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Recruitment of *Callinectes sapidus* Rathbun 1896 Megalopae from Three Southwestern Gulf of Mexico Lagoon-system Inlets

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Abstract: This study evaluated the highest recruitment time of *Callinectes sapidus* (Rathbun, 1896) megalopae and the relation of megalopae density with temperature, salinity, velocity and direction of current flow in three inlets of the Southwestern portion of the Gulf of Mexico. Collections were made at night, using for the capture a conical 243-mm mesh net. The total abundance of *C. sapidus* for the three coastal systems was of 2,579,725 megalopae. The average temperature was of 28.23±1.37°C, salinity of 23.54±7.10 psu and stream velocity of 0.39±0.18 m sec^{-1}. During the study, recruitment peaks were observed between 22:00 and 02:00 h. The maximal recruitment was registered in the SM river inlet, whereas Puerto Real inlet representing the lowest recruitment registered. The correlation between salinity and megalopae density was significant (p = 0.05) in the three coastal systems. The highest density was registered when salinity was > 23 psu. Recruitment was related to the influx of seawater towards the coastal systems. There were no significant differences in magalopae density (p = 0.05) between consecutive sampling cycles.

Key words: Recruitment, crabs, *Callinectes*, megalopae, lagoon, density

INTRODUCTION

Crabs of the *Callinectes* genus are among the dominant benthic macroinvertebrates along the Atlantic coast of North and South America (Rosas *et al*., 1994; Cházaro-Olvera *et al*., 2000). The geographic range of *C. sapidus* Rathbunae 1896 extends occasionally from Nova Scotia, Maine and northern Massachusetts to northern Argentina, including Bermuda and the Antillas. Additional records of *C. sapidus* from the Mediterranean and western European coasts are likely due to larval introductions via ship ballast water (Williams, 1984; Ruíz, 1993; Guerin and Stickle, 1997). In the southern Gulf of Mexico (GOM), the blue crab, *C. sapidus* Rathbun 1896 supports important commercial fisheries (Alvarez and Calderón, 1996).

Two migratory events occur during the life cycle of *C. sapidus*, during the first event the adults are transported to the estuary inlet (Williams, 1984); whereas the second event is characterized by the return of megalopae to the adult habitat (Lukenbach and Orth, 1992; Brumbaugh, 1996; Cházaro-Olvera and Peterson, 2004). In this regard, adult blue crabs stock size is determined by the successful recruitment of planktonic postlarvae (Wenner *et al*., 2005).

Recruitment of brachyuran megalopae is highly episodic (Queiroga *et al*., 1994; Queiroga, 1996; Abello and Guerao, 1999). The suitability of recruitment in the estuarine habitat depends on numerous

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behavioral and environmental factors (Dittel and Epifanio, 1982; Olmi *et al.*, 1993; Miller and Emlet, 1997), often associated with tidal range, wind direction and variations in salinity or temperature (Jones and Epifanio 1995; Mense *et al.*, 1995; van Montfrans *et al.*, 1995; Rabalais *et al.*, 1995; Wrona *et al.*, 1995). During efflux, some chemical signals and negative phototaxism stimulate megalopae to abandon the water column (Little and Epifanio, 1991; Forward and Rittschof, 1994; Forward *et al.*, 1997). In this way, recruitment density is also associated with this behavioral pattern, since maximal swimming activity is present at night (Epifanio *et al.*, 1984).

Although recruitment is commonly considered as one of the major events affecting benthic populations, knowledge about several factors related with this process is still poor, especially those associated with tropical environments (Paula *et al.*, 2003). Megalopae recruitment patterns of *C. sapidus* in the estuarine inlets from the southwestern GOM are unknown; therefore, the present study was aimed at identifying the recruitment peaks and determining the relation between recruitment of *C. sapidus* megalopae and environmental variables, such as velocity and driven currents, tidal flooding, salinity and temperature, in three GOM estuaries of different latitude.

