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Research Article

Brachyura megalopae in the Jamapa River estuary, Veracruz, southwestern of the Gulf of Mexico

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ABSTRACT. The present study analyzes the diversity and abundance of infraorder Brachyura megalopae and their relationship with the environmental factors in the Jamapa River estuary, Veracruz, México. The environmental factors of dissolved oxygen, water temperature, total dissolved solids, pH, and salinity were measured. Crabs were captured using light traps and shrimp bait. The generalized linear model was used to determine the relationship between the environmental factors and the five sampling months and the five sampling sites and was used to determine the relationship between the abundance of the megalopae and the sampling months, sites, and environmental factors. A total of 5398 megalopae belonging to seven species of Brachyura were collected. The most abundant species were *Minuca vocator* and *M. burgersi*, with 2174 and 2156 megalopae, respectively; these species are common in low-salinity estuaries. The highest diversity was found at the southern boundary of the estuary with six species, 2.24 bits ind^{-1}. The statistical analyses showed that the values of the environmental factors related to the climatic season determine (i.e. temperature and salinity) the abundance of the megalopae. Based on the diversity values evaluated, it can be established that the Jamapa River estuary has intermediate stability.

Keywords: Crustacea; Decapoda; megalopae; larval development; recruitment; assemblage; diversity

INTRODUCTION

The infraorder Brachyura is one of the most diverse groups in the subphylum Crustacea, with about 7000 described species in 98 families (Ahyong et al. 2011). Brachyurans undergo four developmental stages (larva, megalopae, juvenile, and adult). In Brachyura, the larval stage is called the zoea, which, depending on the species, can have from two to eight molts when transforming into the new stage named "megalopae" or "decapodite", which is classified as a transition state between the planktonic life of the larva and the life of the juvenile benthic larva (Gore 1985, Martin et al. 2014).

According to the marine environment's vertical structure, the zoea's first stage is found in the upper part of the water column; the following zoea stages are in deeper areas (Cházaro-Olvera et al. 2020). The megalopa is more active than the zoea because the pleopods are fully functional and can remain in the water column or move to the benthic zone (Queiroga 1996).

This active movement of the megalopa is very important since it determines the recruitment mechanisms to the area where the adult populations are found within an estuary (Sandifer 1975, Dittel & Epifanio 1982, Pessani et al. 2004, Cházaro-Olvera et al. 2007a, 2014).

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On the other hand, the megalopa stage is a critical stage for population dynamics as, in this stage of development, the highest mortality of the entire life cycle (Cházaro-Olvera et al. 2007a). During the transport of the megalopa to the parental environment, they go from higher salinities in the marine environment (~35) to lower salinities in the estuary, which can even be lower than 3 (Cházaro-Olvera et al. 2007a). Thus, the recruitment of megalopae is determined by factors associated with tidal conditions and chemical and visual variables that determine some orientation responses (Rittschof et al. 1998, Diaz et al. 1999, Cházaro-Olvera et al. 2007a, 2009). Another important factor is the time spent in the megalopae stage. A longer period may increase the probability that some population members will be transported from the ocean to the estuarine habitat where the adults are found (Sulkin & Epifanio 1986). In other latitudes, numerous studies have been carried out to explain the mechanisms of recruitment and abundance of different species in the megalopa stage (Forward et al. 2004, Pardo et al. 2012), especially in species of commercial importance such as the blue crab, *Callinectes sapidus*. In Mexico, there are few investigations on the recruitment of megalopae in estuarine systems (Cházaro-Olvera 1996, Cházaro-Olvera et al. 2007a,b). The objective of the present study was to evaluate the composition, distribution, and abundance of the Brachyura species in the megalopae stage and determine their relationship with environmental factors in the Jamapa River estuary, Veracruz, southwestern of the Gulf of Mexico.

