

## Density of mysis of *Penaeus aztecus* Ives, 1891 on a reef in the Southwest of the Gulf of Mexico

## Densidad de mysis de *Penaeus aztecus* Ives, 1891 en un arrecife del suroeste del Golfo de México

Sergio Cházaro-Olvera<sup>1\*</sup>, Ángel Morán-Silva<sup>1</sup>, Rafael Chávez-López<sup>1</sup>, Horacio Vázquez-López<sup>1</sup>, Asela del Carmen Rodríguez-Varela<sup>1</sup>

Recibido: 24 de junio de 2020.

Aceptado: 22 de noviembre de 2020.

Publicado: diciembre de 2020.

### ABSTRACT

**Background.** The Parque Nacional Sistema Arrecifal Veracruzano (PNSAV) is in the southern Gulf of Mexico and supports an important shrimp fishery based on three species of Dendrobranchiata: the brown shrimp, *Penaeus aztecus*, the white shrimp, *P. setiferus* and the pink shrimp, *P. duorarum*. **Objective.** Analyze the distribution and abundance of *P. aztecus* during the mysis stage and determine its relationship with environmental factors in the PNSAV. **Methods.** We measured temperature, salinity, and dissolved oxygen *in situ*. The planktonic samples from four transects were collected during cold fronts and rainy weather conditions from 2011 to 2013. **Results.** In rainy conditions the temperature varied from  $27.49 \pm 0.46$  to  $29.98 \pm 0.02^\circ\text{C}$ , salinity from  $32.18 \pm 0.06$  to  $35.40 \pm 0.52$ , and dissolved oxygen from  $3.64 \pm 0.13$  to  $6.18 \pm 0.64 \text{ mgL}^{-1}$ ; during cold fronts the temperature varied from  $23.21 \pm 0.05$  to  $25.74 \pm 0.37^\circ\text{C}$ , salinity from  $34.59 \pm 0.39$  to  $35.84 \pm 0.17$ , and dissolved oxygen from  $4.04 \pm 0.06$  to  $6.02 \pm \text{mgL}^{-1}$ . The highest average density with  $6,938 \pm 326$  mysis  $100 \text{ m}^{-3}$ , was found during rainy season in 2011 in the southern transect nearshore, followed by  $3,321 \pm 339$  mysis  $100 \text{ m}^{-3}$  in the offshore-south-central transect during cold fronts weather conditions in 2013, and  $3,056 \pm 236$  mysis  $100 \text{ m}^{-3}$  in the south-central foreshore transect during cold fronts weather condition in 2011. **Conclusions.** The highest density of *P. aztecus* during mysis stage was recorded in southward foreshore area from PNSAV, during rainy conditions and related to large values of dissolved oxygen concentrations.

**Key words:** coral reef, ecology, fisheries, larvae, shrimp brown

### RESUMEN

**Antecedentes.** El Parque Nacional Sistema Arrecifal Veracruzano (PNSAV) está ubicado en el sur del Golfo de México y soporta una importante pesquería de camarones basada en tres especies de Dendrobranchiata: el camarón café, *Penaeus aztecus*, el camarón blanco, *P. setiferus* y el camarón rosado, *P. duorarum*. **Objetivo.** Analizar la distribución y abundancia de *P. aztecus* en estadio de mysis y determinar su relación con los factores ambientales en el PNSAV. **Métodos.** Se midió la temperatura, la salinidad y el oxígeno disuelto *in situ*. Se recolectaron muestras planctónicas de cuatro transectos durante frentes fríos y condiciones climáticas lluviosas de 2011 a 2013. **Resultados.** La temperatura varió de  $27.49 \pm 0.46$  a  $29.98 \pm 0.02^\circ\text{C}$ , la salinidad de  $32.18 \pm 0.06$  a  $35.40 \pm 0.52$  y el oxígeno disuelto de  $3.64 \pm 0.13$  a  $6.18 \pm 0.64 \text{ mgL}^{-1}$  en época de lluvias. Durante los frentes fríos, la temperatura varió de  $23.21 \pm 0.05$  a  $25.74 \pm 0.37^\circ\text{C}$ , la salinidad de  $34.59 \pm 0.39$  a  $35.84 \pm 0.17$  y el oxígeno disuelto de  $4.04 \pm 0.06$  a  $6.02 \pm \text{mgL}^{-1}$ . La densidad media más alta fue de  $6,938 \pm 326$  mysis  $100 \text{ m}^{-3}$ , que se encontró durante las lluvias en 2011 en el transecto sur, cercano a la costa, seguido por  $3,321 \pm 339$  mysis  $100 \text{ m}^{-3}$  en el transecto centro-sur, costa afuera durante los frentes fríos en 2013 y  $3,056 \pm 236$  mysis  $100 \text{ m}^{-3}$  en el transecto centro-sur durante los frentes fríos en 2011, en la zona de la costa. **Conclusiones.** La mayor densidad de mysis de *P. aztecus* se registró en la zona de playa al sur del PNSAV, durante las condiciones de lluvia y se relacionó con el aumento de las concentraciones del oxígeno disuelto.