MATERIALS AND METHODS

Three estuarine inlets in three Mexican states from the southwestern portion of GOM were sampled in autumn 2003. The localities surveyed were: Camaronera Lagoon, Alvarado (CV), Veracruz

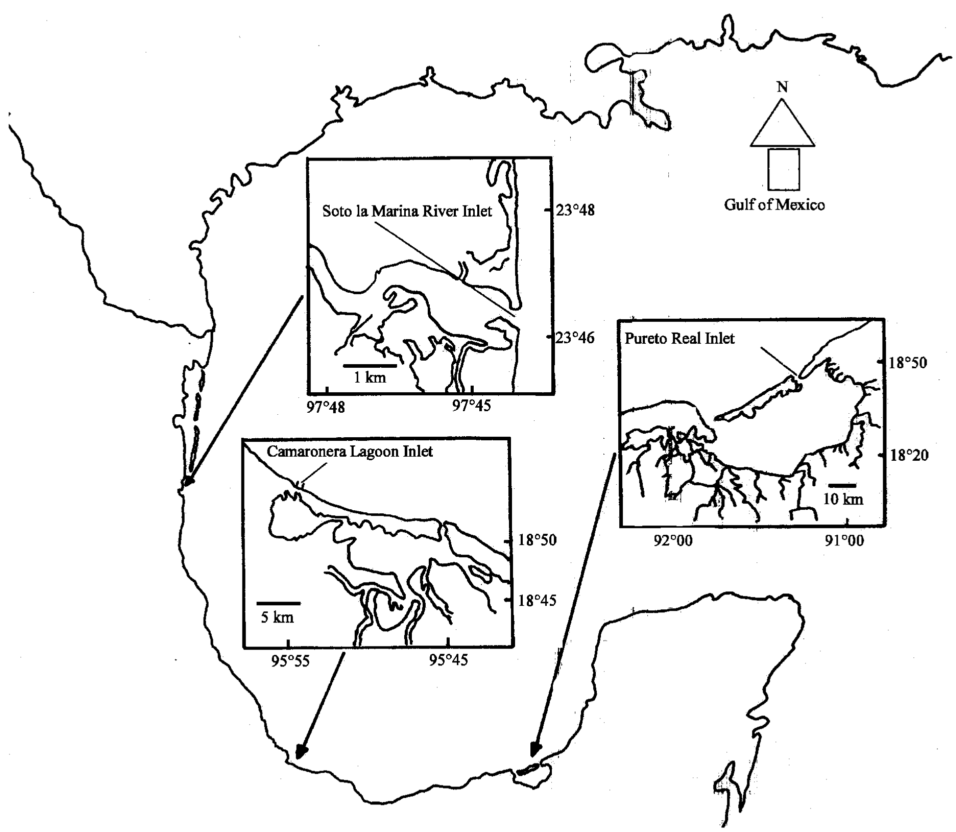

Fig. 1: Locations of sampling sites in the GOM

State (18°50′ and 18°52′ LN; 95°54′ and 95°58′ LW) on September 29 and 30; Soto la Marina River (SM), Tamaulipas State (23° 45′55" and 23°46′ 27" LN; 97° 44′05" and 97° 44′21" LW) on October 15 and 16; and Puerto Real, Términos Lagoon (PR), Campeche State (18° 30′ and 18° 40′LN; 92°00′ and 92° 50′ LW) on November 1 and 2 (Fig. 1).

These areas constitute transitional subsystems between marine and brackish environments, exerting a strong influence on the migration and distribution of organisms and on biodiversity levels within the lagoon-estuary systems. The SM inlet is located in the Laguna Madre System with a mean depth of 1.0 m. This system has a sand barrier island parallel to the coast that, in conjunction with land drainage, influences sediment composition of the estuary. The CV inlet is located at the Camaronera lagoon of the Alvarado Lagoonal System and was built during 1980's. It includes two artificial pipes, which allow for water exchange between the GOM and the lagoon system by the hydrodynamic effect. This lagoon has a mean depth of 2.2 m and extensive meadows of *Ruppia maritima* (Linnaeus, 1753). The PR inlet, one of several inlets of Términos lagoon, has a mean depth of 2.0 m and is located at the eastern portion of the lagoonal system. It is a natural channel and the bottom is covered with *Thalassia testudinum* Banks and Soland. ex Koenig (1805) and *Halodule beaudettei* (den Hartog) den Hartog 1970. The most common sediments are sandy-limestone (Cházaro-Olvera *et al.*, 2002).