MATERIALS AND METHODS

Study area

The confluence of the Cotaxtla and Jamapa rivers forms the Jamapa River estuary. The inlet of the Jamapa River is an estuary whose water runoff reaches the Veracruz Reef System (VRS) (Liaño-Carrera et al. 2019). The Jamapa River originates on the border of the states of Puebla and Veracruz and flows into the Gulf of Mexico in Boca del Río, Veracruz. The Jamapa River basin is located between 18°45'-19°14'N and 95°56'-97°17'W. It has a warm sub-humid climate, with an average annual temperature higher than 22°C; the temperature of the coldest month is 18°C. The precipitation of the driest month is 26 mm (March), with a rainy season in summer from 313 mm (September). The climate in the Gulf of Mexico is divided seasonally into dry, rainy seasons, and cold fronts (Carrillo et al. 2007). Cold fronts occur from October to March and are anticyclonic cold wind currents that enter the Gulf of Mexico from North America (Ojeda et al. 2017). The “dry weather conditions” occur from May to June, with scarce rainfall. The 'rainy weather conditions' occur from July to September when temperatures and precipitation increase (Zavala-Hidalgo et al. 2006). The soil comprises six soil types, with regosol and vertisol being the most predominant (Fuentes-Mariles et al. 2014). The level of the Jamapa River in its estuarine area has a micro-tidal modulation. Its tidal range is lower than 1 m, with a biweekly synodic semidiurnal, diurnal, and lunisolar component (Salas-Monreal et al. 2019). The Jamapa River estuary has a navigation channel in the southern part that generates significant changes in its dynamics (Salas-Monreal et al. 2019). The Jamapa River estuary is important because its water discharges are rich in nutrients and are directed to the VRS. On the south side, the water exchange between the river and the ocean is more continuous than on the north side; however, the water can remain static for longer than 24 h due to its low speed. On the other hand, the continuous supply of water from the Moreno Stream shows high contamination due to the urban discharges it directly receives (Salas-Monreal et al. 2020) (Fig. 1).

Fieldwork

The collection of specimens was carried out at five stations: one of them was located to the south of the estuary, at the jetty of the Instituto Tecnológico de Boca del Río, Veracruz (ITBOCA); another station was located to the north of the estuary near the mouth of the Moreno Stream, at the jetty of the Instituto de Ciencias Marinas y Pesquerías de la Universidad Veracruzana (ICIMAP); a third station was located near the mouth of the estuary called Barco; and two stations (Venecia and Estero) were located to the southeast, in the area of communication with the Mandinga Lagoon. The sampling campaign was carried out in September (rainy season), November of 2018, January, March (cold front season), and May (dry season) of 2019. The biological material was collected during 12 h using a light trap (Cházaro-Olvera et al. 2018), which was placed at the sampling sites at a depth of 0.5 m during the full moon phase since in this lunar phase, the effect of positive phototropism of zooplankton is maximized. The trap was placed at 20:00 h on the first sampling day and removed at 8:00 h the following day. Each sample was filtered through a 300 µm sieve and preserved in 0.5 L plastic bottles. Subsequently, the samples were fixed with 70% ethyl alcohol and labeled with information on the location, date, time, and type of sampling. The abiotic parameters of water temperature (°C), salinity, total dissolved solids (ppm), dissolved oxygen (mg L^{-1}),

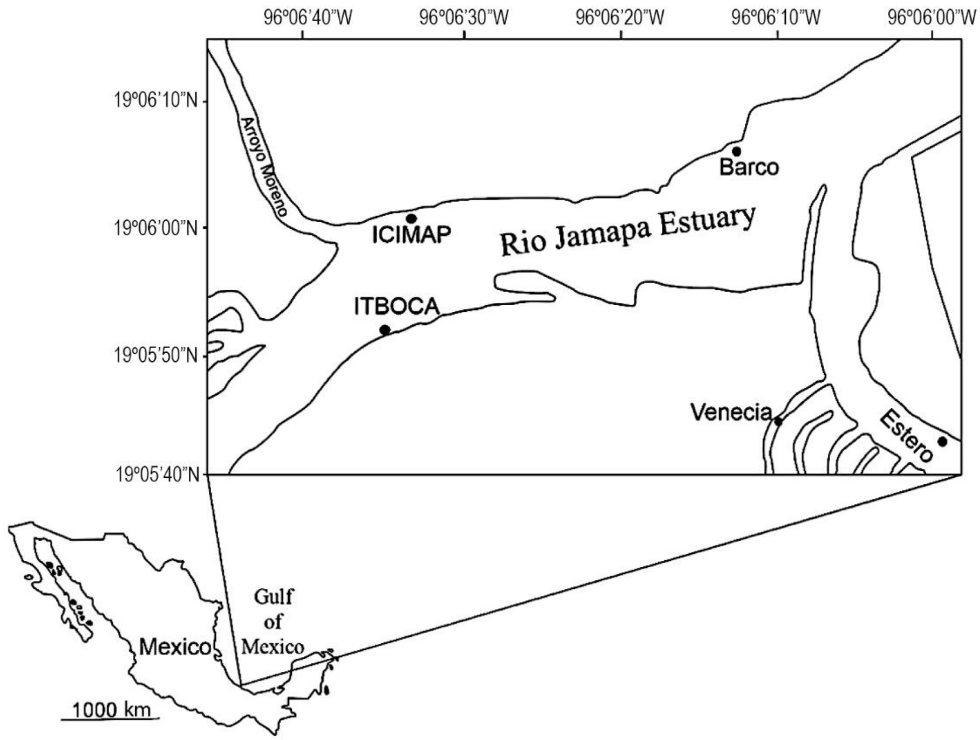

Figure 1. Location of sampling sites in the estuary of the Río Jamapa, Boca del Río, Veracruz, México. ITBOCA: Instituto Tecnológico de Boca del Río; ICIMAP: Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana.

and pH were measured *in situ* with a Hanna® HI 9828 multiparameter every month and at each site at the beginning and end of the sampling; later the average and standard deviation were obtained.

