAL AND BATHYMETRIC DISTRIBUTION

According to the capture sites of the 3 species, a crammed distribution was observed in all the sampling area with the largest relative abundances concentrated in the northern part of Sinaloa (Topolobampo-Agiabampo), south of Sonora (Las Guásimas-Agiabampo), and north of Nayarit (San Blas) (Fig. 3).

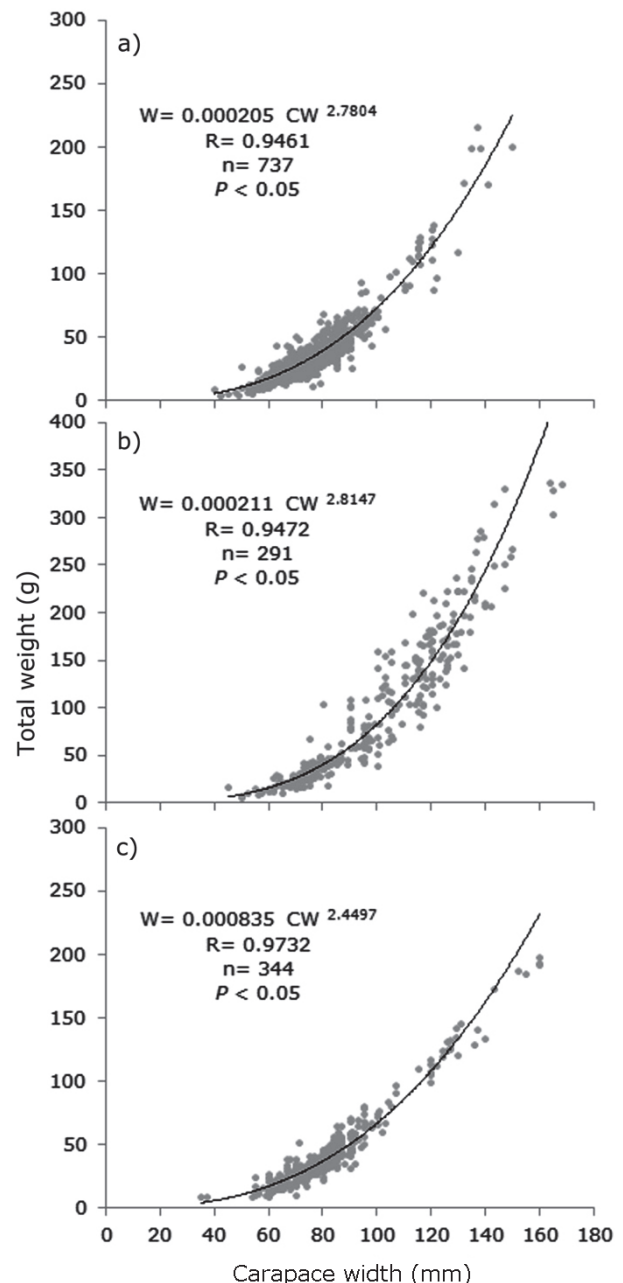


Figure 2. Relationship between carapace width and total weight of both sexes of: a) *C. arcuatus*, b) *C. bellicosus*, and c) *C. toxotes* captured in the eastern Gulf of California from September 2004 to March 2005 / Relación entre el ancho de caparazón y el peso total de: a) *C. arcuatus*, b) *C. bellicosus* y c) *C. toxotes* tomando organismos de ambos sexos, durante septiembre 2004 a marzo 2005, en la parte oriental del Golfo de California