Two sampling cycles were run at CV and SM and one at PR, for a total of 5 sampling cycles. Collections were made over a 13 h period with a 1.0 m length and 0.5 m diameter conical plankton net constructed of 243 μm mesh. Collections were filtered for 15 min every hour and samples were placed in labeled plastic bags with 4% formalin solution. Simultaneously, we recorded water temperature with a Brannan thermometer of 10 to 110°C, salinity (psu) with a salinometer, model YSI 33, current velocity (m sec^{-1}) with a Foretsry 2030 r6 flowmeter and flow direction.

All megalopae were identified according to the descriptions in Rocha-Ramírez *et al.* (1996) and Cházaro-Olvera (1996). Megalopae density was standardized as nnmber/1000 m^3 following APHA-AWWA-AWRA (1998) and data were normalized with logarithm ($\log_{10}$). Correlations of density vs. water temperature, salinity and current velocity were tested with Pearson's correlation analysis. Density between the two consecutive sampling days in each site was compared by means of variance analysis (ANOVA) (Sokal and Rohlf, 1995).

RESULTS

Environmental Variables

In SM during cycle I, temperature oscillated between 27 and 29°C; the lowest salinity value was registered at 18:00 h (21 psu) and the highest at 03:00 h (31 psu); current velocity was relatively constant, with an interval of 0.36 m s^{-1} as lowest value and a high of 0.41 m s^{-1}; influx was constant (Fig. 2A).

In cycle II, temperature oscillation was from 28 to 29°C; the lowest salinity was registered at 19:00 h with 20 psu and the highest at around 00:00 and 01:00 h with 24 psu; current velocity during the first five hours was 0.32 m sec^{-1}, diminishing to 0.24 m sec^{-1} starting at 23:00 h in cycle II; influx was recorded until 1:00 h (Fig. 2B).

In CV during cycle I, the temperature was initially of 30°C and 29°C towards the end; salinity had the lowest value at 19:00 h (8.8 psu) and the highest at 23:00 h (32 psu); the lowest current velocity value was registered at 19:00 h (0.29 m s^{-1}) with an increment of up to 0.9 m s^{-1} at 00:00 h. During the first two hours, current direction was efflux and from 20:00 h it shifted to influx until the end of the cycle (Fig. 3A). In cycle II, the temperature was constant (29°C); during the first hours, the lowest salinity value was 8 psu with an increment of up to 31 psu at 01:00 h; the registered current velocity was 1.2 m sec^{-1} at 19:00 h and 0.17 m sec^{-1} at 23:00 h. Efflux was registered from 18:00 h to 22:00 h; from 23:00 h to 2:00 h, a constant influx was registered (Fig. 3B).

In PR, only one sampling cycle was conducted in this system. The highest temperature value was 27°C at 20:00 h and the lowest, 24°C, at around 5:00 h; salinity showed an increasing tendency, with