Laboratory work

The biological material was transported to the Crustacean Laboratory of the FES Iztacala, where it was reviewed, separated, and identified up to species with the help of a stereoscopic microscope and an optical microscope, following the criteria of Costlow & Bookhout (1959, 1961), Diaz & Ewald (1968), Domingues & Hebling (1989), Rieger (1998, 1999), Bullard (2003), Pessani et al. (2004), and Martin et al. (2014).

Statistical analysis

The generalized least squares (GLS) model was used to determine the relationship between the environmental factors, the five months, and the five sampling sites (Zuur et al. 2007). After finding statistically significant differences between the means of the environmental factors of the months and sampling sites, Tukey's *post-hoc* test was applied (Sokal & Rohlf 1995).

The generalized linear model (GLM) was used to determine the relationship between the abundance of Brachyura species in the megalopae stage with sites, months, and environmental factors. A Poisson logarithmic linear model was used to count, considering each species abundance as a dependent variable in each month and sampling sites and variables to environmental factors as independent. A type III analysis was performed, and the chi-square statistic was obtained using the Wald model. Previously, the values of the environmental factors were transformed to arcsine and the abundance values of the species to log (n+1) (Zuur et al. 2007). Both temporally and spatially, the Shannon-Wiener (H') diversity and species richness (Magurran 1988) were obtained. GLS and GLM analyses were performed using SPSS v25 software, and the community parameters were obtained using PAST software (Harmer et al. 2001).

RESULTS

Environmental parameters

The highest average dissolved oxygen value was recorded in May as 6.65 ± 0.04 mg L^{-1} at the ICIMAP site, while the lowest value was in November as 3.65 ± 0.65 mg L^{-1} at the Barco site (Table 1). The concentration of dissolved oxygen had a positive relationship ($r = 0.74$) and was significant ($P < 0.001$) with the sites

Table 1. Environmental factors of the Jamapa River estuary, Boca del Río, Veracruz. ITBOCA: Instituto Tecnológico de Boca del Río; ICIMAP: Instituto de Ciencias Marinas y Pesquerías, Universida Veracruzana.