**Palabras clave:** arrecife de coral, ecología, pesca, larvas, camarón café.

<sup>1</sup> Grupo Académico y de Investigación Acuática (GAIA), Carrera de Biología, Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México. Av. de los Barrios No.1, Los Reyes Iztacala, Tlalnepantla, Estado de México, 54090. México.

**\*Corresponding author:**

Sergio Cházaro-Olvera: chazaro@campus.iztacala.unam.mx, schazaro@gmail.com

**To quote as:**

Cházaro-Olvera, S., Á. Morán-Silva, R. Chávez-López, H. Vázquez-López & A. del C. Rodríguez-Varela. 2020. Density of mysis of *Penaeus aztecus* Ives, 1891 on a reef in the Southwest of the Gulf of Mexico. *Hidrobiológica* 30 (3): 233-242.

## INTRODUCTION

The Parque Nacional Sistema Arrecifal Veracruzano (PNSAV) is a highly productive ecosystem (Rodríguez-Gómez *et al.*, 2013), which is the reason it was designated as a Marine Protected Area under the classification of National Marine Park in 1992 (DOF, 1992, 2012) and has since been declared a Biosphere Reserve within the Man and the Biosphere Program (UNESCO, 2006) and registered as a Ramsar site (number 1346) (FIR, 2004). This reef system is comprised of several individual coral reefs, divided into northern and southern groups by the influence of the fluvial plume of the Jamapa River (Horta-Puga *et al.*, 2016).

Coral reef ecosystems such as PNSAV show an intricate architectural complexity (Jordán-Dahlgren, 2004), and support benthic and planktonic invertebrate assemblages of high biodiversity (Horta-Puga *et al.*, 2007). Some of the zooplankton biota found in the PNSAV have been studied, such as appendicularians, chaetognaths, pteropods, copepods, as well as fish species (Flores-Coto, 1965, 1974; Leal-Rodríguez, 1965; Vega-Rodríguez, 1965; Aguayo-Saviñón, 1966; Campos, 1980; 1980; Suárez, 1992; Campos-Hernández & Suárez-Morales, 1994; Ayala-Rodríguez *et al.*, 2016). Okolodkov *et al.* (2011) conducted a study on the biomass of plankton, reporting that invertebrates are the most abundant group of zooplankton in this reef system. Cházaro-Olvera *et al.* (2019) found that 13.77% of the community of zooplankton were decapods, including commercial species such as *Callinectes* sp., *Menippe* sp., and *Penaeus* sp. Around 259 species of Crustacea have been found in the PNSAV, nine species belonging to suborder Dendrobranchiata (Hermoso-Salazar & Arvizu-Coyotzi, 2015).

The PNSAV is located in the southern Gulf of Mexico and this region supports an important shrimp fishery based on three species of Dendrobranchiata: the brown shrimp, *Penaeus aztecus* Ives, 1891, the white shrimp, *P. setiferus* Linnaeus, 1767, and the pink shrimp, *P. duorarum* Burkenroad, 1939 (Gracia & Soto, 1990; Gómez-Ponce *et al.*, 2018).

The shrimp fishery is the fourth most important by catch volume in the Gulf of Mexico. Almost 80% of total capture corresponds to *P. aztecus*, caught mainly in the Tamaulipas and Veracruz states; in the latter, between the years 2004 and 2013, up to 10% of Gulf of México total catch was obtained (INP, 2014).

All *Penaeus* spp. stages are free living, the three commercially important penaeids spawn eggs in coastal waters, usually at depths of <50 m. The larvae become planktonic after hatching and transitioning through a series of stages, i.e., nauplius, zoea (including protozoea and mysis stages), and later, as tidal and wind-driven currents carry the larvae shoreward, the decapodid and juvenile stages eventually enter the estuary, become demersal, and move into coastal marshes to feed and grow before returning to shelf waters as sub-adults (Ditty & Alvarado, 2011; Martin *et al.*, 2014). Larval development is regular anamorphic (Anger, 2001), meaning that the appearance of characters and shape changes are gradual.