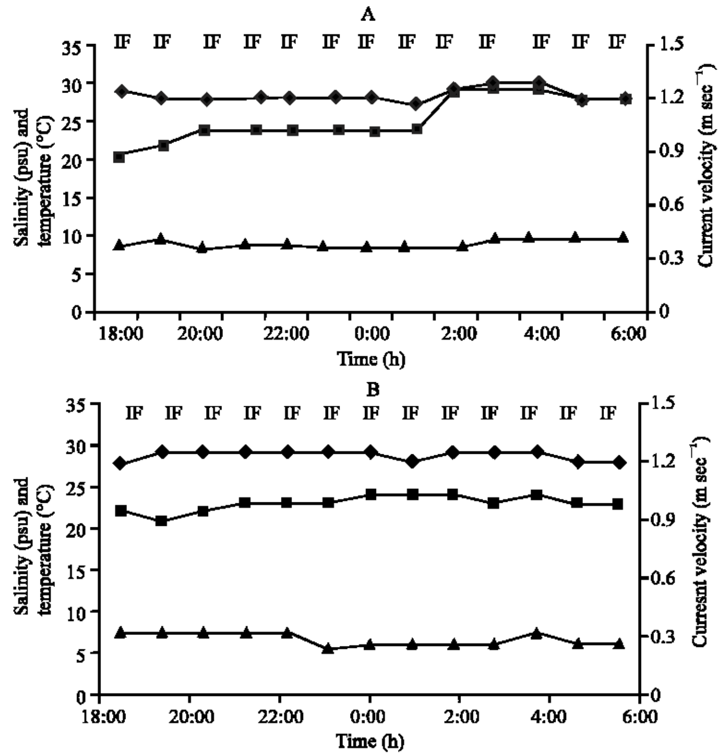

Fig. 2: Plot of (A) environmental variables, in the Camaronera lagoon inlet, Veracruz State in Cycle I and (B) Cycle II Salinity (■), Temperature (♦), Current velocity (▲), IF = influx, EF = efflux

Table 1: Recruitment of megalopae of *Callinectes sapidus* in three GOM estuaries of different latitude (number of megalopae/1000 m^3). Soto la Marina River (SM), Tamaulipas State (23° 45′55" and 23° 46′ 27" LN); Camaronera Lagoon, Alvarado (CV), Veracruz State (18° 50′ and 18° 52′ LN); and Puerto Real, Términos Lagoon (PR), Campeche State (18° 30′ and 18° 40′LN)

Hour of sampling	Cycle 1 SM inlet	Cycle 2 SM inlet	Cycle 1 CV Lagoon inlet	Cycle 2 CV Lagoon inlet	CV cycle 1 PR inlet
18:00	980	0	0	0	50
19:00	1700	0	0	0	300
20:00	89460	19420	0	0	20
21:00	367090	19930	245	0	0
22:00	62120	30570	1700	900	0
23:00	12500	276790	3390	4650	4560
00:00	0	476450	1500	6320	8560
01:00	32650	223690	1200	9630	200
02:00	84190	211110	1120	7560	310
03:00	112530	0	690	2240	650
04:00	210470	156930	570	1660	160
05:00	61400	1250	430	500	340
06:00	67900	250	0	480	345
Total	1102990	1416390	10845	33940	15495

the lowest value of 23 psu between 18:00 and 19:00 h, whereas the highest value with 29 psu was recorded at 00:00 h; current velocity was relatively constant during the entire cycle. Initially, the current velocity recorded was of 0.32 m sec^{-1} from 18:00 h to 22:00 h, later, at 23:00 h, the lowest value was registered (0.24 m sec^{-1}), showing an increment starting at 2:00 h until reaching 0.32 m sec^{-1}. The influx was constant during the entire cycle (Fig. 4).

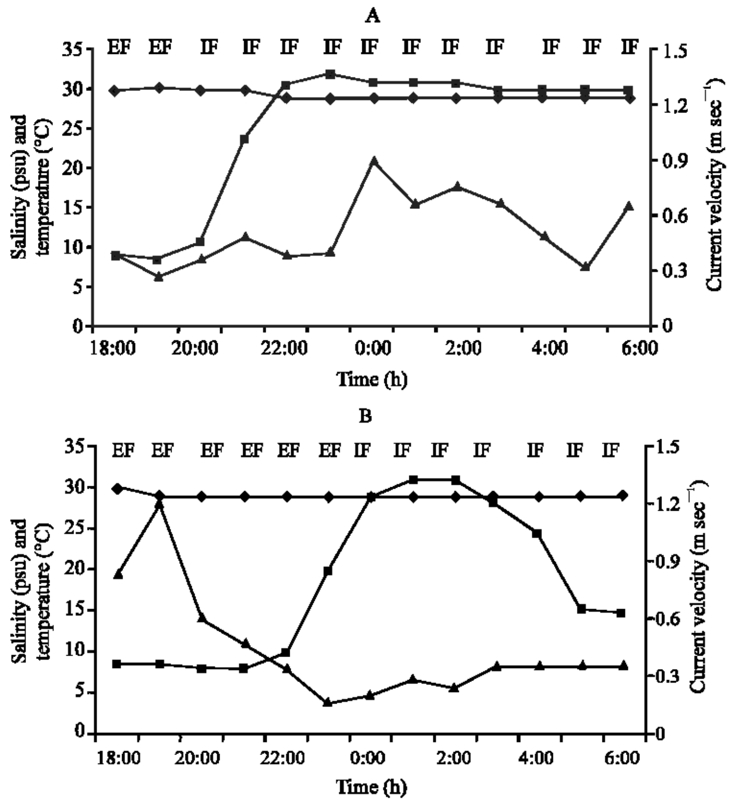

Fig. 3: Plot of (A) environmental variables, Soto La Marina River inlet, Tamaulipas State in Cycle I and (B) Cycle II. Salinity (■), Temperature (♦), Current velocity (▲), IF = influx, EF = efflux