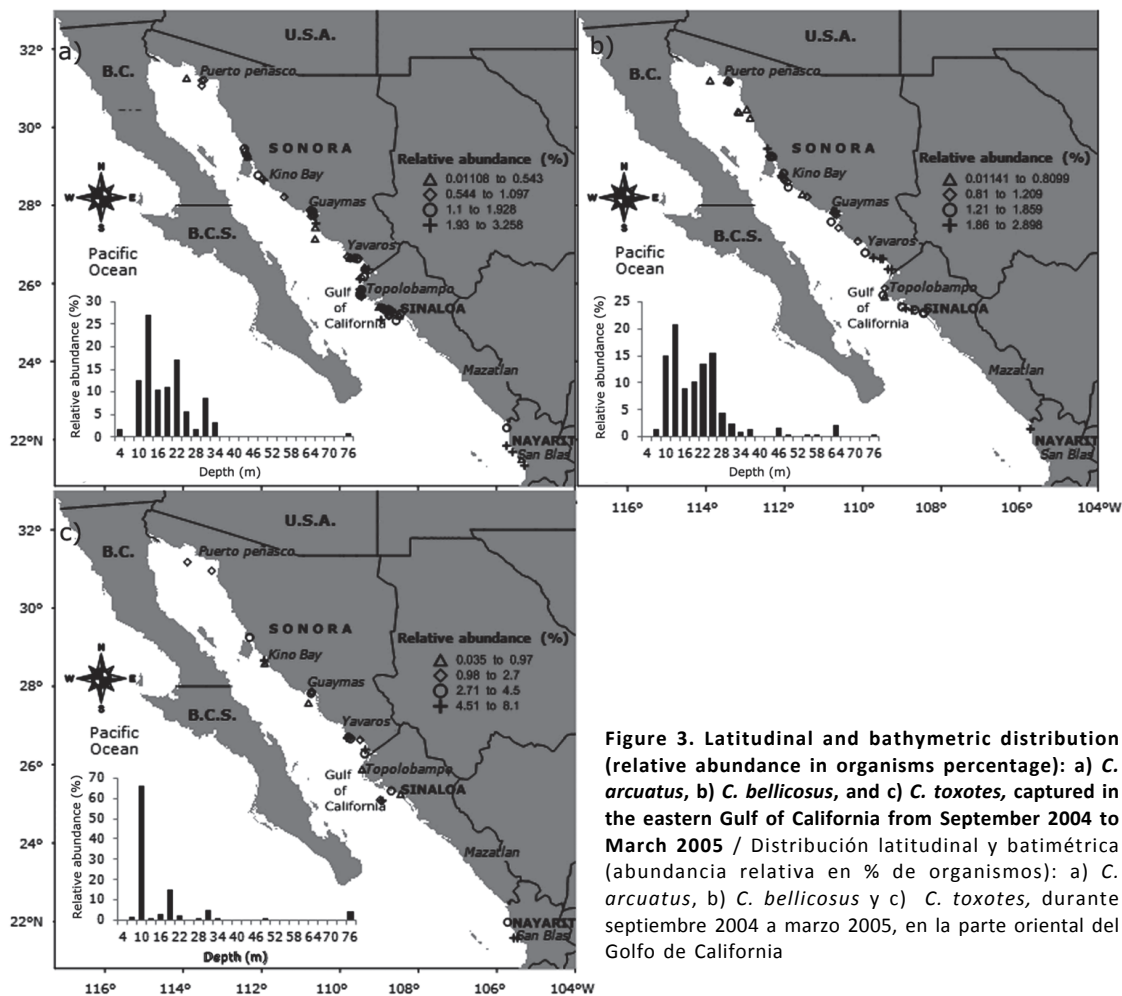


Figure 3. Latitudinal and bathymetric distribution (relative abundance in organisms percentage): a) *C. arcuatus*, b) *C. bellicosus*, and c) *C. toxotes*, captured in the eastern Gulf of California from September 2004 to March 2005 / Distribución latitudinal y batimétrica (abundancia relativa en % de organismos): a) *C. arcuatus*, b) *C. bellicosus* y c) *C. toxotes*, durante septiembre 2004 a marzo 2005, en la parte oriental del Golfo de California

Table 1. Monthly sex proportion analyses of *C. arcuatus*, *C. bellicosus*, and *C. toxotes*, captured in the eastern Gulf of California from September 2004 to March 2005 / Análisis mensual de la proporción de sexos *C. arcuatus*, *C. bellicosus* y *C. toxotes* durante septiembre 2004 a marzo 2005, en la parte oriental del Golfo de California