The brown shrimp, *P. aztecus*, typically occur from the west of the Mississippi River Delta to the Mexican State of Tamaulipas, however, they have also been caught from Martha's Vineyard, Massachusetts, to the Florida Keys, and in the west and south of the Gulf of Mexico, from Apalachicola Bay, Florida, to the northwestern coast of the Yucatan Peninsula, Mexico (Felder & Camp, 2009). Spawning peaks of *P. aztecus*

occur from December to April (Zimmerman & Minello, 1984; Rozas & Reed, 1993; Matthews, 2008) and a smaller, secondary peak occurs during late summer and early fall (Rogers *et al.*, 1993).

The pelagic larval stage dispersion is considered to be an advantage for this species because it enhances genetic flow and the colonization of new areas.

The transport of penaeid larvae and postlarvae is a complex process that includes mechanisms such as selective tidal transport induced by synchronized salinity changes (Hughes, 1969), endogenous rhythms (Hughes, 1972), or hydrostatic pressure (Forbes & Benfield, 1986; Rothlisberg *et al.*, 1995). Another hypothesis suggests that changes in coastal water temperature, salinity, and the direction of currents, in combination with the diel movements of larvae and postlarvae, facilitate their transport (Hughes, 1969; Rogers *et al.*, 1993). It has also been suggested that vertical migration, tidal and wind-forced currents are a possible mode of recruitment (Rothlisberg *et al.*, 1983; Wenner *et al.*, 1998).

To this day, larval transport and recruitment research has reached considerable progress, for example, on pre-settlement stages as their entrance to inshore habitats is related to biological and oceanographic variables. Despite these advances, knowledge about the larval recruitment of tropical fish species and invertebrates in the Caribbean Sea and Gulf of Mexico is scarce (Crales *et al.*, 2002), due to this in this contribution were analyzed the distribution and abundance of *P. aztecus* mysis stage and the relationships to environmental factors in PNSAV.

## MATERIAL AND METHODS

The PNSAV is located on the continental shelf of the state of Veracruz, off the coast of Boca del Río and Alvarado municipalities, in the southern Gulf of Mexico (19°00'00"–19°16'00"N, 95°45'00"–96°12'00"W). The park consists of 23 reef banks divided by the estuarine inlet of the Jamapa River; 12 reefs are in front of the port of Veracruz (northern group) and 11 more are in front of the Municipality of Antón Lizardo (southern group). In total, they occupy an area of 52,283 hectares. The park presents islands and platform reefs (Granados-Barba *et al.*, 2007; Horta-Puga *et al.*, 2007).

The Gulf of Mexico is in a transition area; therefore, seasonal variability is less pronounced in the southern tropical half. For that reason, the climate in the PNSAV cannot be divided seasonally; instead we used dry and rainy seasons and cold fronts (Carrillo *et al.*, 2007). Cold fronts are anticyclonic cold wind currents that enter the Gulf of Mexico from North America, generating strong northern winds, with occasional precipitation and temperature drops (Carrillo *et al.*, 2007; Ojeda *et al.*, 2017), this season occurs from October to March. The 'dry weather conditions' occur from May to June, with scarce rainfall and higher temperatures. The 'rainy weather conditions' occur from July to September, when temperatures and precipitation increase and winds are weaker (Carrillo *et al.*, 2007; Zavala-Hidalgo *et al.*, 2014). The average annual temperature in the reef zone is 26°C (Chávez *et al.*, 2007).

**Field work.** Samples were collected under cold front and rainy weather conditions in the years 2011, 2012, and 2013. *P. aztecus* larval stages were obtained in 26 sampling stations located in four transects, two transects northward and another two transects southward of the Jamapa river estuarine inlet (Fig. 1).

Horizontal surface hauls were made on the stations using a 1.5 m-long conical net WP2 with a 0.5 m mouth diameter (surface = 0.196 m<sup>2</sup>) and 330 µm mesh opening with a flowmeter (General Oceanics) to determine the volume of filtered water. The hauls were conducted from a boat with an outboard motor and lasted for 5 min at an average speed of 3 knots (1.543 m s<sup>-1</sup>), equivalent to an approximate distance of 450 m and water volume of 350 m<sup>3</sup> for each sampling site. Samples were concentrated and fixed in 500 ml flasks with 10 ml of 4% formaldehyde and neutralized with sodium borate. *In situ* measurements included salinity, surface temperature of water (°C), and dissolved oxygen (mg l<sup>-1</sup>) which were measured using a multiparameter water quality portable meter (Hanna HI 9828).