Month	Sampling site	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Salinity	Total dissolved solids (ppm)
September	ITBOCA	5.28 ± 0.06	7.18 ± 0.01	28.47 ± 0.65	0.97 ± 0.06	890 ± 50
	ICIMAP	3.88 ± 0.96	7.29 ± 0.09	30.05 ± 1.02	1.07 ± 0.23	904 ± 31
	Barco	4.02 ± 0.02	7.18 ± 0.04	29.51 ± 0.58	2.7 ± 0.75	1874 ± 106
	Venecia	4.85 ± 0.22	7.13 ± 0.01	29.48 ± 0.66	8.31 ± 0.93	258 ± 44
	Estero	4.20 ± 0.14	7.19 ± 0.06	29.11 ± 0.17	14.29 ± 1.46	1054 ± 78
	Average	4.44 ± 0.06	7.19 ± 0.06	29.32 ± 0.58	5.47 ± 5.77	996 ± 578
November	ITBOCA	5.38 ± 0.26	7.75 ± 0.26	22.64 ± 0.66	6.16 ± 0.52	4688 ± 1648
	ICIMAP	3.99 ± 0.46	7.03 ± 0.46	24.32 ± 0.54	6.09 ± 1.13	4493 ± 363
	Barco	3.65 ± 0.65	7.16 ± 0.65	27.64 ± 0.11	5.22 ± 0.59	4226 ± 147
	Venecia	4.92 ± 0.1	7.50 ± 0.1	26.09 ± 0.37	22.04 ± 0.46	18.13 ± 1.18
	Estero	4.96 ± 0.0	7.2 ± 0.07	26.45 ± 0.87	22.39 ± 1.12	18.16 ± 1.34
	Average	4.58 ± 0.72	7.33 ± 0.29	25.48 ± 1.97	12.38 ± 8.99	2689 ± 2244
January	ITBOCA	6.01 ± 0.01	7.44 ± 0.01	23.08 ± 0.78	7.04 ± 1.20	5006 ± 626
	ICIMAP	5.11 ± 0.15	7.65 ± 0.03	21.66 ± 0.04	7.46 ± 1.65	5091 ± 617
	Barco	4.11 ± 0.14	7.34 ± 0.02	22.6 ± 0.07	12.89 ± 0.95	10.95 ± 1.05
	Venecia	4.31 ± 0.08	7.85 ± 0.06	22.13 ± 0.71	34.03 ± 0.99	25.97 ± 0.47
	Estero	4.75 ± 0.21	7.34 ± 0.02	22.38 ± 0.87	33.65 ± 0.36	25.53 ± 0.24
	Average	4.85 ± 0.75	7.52 ± 0.22	22.37 ± 0.53	19.01 ± 13.73	2032 ± 2754
March	ITBOCA	6.11 ± 0.14	7.16 ± 0.01	24.61 ± 0.57	6.14 ± 0.26	4913 ± 490
	ICIMAP	5.44 ± 0.32	7.24 ± 0.04	24.42 ± 0.21	8.02 ± 0.86	5842 ± 856
	Barco	5.15 ± 0.05	7.18 ± 0.01	24.81 ± 0.28	17.99 ± 2.33	14.36 ± 1.42
	Venecia	5.07 ± 0.06	7.19 ± 0.02	22.97 ± 0.51	33.93 ± 0.81	27.96 ± 2.37
	Estero	6.19 ± 0.03	7.21 ± 0.04	22.66 ± 0.14	34.99 ± 0.43	27.86 ± 1.6
	Average	5.59 ± 0.53	7.2 ± 0.03	23.89 ± 0.99	20.21 ± 13.77	2165 ± 2950
May	ITBOCA	4.87 ± 0.21	7.62 ± 0.10	31.64 ± 0.11	33.37 ± 0.27	26.04 ± 0.83
	ICIMAP	6.65 ± 0.04	7.34 ± 0.01	30.45 ± 0.17	33.84 ± 0.22	26.89 ± 0.18
	Barco	6.06 ± 0.04	7.53 ± 0.04	28.91 ± 0.16	35.65 ± 0.01	27.57 ± 0.76
	Venecia	5.7 ± 0.37	7.56 ± 0.37	28.81 ± 0.32	35.39 ± 0.54	26.89 ± 0.18
	Estero	5.43 ± 0.27	7.44 ± 0.27	28.92 ± 0.23	35.57 ± 0.04	27.13 ± 0.28
	Average	5.74 ± 0.67	7.49 ± 0.11	29.74 ± 1.26	34.76 ± 1.08	26.9 ± 0.56

and sampling months (Table 2). No statistically significant differences in dissolved oxygen concentrations were found between the sites ($P = 0.15$); however, there were statistically significant differences between the sampling months ($P < 0.05$). The *post-ho*c Tukey test showed significant differences between May and September ($P < 0.05$).

The highest average pH value was recorded in January as 7.85 ± 0.06 at the Venecia site, while the lowest was in November as 7.03 ± 0.46 at the ICIMAP site (Table 1). The sampling sites and months showed a positive ($r = 0.79$) and significant ($P = 0.001$) relationship. Statistically significant differences were found among the sampling months ($P < 0.001$) (Table 2). The Tukey test found significant differences between January and September ($P < 0.05$).

The average temperature ranged from 21.66 ± 0.04°C in January at the ICIMAP site to 31.64 ± 0.11°C in May at the ITBOCA site (Table 1). The water temperature presented a positive ($r = 0.73$) and significant relationship with the sampling sites and months ($P = 0.002$); no statistically significant differences were found between the sites ($P = 0.21$); however, there were statistically significant differences among the sampling months ($P < 0.001$) (Table 2). Tukey's test showed significant differences between January-May, January-September, March-May, and May-Nov ($P < 0.05$).

Salinity presented the highest value in May at 35.65 ± 0.01 at the Barco site and the lowest at 0.97 ± 0.06 in September at the ITBOCA site (Table 1). Salinity showed a positive ($r = 0.91$) and statistically significant

Table 2. Generalized least squares model (GLS) for environmental factors registered in the inlet of the River Jamapa, Boca del Río, Veracruz during 2018 and 2019. df: degrees of freedom, F: statistic in ANOVA (analysis of variance), and *P*: probability level.

		Dissolved oxygen		pH		Temperature		Total dissolved solids		Salinity	
Origin	df	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Corrected model	8	5.79	0.001	7.44	<0.001	5.39	0.002	3.19	0.023	18.74	<0.001
Intersection	1	360.44	<0.001	11810.17	<0.001	3172.72	<0.001	23.01	<0.001	286.41	<0.001
Site	4	1.98	0.15	3.27	0.04	1.66	0.21	4.31	0.015	14.17	<0.001
Month	4	9.62	<0.001	11.6	<0.001	9.13	<0.001	2.09	0.13	23.29	<0.001
Error	16										
Total	25										
Correlation coefficient (*r*)		0.74		0.79		0.73		0.62		0.91	

relationship with the sampling sites and months (*P* < 0.001). Significant differences were found between sites and between months (*P* < 0.001). The Tukey's test showed differences among the sites ITBOCA-Estero, ITBOCA-Venecia, ICIMAP-Estero, ICIMAP-Venecia, Barco-Estero, and Barco-Venecia (*P* < 0.05). Likewise, differences were found in May with the other five sampling months and January with September (*P* < 0.05).