	<i>C. arcuatus</i>		<i>C. bellicosus</i>		<i>C. toxotes</i>	
	Female	Male	Female	Male	Female	Male
Sep	206	36	63	19	93	5
Oct	155	31	60	26	132	33
Nov	141	27	58	25	27	1
Dec	50	13	9	7	24	0
Jan	5	1	0	0	17	10
Feb	8	3	1	1	0	0
Mar	3	1	0	0	2	0
Total	568	112	191	78	290	45

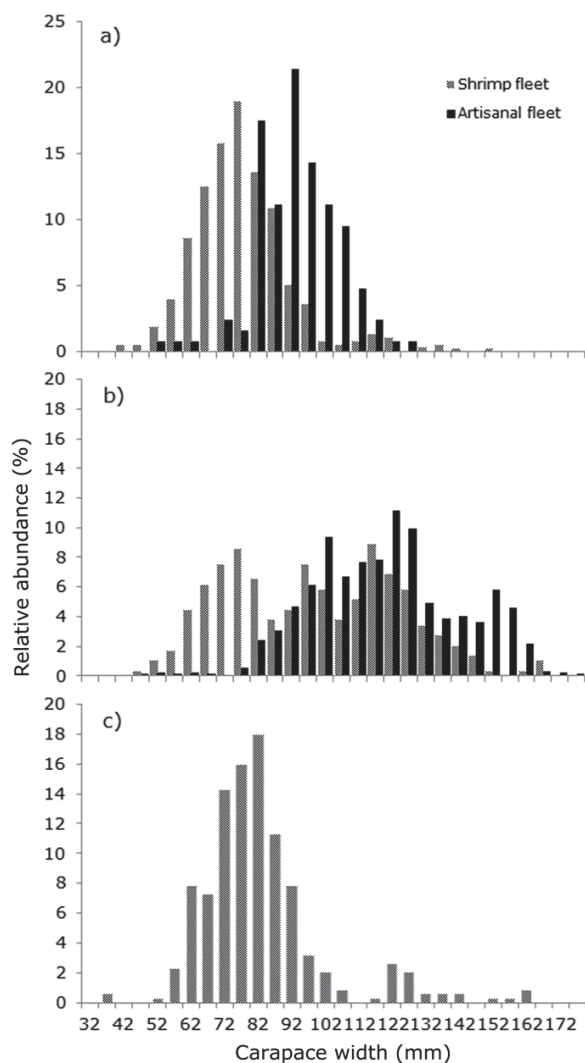


Figure 4. Size distribution: (a) *C. arcuatus*, (b) *C. bellicosus*, and (c) *C. toxotes*, captured in the eastern Gulf of California from 2000 to 2001 (artisanal fishery) and from September 2004 to March 2005 (shrimp fleet) / Distribución de tallas de: a) *C. arcuatus*, b) *C. bellicosus* y c) *C. toxotes*, obtenidas durante 2000 a 2001 (pesca ribereña) y de septiembre 2004 a marzo 2005 (flota camaronera), en la parte oriental del Golfo de California

In general, the 3 species were captured in a range from 10 to 76.8 m in depth (operation limit of the shrimp fleet); it is unknown if they are distributed at greater depth. However, the highest relative abundances were shown in the range from 10 to 34 m (Fig. 3).

SIZE STRUCTURES, GROWTH AND LONGEVITY

The sizes of the 3 species were in the range from 35 to 168

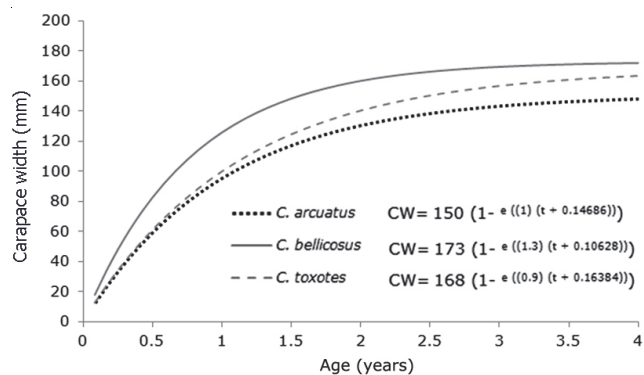


Figure 5. Growth curves of combined sexes of *C. arcuatus*, *C. bellicosus*, and *C. toxotes*, captured in the eastern Gulf of California from September 2004 to March 2005 / Curvas de crecimiento de sexos combinados de *C. arcuatus*, *C. bellicosus* y *C. toxotes*, durante septiembre 2004 a marzo 2005, en la parte oriental del Golfo de California