**Laboratory work.** The biological material was transferred to the Crustacean Laboratory at the Facultad de Estudios Superiores Iztacala of the Universidad Nacional Autónoma de México. Samples were transferred to 70% alcohol 24 h after fixation. Larvae and decapodids species sorting was carried employing Calazan (1993) and Dos Santos & Lindley (2001) identification keys. A Motic SMZ-168 stereoscopic microscope and a Leica DM750 microscope were used. The total number of individuals per species was counted and mysis density was standardized to the number of mysis per 100 m<sup>3</sup> (Suárez-Morales & Gasca, 2000).

**Statistical analysis.** The generalized least squares (GLS) model was used to compare temperature (°C), salinity, and dissolved oxygen (mg l<sup>-1</sup>) under cold front (Cf) and rainy (R) weather conditions (Wc) during three sampling years (2011, 2012, and 2013), transects (Northern, N; North central, Nc; South central, Sc; Southern, S) and shore zones (Fs, Foreshore; Ns, Nearshore; Offs, Offshore) (Chowdhury & Behera, 2019) (Zuur *et al.*, 2007). GLS was performed using SPSS v25.

To test whether the density of the species changed as a function of weather conditions and sampling zones, a two-way factorial design was performed. Zones (three) and weather conditions (two) were considered as fixed orthogonal factors. This design was applied to analyze the density of zoeae using a permutational multivariate analysis of variance (PERMANOVA) test. The values of environmental parameters were arcsine transformed and normalized. The values of the density of the species were transformed into the Log (n+1). The resemblance matrix for the density of the species was achieved using the Bray-Curtis similarity (Clarke & Gorley, 2016). The analysis was computed with 9999 permutations of residuals in a reduced model. Pairwise tests using a t-statistic were used to identify differences between weather conditions, latitudinal zones and shore zones. PERMANOVA were performed as implemented in the PRIMER V7 and PERMANOVA add-ons (Anderson *et al.*, 2008; Clarke & Gorley, 2016).