The total dissolved solids presented a high variation since the highest average value was 5842 ± 856 ppm at the ICIMAP site in March, while the lowest was 10.95 ± 1.05 ppm in May (Table 1). The total dissolved solids showed a positive (*r* = 0.62) and statistically significant relationship with the sampling sites and months (*P* = 0.023). No statistically significant differences were found between months (*P* = 0.13); however, there were statistically significant differences between the sites (*P* = 0.015) (Table 2). The Tukey test showed statistically significant differences between ICIMAP and Venecia sites (*P* < 0.05).

Megalopae abundance and diversity

Seven species of Brachyura were found in the megalopae stage: *Callinectes sapidus* Rathbun, 1896; *Panopeus herbstii* H. Milne Edwards, 1834; *Armases ricordi* (Rathbun, 1897); *Pachygrapsus gracilis* (de Saussure, 1857); *Minuca vocator* (Herbst, 1804); *M. burgersi* (Holthuis, 1967); and *Ucides cordatus* (Linnaeus, 1763) (Fig. 2).

A total of 5398 megalopae were collected, the most abundant species being the fiddler crabs *M. vocator* with 2174 megalopae, followed by *M. burgersi* with 2156 megalopae (Table 3). The highest abundance was found in September, with 1254 individuals at the ITBOCA site.

The abundance of *A. ricordi* was significantly related to the dissolved oxygen, pH, temperature, and salinity (*P* < 0.05). The changes in the abundance of the fiddler crab *M. vocator* were significantly related to the five physicochemical factors (*P* < 0.05). The abundance of *M. burgersi* was significantly related to temperature, dissolved oxygen, pH, and salinity (*P* < 0.05). The abundance of the blue crab *C. sapidus* was significantly related to dissolved oxygen, pH, salinity, and total dissolved solids (*P* < 0.05). The abundance of the swamp crab *P. gracilis* was significantly related to all physicochemical factors (*P* < 0.05). The abundance of megalopae of *U. cordatus* was significantly related to temperature, salinity, and total dissolved solids (*P* < 0.05) (Table 4). Finally, the panopeid *P. herbstii* was only related significantly with the dissolved oxygen (intersection = -44.19, B = 8.14) (*P* < 0.05).

Species richness and diversity

The highest richness occurred at the ITBOCA site, with six species in September, March, and May, and the Estero site, with six species in September and November; the remaining sampling sites presented one to five species. The highest diversity occurred at the ITBOCA site with 2.4 bits ind^{-1} in May, followed by March at the same site with 2.24 bits ind^{-1} (Table 3).

DISCUSSION

The lowest average temperature values registered in January and March (cold fronts season) are consistent with the ones reported by Jasso-Montoya (2012), Avendaño-Álvarez (2013), Contreras-Espinoza (2016), and Castañeda-Chávez et al. (2017), who registered values between 23 and 24°C in those months. The