mm CW during the study period. Those that prevailed were in the range from 62 to 97 mm. In particular, *C. bellicosus* showed the largest sizes (45 to 168 mm CW) while *C. toxotes* showed the smallest (35 to 160 mm). The size frequency histogram of the 3 species showed a bimodal distribution (Fig. 4).

The growth parameters obtained showed that these 3 species have an accelerated growth ($K_{C. arcuatus} = 1.0$, $K_{C. bellicosus} = 1.3$, $K_{C. toxotes} = 0.9$), corresponding to their estimated longevity (*C. arcuatus* 2.85, *C. bellicosus* 2.19, and *C. toxotes* 3.16), which is less than 3 years (Table 2, Fig. 5). The winter point and amplitude of the growth curve were not detected in the model, which means no temperature effects on growth parameters were found in any of the 3 species for the study period. The growth performance index show that *C. bellicosus* has faster growth ($\phi' = 5.590$), followed by *C. toxotes* ($\phi' = 5.405$) and *C. arcuatus* growing slower ($\phi' = 4.352$) than the others.

RECRUITMENT PATTERN

The recruitment pattern analysis shows a continuous period for the 3 species with a maximum from May to August; in particular, from May to July for *C. arcuatus*; from July to September for *C. bellicosus*; and from June to August for *C. toxotes* (Table 3).

MORTALITY (NATURAL, BY FISHING, TOTAL) AND EXPLOITATION RATES

Natural (M), total (Z), by fishing (F) mortality and exploitation (E) estimates obtained for the 3 species are

Table 2. Growth parameters of 3 crab species reported by different authors in different areas of the Pacific and in this work in the Eastern Gulf of California / Parámetros de crecimiento de las 3 especies de jaibas en diversas áreas del Pacífico realizados por diversos autores y en este trabajo en la parte oriental del Golfo de California

Area of Study	<i>C. arcuatus</i>			<i>C. bellicosus</i>			<i>C. toxotes</i>			Author and Year
	L_{∞}	K	t_0	L_{∞}	K	t_0	L_{∞}	K	t_0	
Coastal Lagoon Las Guásimas, Sonora	♂♀140	0.84	0.124	♂♀169	0.9	0.110				Hernández & Arreola-Lizárraga (2007)
Santa María-La Reforma, Sinaloa				♀126	4.39	0.118				Rodríguez-Domínguez (2012)
Gulf of Nicoya, Costa Rica	♂♀142	0.89								Fischer & Wolff (2006)
Gulf of Tehuantepec, Chiapas	♂♀140	0.35	0.307							Ramos-Cruz (2008)
Navachiste Bay, Guasave, Sinaloa	♂156 ♀141	2.00 2.40	0.002 0.034	♂174 ♀149	2.80 3.7	0.450 0.029				Salazar <i>et al.</i> (2003)
Coastal Lagoon Las Guásimas, Sonora	♂♀175	1.00		♂♀161	1.00					Reyes-Benítez (2007)
Coyutlán Lagoon, Colima	♂♀161	1.43	0.119							Estrada-Valencia (1999)
La Paz, B.C.S.	♂182 ♀232	0.80 0.50	0.160 0.090	♂♀161	0.8	0.230				Escamilla-Montes (1998)
Mar Muerto Lagoon Oaxaca-Chiapas	♂♀152	0.63	0.109	♂♀180	0.68	0.180	♂♀209	0.47	0.940	Gil & Sarmiento (2001)
Eastern Gulf of California	♂♀150	1.00	0.146	♂♀173	1.30	0.108	♂♀168	0.90	0.163	This study

shown in Table 4. The exploitation rate values do not indicate a significant degree of overexploitation for any of the 3 species ($E < 0.5$).