Recruitment Density

In SM, two recruitment peaks were obtained for each cycle. During cycle I, the lowest density was 12,500 megalopae/1000 m^3 at 23:00 h, whereas the highest value was 367,090 megalopae/1000 m^3 at 21:00 h (Table 1). In cycle II, the lowest density was at 21:00 h with 19,930 megalopae/1000 m^3 and the highest density was registered at 00:00 h with 476,450 megalopae/1000 m^3 (Table 1). A significant correlation between densities and the environmental variables was found for both cycles (p = 0.05) (Table 2) with the exception of temperature in cycle II. The highest correlation values were with salinity.

The variance analysis (ANOVA) used to compare both cycles did not evidence significant differences (p = 0.05). In CV, one recruitment peak was obtained for each cycle. A total of 26 samples were analyzed and a total of 44,785 *C. sapidus* megalopae were obtained. During cycle I, the lowest density of *C. sapidus* was 245 megalopae/1000 m^3 at 21:00 h, whereas the highest value was 3, 390 megalopae/1000 m^3 at 23:00 h (Table 1). In cycle II, the lowest density was at 06:00 h with 480 megalopae/1000 m^3 and highest density was registered at 23:00 h with 9, 630 megalopae/1000 m^3 (Table 1). A significant correlation between densities and the environmental variables was found for both cycles (p = 0.05) (Table 2) with the exception of temperature, which remained constant, in cycle II. The correlation coefficient was larger with salinity and temperature.

The variance analysis (ANOVA) used to compare between both cycles did not evidence significant differences (p = 0.05).

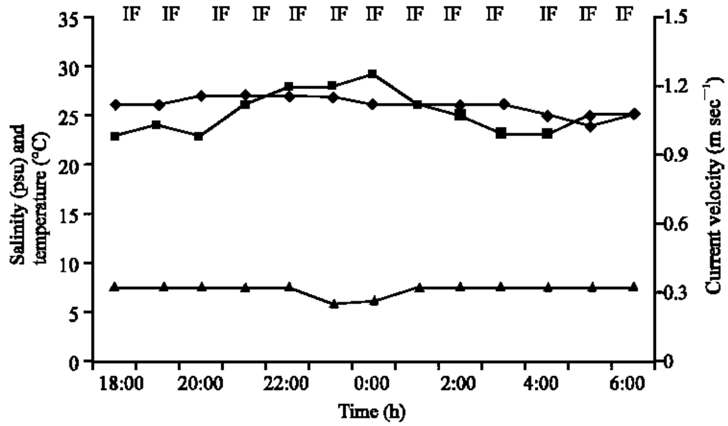

Fig. 4: Plot of environmental variables, in the Puerto Real Lagoon Inlet Terminos lagoon, Campeche State. Salinity (■), Temperature (♦), Current velocity (▲), IF = influx, EF = efflux

Table 2: Summary of the correlation coefficients between magalopae density and three environmental variables

Variables	Cycle I salinity (psu)	Temperature (°C)	Current velocity (m sec^{-1})	Cycle salinity (psu)	Temperature (°C)	Current velocity (m sec^{-1})
Camaronera lagoon inlet	0.811	0.634	0.465	0.834	*	0.53
Soto La Marina River inlet	0.877	0.617	0.419	0.776	0.272**	0.95
Puerto Real inlet	0.897	0.879	0.53	0.971	0.971	0.971
Términos lagoon	0.95	0.81	0.745			

All coefficients are significant (p = 0.05) except those noted by ** (p = 0.05), * constant

In PR, one recruitment peak was registered. A total of 13 samples were analyzed and 15,560 megalopae of *C. sapidus* were obtained. The highest recruitment density was registered at 00:00 h with 8,560 megalopae/1000 m^3 and the lowest value was registered at 18:00 h with 50 megalopae/1000 m^3 (Table 1). A significant correlation between *C. sapidus* density and the environmental variables was found (p = 0.05) (Table 2).