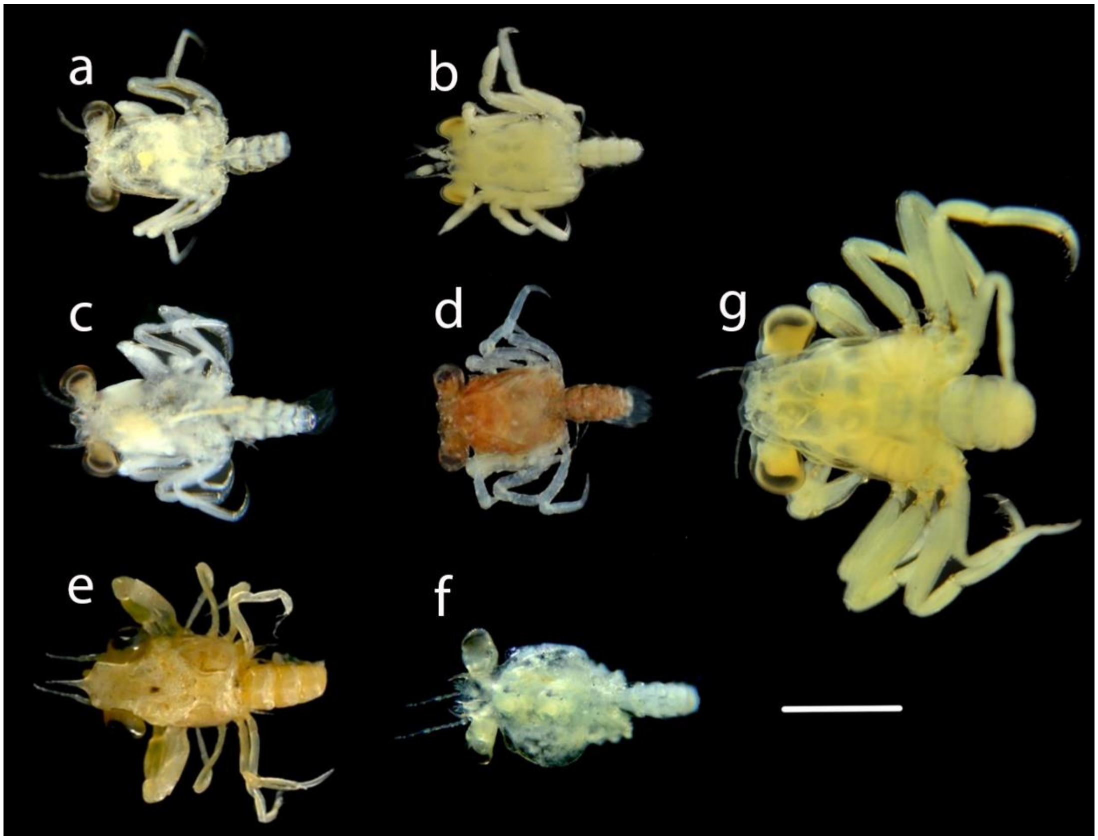

Figure 2. Brachyura, megalopa stage in the inlet of the Jamapa River estuary. a) *Minuca vocator* (Herbst, 1804), b) *M. burgersi* (Holthuis, 1967), c) *Ucides cordatus* (Linnaeus, 1763), d) *Armases ricordi* (Rathbun, 1897), e) *Callinectes sapidus* Rathbun, 1896, f) *Panopeus herbstii* H. Milne Edwards, 1834, g) *Pachygrapsus gracilis* (de Saussure, 1857). Scale: 1 mm.

results also agree with Cházaro-Olvera et al. (2022a), who registered an average of 25.11 ± 0.12°C in ITBOCA in the cold fronts season. Contreras-Espinoza (2016) mentioned that the Jamapa River temperature was 25°C in the cold fronts and 29.4°C in the rainy season. Therefore, the temperature values in the Jamapa River estuary are related to the region's climatic seasons and other tropical coastal regions of Mexico (Zavala-Hidalgo et al. 2006). We consider it important to compare the values obtained in this study with the established in the Norma Oficial Mexicana NOM-001-SEMARNAT-2021, which establishes the maximum permissible limits of pollutants in wastewater discharges into aquatic systems owned by Mexico. The temperature in the sampling months ranged between 21 and 30°C, which does not exceed the maximum permissible limit of 35°C defined by the Official Mexican Standard (NOM-001-SEMARNAT-2021).

The total dissolved solids were highest in the cold fronts season and rainy season; the above is related to the mixing of sediments caused by the wind and by transport by river discharge, respectively. In September, at the Barco and Estero stations, values close to the limit or that exceed the permitted limit were found; in November, at ITBOCA, ICIMAP, and Barco, they were above the limit established by the official Mexican standard. In January and March, the sites above the limit established by the official Mexican standard were ITBOCA and ICIMAP. Cházaro-Olvera et al. (2022b) also found high values in the cold fronts of 732 to 1443 ppm. Therefore, it was observed that the values of total dissolved solids in some months and sites exceeded the maximum permissible limit of 1000 ppm, established by the Official Mexican Standard (NOM-001-SEMARNAT-2021 and NOM-127-SSA1-1994 for drinking water).

The pH values recorded in this study were slightly alkaline. In the Jamapa River basin, pH values ranging from 6 to 9 have been recorded (Houbron 2010). The pH values at the mouth of the Jamapa River are among the values registered by SEMARNAT (2002) at the Tejar station and those established by the Official Mexican Standard (NOM-127-SSA1-1994), which ranged from 6.5 to 8.5 for drinking water. It is important

Table 3. Abundance and diversity of megalopae collected in the inlet of the River Jamapa, Boca del Río, Veracruz, during 2017 and 2018. H: diversity, ITBOCA: Instituto Tecnológico de Boca del Río, ICIMAP: Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana, S: specific richness, J: equity. In bold is the greatest abundance and diversity.