SIZE COMPARISON (SHRIMP FLEET/ARTISANAL FISHING)

To compare sizes, only the distributions of *C. arcuatus* and *C. bellicosus* were used because the third species is not target of commercial fishing by the artisanal fleet in Sonora (where the samplings were performed).

Sizes of 126 organisms of *C. arcuatus* and 877 of *C. bellicosus* were obtained in the 3 sites off the Sonora coastline. Size ranged from 54 to 126 mm in CW for the first species and from 49 to 175 mm for the second one.

The goodness of fit χ^2 test showed significant differences between size frequency of *C. arcuatus* and *C. bellicosus* ($\chi^2_{\text{cal}} = 19.069 - \chi^2_{\text{tab}} = 32.7$, $P < 0.05$, d.f. = 21 and $\chi^2_{\text{cal}} = 713 - \chi^2_{\text{tab}} = 36.4$, $P < 0.05$, d.f. = 24) which means that each fleet operates on different population fractions (sizes), albeit with a light overlap between them.

The shrimp fleet extracted mostly small-sized organisms (50-120 mm CW) while the artisanal fleet extracted the organisms in larger sizes (75-155 mm CW) (Fig. 4) likely due to fishing gear selectivity.

DISCUSSION

In coastal waters of the American continent, 14 *Callinectes* species have been reported, of which 11 are restricted to the tropics and sub-tropics where the majority are exploited for human consumption (Fischer & Wolff 2006). In the Mexican Pacific, particularly in the Gulf of California, 3 of these species (*C. arcuatus*, *C. bellicosus*, and *C. toxotes*) constitute an important fishery resource in this area. The states of Sinaloa, Sonora, and Baja California Sur (in order of importance) contribute the most to artisanal fishery (Ramírez-Félix *et al.* 2003, Molina-Ocampo *et al.* 2006).

In our work performed in the Eastern Gulf of California, 5 *Callinectes* species were found (*C. arcuatus*, *C.*

Table 3. Recruitment pattern analyses of 3 crab species captured in the Gulf of California from September 2004 to March 2005 / Patrón de reclutamiento de las 3 especies de jaibas durante septiembre de 2004 a marzo de 2005, en la parte oriental del Golfo de California

Month	% Recruitment		
	<i>C. arcuatus</i>	<i>C. bellicosus</i>	<i>C. toxotes</i>
Jan	1	1.6	0.03
Feb	3.7	4.44	0.48
Mar	6.3	4.82	1.12
Apr	12.3	6.19	1.52
May	19	8.4	7.1
Jun	18.63	10.88	20.19
Jul	15.96	18.58	27.23
Aug	11.86	20.25	24.47
Sep	8.17	17.07	12.98
Oct	2.9	7.4	4.01
Nov	0.2	0.39	0.87
Dec	0	0	0

bellicosus, *C. toxotes*, *C. robustus*, and *C. ruber*), of which the 3 first ones are the most abundant and match the species commercially captured in this area (Molina-Ocampo *et al.* 2006). Likewise, the areas of greater abundance of these 3 species (Bahía de Kino, Las Guásimas, Agiabampo, Topolobampo, San Ignacio-Navachiste, and San Blas) match the main sites where the largest captures are registered in the Gulf of California (Carta Nacional Pesquera 2004)². The third species (*C. toxotes*) is captured mostly off the southern part of Sinaloa, and its distribution has been reported from the southern Gulf of California down to Colombia (Paul 1982a, Correa-Sandoval 1991, Hendrickx 1995). In our work the species were not only captured in the southern Gulf but also in the central and southern parts, extending the limit reported in their distribution area.