DISCUSSION

The seasonal species abundance is associated, besides salinity and temperature, with current velocity and direction as well as tide level; these factors regulate vertical migration and, consequently, megalopae recruitment to estuarine systems during tide influx (Zimmerman and Minello, 1984; Castro *et al.*, 1990; Chen *et al.*, 1997).

In CV, artificial inlet, Cházaro-Olvera and Peterson (2004) registered an average temperature for September of 35.0±0.0 and 29.0±1.0°C. Values registered in this study are within this range (29 to 30.5°C) For the SM river inlet of Tamaulipas State, the registered temperature (27 to 29°C) is similar to that reported by Castro *et al.* (1990) for October. Smith (1984) registered in the PR inlet of Términos lagoon, during November, a temperature of 25°C, also Yañez-Arancibia *et al.* (1988) reported a similar value (26.4°C, mean); Vázquez *et al.* (1988) reported an average temperature of 25.7°C for this locality, whereas the range reported in this study was from 24 to 27°C.

The typical range of current velocity is 0.50 to 1 m sec^{-1}. In the studied coastal systems, the current velocity averages were: CV artificial inlet, 0.52 m sec^{-1} in cycle I and 0.47 m sec^{-1} in cycle II; SM river inlet, 0.39 m sec^{-1} in cycle I and for cycle II, 0.30 m s^{-1} and the PR inlet had an average current velocity of 0.30 m sec^{-1}. Tide level and tide currents are a major source of turbulence energy and mixture towards estuarine systems and are used by megalopae in the recruitment process (Hartnoll and Hawkins, 1982; Kennish, 1986; Chen *et al.*, 1997).

Assuming an average velocity current of 0.5 m s^{-1}, an organism could be transported 50 km in six days using the selective transport of tide current; in the present study, current velocity interval was from 0.30-0.49 m s^{-1}. Mechanisms that could potentially favor transport of organisms include the reaction to exogen factors, such as shifts in temperature, salinity and hydrostatic pressure (Tankersley and Forward, 1994).

Tankersley *et al.* (1995), in laboratory conditions, found that *C. sapidus* megalopae rise in the water column as a response to an increment in salinity values, however; these authors also determined that natural shifts in hydrostatic pressure could be detected by the organisms and the response is a movement to the bottom. In this way, megalopae are sensitive enough to detect low salinity values during influx (De Vries *et al.*, 1994). In the present study, maximal recruitment density of *C. sapidus* megalopae was registered when salinity values were incremented due to influx and tide level. Hence, this increment could represent a signal to initiate the ascent of megalopae in the water column.

A regulation model of selective transport due to the tide current could explain these results. Megalopae are stimulated to rise in the water column due to increments in salinity, pressure and turbulence generated by tide current variations; subsequently, organisms swim in the water column during tide influx towards the estuarine systems. After influx, turbulence drops to lower levels and megalopae descend to the bottom and leave the estuary until the next nocturnal tide influx. On the other hand, megalopae do not rise during the day-time influx because light inhibits the ascent; hence, megalopae recruitment transport in coastal system inlets is discontinuous (Forward and Rittschof, 1994; Welch and Forward, 2001).

In coastal systems, inlets show increments of salinity positively associated with current velocity due to the influx by the tide effect. In this way, in the three studied systems, variations in megalopae recruitment were associated with variations in current velocity.

The capability of most estuarine organisms to penetrate into the estuaries is determined by the dramatic salinity shifts. Such is the case of megalopae of the genus *Callinectes* (Guerin and Stickele, 1992; Cházaro-Olvera and Peterson, 2004). Organisms abundance in estuarine systems is the result of reproductive and transport mechanisms influenced by tide influx and currents (Epifanio *et al.*, 1984). According to this, most megalopae were captured during influx, associated with salinity values over 23 psu, whereas a reduced number were captured during efflux.

The high recruitment density of blue crab megalopae is explained by their tolerance to a wide salinity range, from 0.5-38 psu, being considered as an eurihaline and eurithermic species (Williams, 1984; Raz-Guzmán *et al.*, 1986). In addition, penetration season of megalopae to estuarine systems has been registered at the end of summer, from August to October (Boylan and Wenner, 1993; Rabalais, 1993).