Species	Venecia					Estero					ICIMAP					Barco					ITBOCA					
	Sep	Nov	Jan	Mar	May	Sep	Nov	Jan	Mar	May	Sep	Nov	Jan	Mar	May	Sep	Nov	Jan	Mar	May	Sep	Nov	Jan	Mar	May	Total
C. sapidus	67	4	15			66	2	1	1		12	1	14	1	17		201	142	1		6	1	45	9	7	613
P. herbstii																								9	1	10
A. ricordi	36			1		24	61	1			24	3	10					21		5	2			1	8	197
P. gracilis	10					1	1			2			1		23		10				115	1	6	5	6	181
M. vocator	500	17	9		3	340	70			1	310	23	190		3		2	2	1	4	532	73	72	12	10	**2174**
M. burgersi	367	50	12		1	460	96			1	125	37	130		8	1	54	67	1		598	67	54	22	5	**2156**
U. cordatus						1	3				1						38	23			1					67
Total	980	71	36	1	4	892	233	2	1	4	472	64	345	1	51	1	305	255	3	9	**1254**	142	177	58	37	5398
S	5	3	3	1	2	6	6	2	1	3	5	4	5	1	4	1	5	5	3	2	6	4	4	6	6	
H'	1.53	1.08	1.56		0.81	1.46	1.73	0.99		1.5	1.28	1.29	1.36		1.71		1.42	1.64	1.59	0.99	1.41	1.11	1.72	**2.24**	**2.4**	

Table 4. Generalized linear model. Relationship between the abundance of Brachyura species (B) in the megalopa stage with the sites, months, and environmental factors in the estuary of the Jamapa River, Boca del Río, Veracruz, Mexico. DO: dissolved oxygen, Temp: temperature.

Parameter	*A. ricordi*			*C. sapidus*			*M. burgersi*			*M. vocator*			*P. gracilis*			*U. cordatus*		
	B	X^2	*P*	B	X^2	*P*	B	X^2	*P*	B	X^2	*P*	B	X^2	*P*	B	X^2	*P*
Intersection	27.29	54.71	<0.05	7.97	15.55	<0.05	-33.73	860.36	<0.05	-30.42	546.68	<0.05	-14.03	5.73	<0.05	48.3	24.7	<0.05
DO (mg L^{-1})	0.38	11.09	<0.05	0.43	50.05	<0.05	0.13	10.28	<0.05	0.61	255.37	<0.05	-1.89	80.66	<0.05	-0.96	0.71	0.4
pH	-2.98	41.25	<0.05	-0.84	10.58	<0.05	4.45	1193.27	<0.05	3.85	527.2	<0.05	2.45	7.98	<0.05	-2.47	1.23	0.27
Temp (°C)	-0.16	14.47	<0.05	-0.03	2.99	0.084	0.21	495.55	<0.05	0.19	296.32	<0.05	0.22	29.96	<0.05	-1.18	6.3	<0.05
TDS (ppm)	3.8E-05	0.58	0.45	3.2E-05	317.27	<0.05	1.3E-06	0.23	0.635	1.0E-03	20.8	<0.05	4.9E-05	32.67	<0.05	7.1E-05	11.5	<0.05
Salinity	-0.06	23.25	<0.05	-0.02	13.39	<0.05	-0.05	450.42	<0.05	-0.08	604.37	<0.05	0.06	14.56	<0.05	0.37	9.32	<0.05

to mention that these pH values are related to a concentration of hydroxyl ions, which provide a buffer effect to the water, avoiding its acidification (Bates 1973).

Regarding dissolved oxygen, Castañeda-Chávez et al. (2017) found an average of 5.63 mg L^{-1} in the dry season, 5.35 mg L^{-1} in the rainy season, and 5.55 mg L^{-1} in the cold fronts weather season. The mentioned values are consistent with the dissolved oxygen values recorded in this study. It is important to highlight that according to the ecological criteria for water quality (CE-CCA-001/89 1989), the recommended value for the protection and adequate development of aquatic life should be 5 mg L^{-1}. In September, November, and January, the water quality decreased. In this zone, there is a strong influence of anthropogenic activities that discharge their wastewater into this river (Castañeda-Chávez et al. 2017, Salas-Monreal et al. 2020), in addition to a large amount of organic matter transported in the rainy season, which alters the concentration of dissolved oxygen.

In the Jamapa River estuary, salinity values between 10 and 20 have been recorded (Aké-Castillo et al. 2016). González-Vázquez et al. (2019) found salinity values from 6 to 11 in April in the Jamapa River estuary and from 15 to 21 in El Estero; likewise, they mention values less than 2 in September at both sites. In the present work, a wide variation of salinity was also observed with values from 0.97 ± 0.06 in September (rainy season) to 35.65 ± 0.01 in May (dry season); a clear relationship was observed between salinity values and climatic seasons reported for the Mexican humid tropics.