Population parameters are important to understand resource management strategies sustainably. For the first time, our work reports population dynamics of *C. arcuatus*, *C. bellicosus*, and *C. toxotes* captured by shrimp fleet along the eastern coastline of the Gulf of California in a range from 10 to 77 m in depth. For the first

Table 4. Mortality and exploitation rates of the 3 *Callinectes* species captured in the eastern Gulf of California and analyzed from September 2004 to March 2005 / Tasas de mortalidad y explotación de las 3 especies de *Callinectes* analizadas durante septiembre de 2004 a marzo de 2005, en la parte oriental del Golfo de California

Species	M	Z	F	E
<i>C. arcuatus</i>	1.5	2.9	1.4	0.48
<i>C. bellicosus</i>	1.95	2.7	0.75	0.28
<i>C. toxotes</i>	1.35	2.4	1.05	0.44

2 species, existing reports in the Gulf area are limited to describing these population parameters in depths less than 15 m where artisanal fleet operates. Literature data (Hendrickx 1983, 1984) report an incidence of *Callinectes* species at depths ranging from 4 to 40 m. In our work the capture of *C. arcuatus* is reported at depths ranging down to 75 m, *C. bellicosus* down to 76 m, and *C. toxotes* down to 77 m. These results confirm there is a lack of knowledge on bathymetric distribution and population dynamics of the portion living in deeper areas in the Gulf of California than in those where artisanal fishery operates.

Size frequency distribution offers information on population dynamics in processes such as, growth, mortality, and recruitment, as well as potential migratory population movements. In our work < 95 mm in CW size structure of *C. arcuatus* constituted 92% of the organisms; < 115 mm of *C. bellicosus* constituted 67% of the organisms; and < 100 mm of *C. toxotes* comprised 89% of the organisms, capture size recommended for each one of these species in the Mexican Pacific coastline (Ramírez-Félix *et al.* 2003). The 3 species showed similar characteristics in size structure where organisms in sizes higher than 100 mm in CW were scarce, which could be attributed to the fact that organisms were captured with 50-mm mesh trawling nets that confer low selectivity to this type of fishing gear.

Moreover, by the way this type of net operates at an average speed of 5.5 km h⁻¹ (relatively low speed), it is assumed that larger size organisms have the time to avoid the nets or escape (Fisher & Wolff 2006, López-Martínez *et al.* 2008). Likewise, significant size distribution differences were found between *C. arcuatus* and *C. bellicosus* captured both by artisanal fishery and shrimp

²Carta Nacional Pesquera. 2004. Segunda sección, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. México, D.F.

fleet, concluding that the shrimp fleet (industrial) extracts mostly organisms of these 2 species in smaller sizes (50-120 mm CW) while smaller ships (artisanal) extract larger ones (75-155 mm CW). Hernández & Arreola-Lizárraga (2007) reported size distribution differences in *C. arcuatus* and *C. bellicosus* obtained from samplings performed with trawling nets in a coastal lagoon (Las Guásimas, Sonora) and in those analyzed by Molina-Ocampo (2001) and Nevárez-Martínez *et al.* (2003) from commercial captures with traps. To conclude, average sizes captured with trawling nets for *C. arcuatus* and *C. bellicosus* were 18 and 42 mm, respectively, whereas those coming from commercial captures were 65 and 72 mm, respectively.

These results showed a major abundance of the 3 species from September to November (Table 1) with major incidence of females and large organisms (juveniles and adults), which could suggest a potential species migration to high seas. Arreola-Lizárraga *et al.* (2003) reported *C. arcuatus* and *C. bellicosus* inhabit in the inner parts of the coastal lagoons (Las Guásimas, Sonora) during spring-summer, and their abundance decreases during autumn. Likewise, it is mentioned that female presence is scarce in the lagoon during this period when adult males are more abundant. Estrada-Valencia (1999) reported male dominance in the captures in another coastal lagoon in the Gulf (Cuyutlán, Colima) during this same period. Considering that reproduction of these organisms is performed at open seas (Molina-Ocampo *et al.* 2006), it is possible to consider the hypothesis that female dominance at high seas during this period (September-November) responds to a migratory process with reproductive purposes.