In this study, maximal recruitment was registered in the SM river inlet with 2, 519, 380 megalopae. For the CV artificial inlet, the registered recruitment was of 10, 845 megalopae in cycle I and 33, 940 megalopae in cycle II. *C. sapidus* is a particularly important species in the Términos lagoon, which has led to several reports related with density and distribution of adult organisms (Román-Contreras, 1986). However, the recruitment registered in PR inlet was of 15, 560 megalopae, representing the lowest recruitment registered for this species. From the total density percentage, 98.94% of the megalopae were captured during influx and 1.06% during efflux.

Previous reports have documented the presence of *C. sapidus* in the Atlantic coast of the United States and the GOM. Dittel and Epifanio (1982) considered *C. sapidus* as a common species in Delaware Bay, they registered average densities of 5, 500 megalopae/1000 m^3; this species has been collected at high densities in Chesapeake Bay at the end of summer (Sandifer, 1973). During a 24 h cycle, Epifanio *et al*. (1984) registered, in September, a maximal recruitment of *C. sapidus* megalopae of 9, 200 megalopae/1000 m^3 at 23:00 h during influx period. In Charleston Harbor (South Carolina), Mense and Wenner (1989) captured a total of 6,762 *C. sapidus* megalopae, with a maximal recruitment of 26, 500 megalopae/1000 m^3 during October at Creek inlet, with a salinity value of 32 psu and a temperature of 26°C.

In this study, maximal recruitment densities were registered in the CV artificial inlet and in the SM river inlet, located in Veracruz and Tamaulipas states, respectively; where fishing activities of this species have reached an acceptable degree of development. It has been estimated that 90% of the domestic consumer market is covered by this region. Catchment statistics of GOM from 1985 to 1990 revealed an interval between 7, 000 to 9, 000 metric tons per year, with the following percentages: Yucatán, 3.97%; Tabasco, 12.60%; Campeche, 14.35%; Veracruz, 31.63% and Tamaulipas, 37.45% (Rodríguez de la Cruz, 1994).

The ANOVA conducted for each site did not show significant differences between sampling cycles, indicating that recruitment is a continuous global process, limited by seasonal and temporal reproductive pulses, as well as habitat dispersion responsible for organisms establishment (Gracia and Kenser, 1980).

In conclusion, maximal recruitment of megalopae occurs at around 23:00 h from August to October in the estuarine systems of GOM and Atlantic coasts, but this condition could change over the years. According to Rabalais *et al*. (1995), megalopae recruitment is not synchronous in GOM. This suggests that megalopae influx to estuarine systems is not regular; instead, it presents pulses also called "recruitment peaks" (Loneragan *et al*., 1998). In the present study, the high densities recorded in the CV artificial inlet and the SM river inlet during August to October could be explained by these "recruitment peaks". In the same way, Goodrich *et al*. (1989) found that megalopae recruitment in Chesapeake Bay had a density pattern represented by 13 peaks during October (1985), August and September (1986). Meredith (1982), in Delaware Bay found a high recruitment density of *C. sapidus* during September and October in consecutive years. Boyland and Wenner (1993) found that a high megalopae recruitment pattern occurred from August to October of 1987 and 1988 at Charleston Harbor, South Carolina. The life cycle of organisms is an important factor to consider in terms of recruitment. The recruitment peaks in these months suggest that spawning occurs during summer, because of this, during winter and spring, the high densities correspond to juveniles, as in the PR inlet, Términos lagoon, where the lowest densities of megalopae were registered.

Considering the relationships between megalopae density and enviroumental variables, it is possible to establish that megalopae recruitment is not only determined by factors associated to tide conditions but also by other variables. Some studies are based on the postulation that arrival of megalopae to settlement sites is facilitated by chemical and visnal variables that determine some orientation responses. These chemical factors have been extensively studied for several invertebrates, including mollusks, lepadomorph barnacles, lobsters and crabs; in the case of megalopae, chemical factors are related with habitat selection (Boudreau *et al*., 1993; Welch *et al*., 1997; Rittschof *et al*., 1998; Diaz *et al*., 1999).

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