Assemblage structure of megalopae

The most abundant species corresponded to the genus *Minuca*; Thurman (1987) recorded six fiddler crab species in the coastal area from Tamaulipas to Yucatan. In Veracruz, the species *Leptuca panacea*, *L. spinicarpa*, *Minuca burgersi*, *M. rapax*, *M. marguerita*, *M. vocator*, and *M. virens* were generally recorded (Barnwell & Thurman 1984, Raz-Guzmán et al. 1992, Hernández-Aguilera et al. 1996, Raz-Guzmán & Sánchez 1996, Pérez-Mozqueda et al. 2014).

Raz-Guzmán & De la Lanza (1993), Domínguez et al. (2003), and Ruiz et al. (2013) mentioned that the blue crab *C. sapidus* is found in the neritic zone, from the mouth of the Rio Grande to the extreme south of the coast of the state of Campeche. Cházaro-Olvera et al. (2007a) mentioned that *Callinectes* megalopae are transported to the recruitment area, where the parents live. These sites suffer great physiological pressure because they change from seawater salinity of 35 to sites with values of 0 salinity. In addition, it is suggested that megalopae can be transported toward estuaries at distances of up to 160 km (Williams 1984). The main spawning event of *C. sapidus* occurs in spring and early summer, finding gravid females from mid-March to late November (Williams 1984), consistent with the present study since after the larvae development, the greatest abundance of megalopae occurred in September and November, except for ICIMAP, which has higher abundance values in January than in November.

The species *P. herbstii* was previously recorded by Peniche-Vera (1979), Sánchez (1980), and Arreguín-Sánchez (1982) at the Mandinga Lagoon, Veracruz, and by Cházaro-Olvera et al. (2006) at Laguna de Alvarado, Veracruz. Sandifer (1973) found that the larvae of *P. herbstii* are found in a range of 2 to 32 of salinity between June and September at a temperature of 25 to 28°C; these environmental factors values are consistent with what was found in the present study.

Aquino-Díaz (2015) mentioned that the species of *Ucides cordatus* is present in Tuxpan, Veracruz in mangrove areas; this coincides with the present work since only a few megalopae were found of this species; most were found at the Barco site. Oliveira (1946) reported a high relationship between the migration of *U. cordatus* and the decrease in salinity. In addition, the increase in megalopa number is associated with the reproductive season in the rainy season. Given the above, after the zoea, it is common to find megalopae of *U. cordatus* in November. Cházaro-Olvera et al. (2007b) mentioned that the highest abundance of *P. gracilis* was found to have a salinity average of 7.06 ± 4.49 in July. On the other hand, Epifanio et al. (1984) registered the highest abundance of *C. sapidus* megalopae in September; both studies correspond to the rainy season in the present study, where the greatest abundance occurred in September.

In the present study, seven species of brachyurans were found in the megalopa stage. Cházaro-Olvera et al. (2006) also found seven species in the Alvarado estuarine lagoon system, Veracruz. However, the abundance was considerably higher with more than 90,000 individuals, unlike what was found in the present study, where a little more than 5000 individuals were collected; this is related to the type of sampling since Cházaro-Olvera et al. (2006) used a Renfro-type net in the artificial inlet of the Camaronera Lagoon, which allows a higher concentration of megalopae during the high tide period. Regarding the diversity of Shannon-Wiener, Barba-Macías (2016) diversity values of 0.29 to 1.99 bits ind^{-1} in the Papaloapan River, results like these were obtained in the present study. Regarding the magnitude of the values of the diversity index, Staub et al. (1970) mentioned that a Shannon-Wiener diversity value of less than 1 is found in places with low environmental stability, values of 1 to 2 in places with intermediate stability, and values greater than 3 in places with stable environmental conditions. Therefore, based on the data obtained in this study, the Jamapa River estuary has low to intermediate stability.

In conclusion, of the seven brachyuran species collected in the megalopa stage, the species of the genus *Minuca* were the most abundant, and they responded to seasonal changes of the five environmental factors measured in this study (temperature, salinity, dissolved oxygen, pH and total dissolved solids). It is important to highlight that extremely high values of total dissolved solids were recorded because of anthropic influence on the Moreno Stream located in the northern zone of the estuary, which can influence the kind of species present in the system. On the other hand, the pH values were between 7 and 8, so the components of the system function as important buffers for the aquatic conditions of the estuary and the discharge of the Jamapa River towards the VRS National Park. The most abundant species were *M. vocator* and *M. burgersi*, species related to low-salinity estuarine environments. The highest abundance of megalopae occurs in September during the rainy season, associated with the main reproductive peak during the dry season. According to the diversity values obtained in this study, the Jamapa River estuary has intermediate stability.

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