The continuous year-round and higher recruit in the summer months (June-August) agrees with that reported by Reyes-Benítez *et al.* (2007) and at the same time with the reproductive pattern observed by Arreola-Lizárraga & Hernández-Moreno (2003) and Nevárez-Martínez *et al.* (2003). It has important impacts for the resource because it coincides with the closed shrimp season (April-August) and with that applied to crab in artisanal fishery. This situation benefits several crab populations as mentioned by López-Martínez *et al.* (2008, 2011), González-Ochoa *et al.* (2009), Rábago-Quiroz *et al.* (2011), and Morales-Azpeitia *et al.* (2011) for different shrimp bycatch fish species.

The 3 species (*C. bellicosus*, *C. arcuatus*, and *C. toxotes*) showed an allometric growth despite the corresponding values of regression coefficient 'b' were

very close to 3, whereas the goodness of fit intervals at 95% and the Student-t test (3, $P < 0.05$) indicated the 3 species tend to grow more in weight than in carapace width (CW). These results disagree with those obtained by Nevárez-Martínez *et al.* (2003), Hernández & Arreola-Lizárraga (2006), and Reyes-Benítez (2007) who reported an isometric growth for *C. bellicosus* and *C. arcuatus*. However, they agree with those reported by Paul (1982b), Molina-Ocampo (2001), and Torre *et al.* (2004), who attributed allometric growth in these species to a phase lag in the optimum biological condition of females due to lower feed rates and more energy loss in the reproduction season. For *C. toxotes* Gil-López & Sarmiento-Náfate (2001) reported and isometric growth both in males and females of this species in the Mar Muerto system, Oaxaca-Chiapas, agreeing with the results in our work.

The estimated growth parameters showed that the relative age at which individuals reach maximum growth is between 3 and 4 years for the 3 species, which agree with those reported for *C. arcuatus* and *C. bellicosus* in several areas of the Gulf of California (Estrada-Valencia 1999, Nevárez-Martínez *et al.* 2003, Reyes-Benítez *et al.* 2007) and in the Gulf of Nicoya, Costa Rica (Fischer & Wolff 2006). On the other hand, Gil-López & Sarmiento-Náfate (2001) mentioned *C. toxotes* required 4 to 5 years to reach its asymptotic size, which is considered exceptionally long taking into account that crustaceans usually have short life, high growth rate, and when subjected to an intense exploitation rate, they have fewer opportunities to reach their maximum size.

Previous studies on growth estimates for *C. arcuatus*, *C. bellicosus*, and *C. toxotes* in the Mexican Pacific (Table 2) are based on data from commercial captures with traps where large size organisms dominate (Estrada-Valencia 1999, Gil-López & Sarmiento-Náfate 2001, Salazar-Navarro *et al.* 2003, Nevárez-Martínez *et al.* 2003, Reyes-Benítez *et al.* 2007). Due to the previous information, absence of small sizes generates a regression range problem and with it an over-estimation (in L_{∞}) or underestimation (in K) of growth parameters, which has been documented by López-Martínez *et al.* (2005) in peneid shrimp and by Rábago-Quiroz *et al.* (2008) in fish. On the other hand, growth parameter estimates of *C. arcuatus* and *C. bellicosus* performed by Hernández & Arreola-Lizárraga (2007) with data from samplings captured with trawling nets in a coastal lagoon (Las Guásimas, Sonora) where small sizes dominate generate an underestimation in L_{∞} . In the case of growth estimates of *C. arcuatus* in the Gulf of Nicoya, Costa Rica (Fischer & Wolff 2006) and in those

performed by Ramos-Cruz (2008) in the Gulf of Tehuantepec, Chiapas, they show lower values of L_{∞} to those obtained in our work (Table 2), which could be attributed to oceanographic conditions of the area favoring the species to reach larger sizes.

The F values estimated for the 3 species in our study reveal that the current exploitation they are subjected to by the shrimp fleets is relatively low ($E < 0.48$). However, given that at least 2 (*C. arcuatus* and *C. bellicosus*) of the 3 species analyzed here are target of artisanal fisheries, an analysis considering the combined effect of both fleets should be performed to define crab population health.

In conclusion, some differences in dynamic population parameters were found based on data from commercial captures with traps and those obtained with data of incidental captures from the shrimp trawling fleet. Therefore, an analysis including all the aspects of the population dynamics of these resources is considered necessary with the purpose of proper fishery management.

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