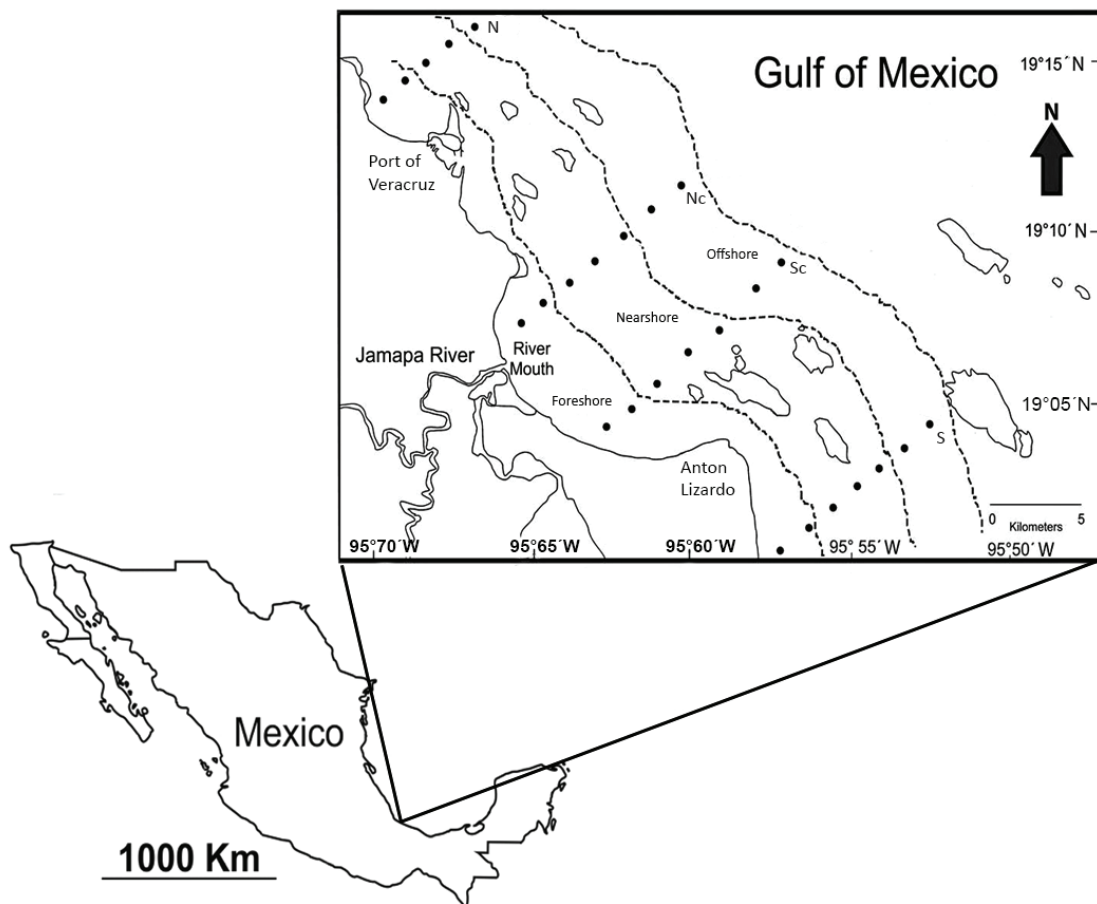


Figure 1. Location of the sampling stations and transects in PNSAV study area.

The relationships among *P. aztecus* mysis densities and water temperature, salinity and dissolved oxygen mean values were explored with Non-metric multidimensional scaling ordination method (NMDS), using a resemblance matrix constructed with the Bray-Curtis index. NMDS was performed using PAST software (Hammer *et al.*, 2001).

## RESULTS

**Environmental factors.** In rainy weather conditions, a temperature variation was determined between  $27.49 \pm 0.46$  °C in north central-Offs and  $29.98 \pm 0.02$  °C in southern-Fs; in weather conditions associated with cold fronts the temperature varied between  $23.21 \pm 0.05$  °C in north central-Fs and  $25.74 \pm 0.37$  °C in southern-Offs (Fig. 2A). The water temperature showed significant differences related to transect location ( $F_{(3,61)} = 7.310$ ,  $p < 0.001$ ), shore zone ( $F_{(2,61)} = 79.757$ ,  $p < 0.001$ ), and weather condition ( $F_{(5,61)} = 322.07$ ,  $p < 0.001$ ). Differences were also found when comparing the northern and north central transects to the southern and south central transects, the three shore zones, and the weather conditions ( $p < 0.05$ ) (Table 1A).

Salinity in rainy weather conditions was  $32.18 \pm 0.06$  in southern-Fs and  $35.40 \pm 0.52$  in the northern-Offs; in cold front weather conditions, the salinity was  $34.59 \pm 0.39$  in the south central-Fs compared to  $35.84 \pm 0.17$  in the northern-Offs (Fig. 2b). Salinity showed significant differences depending on transect ( $F_{(3,61)} = 9.324$ ,  $p < 0.001$ ), shore zone ( $F_{(2,61)} = 30.705$ ,  $p < 0.001$ ), and weather conditions ( $F_{(5,61)} = 17.858$ ,  $p < 0.001$ ). Northern transect salinity had significant differences with respect to the southern and south central transects (but not with north central transect), and the north central transect salinity showed significant differences with respect to the southern transect only. These salinity differences were found among the three shore zones and the two weather conditions ( $p < 0.05$ ) (Table 1B).

In rainy weather conditions the dissolved oxygen level was  $3.64 \pm 0.13$  mgL<sup>-1</sup> in the northern-Fs to  $6.18 \pm 0.64$  mgL<sup>-1</sup> in the southern-Offs; in cold front weather conditions dissolved oxygen ranged from  $4.04 \pm 0.06$  mgL<sup>-1</sup> in the north central-Fs to  $6.02 \pm$  mgL<sup>-1</sup> in the southern-Offs (Fig. 2c). The dissolved oxygen concentrations showed significant differences depending on transect ( $F_{(3,61)} = 47.474$ ,  $p < 0.001$ ), shore zone ( $F_{(2,61)} = 16.162$ ,  $p < 0.001$ ), and weather conditions ( $F_{(5,61)} = 6.588$ ,  $p < 0.001$ ). Differences in dissolved oxygen concentrations were found between the northern and the southern and south central transects, the three shore zones, and between cold front conditions in 2011 and 2013 with rainy conditions in 2011, and between cold front weather conditions in 2012 with rainy conditions in 2011 and 2012 (Tukey  $p < 0.05$ ) (Table 1C).

**Mysis density.** The highest average density,  $6,938 \pm 326$  mysis 100 m<sup>-3</sup>, was found during rainy season in 2011 in the southern transect-Ns, followed by  $3,321 \pm 339$  mysis 100 m<sup>-3</sup> in the south central-Offs transect during cold front weather conditions in 2013, and  $3,056 \pm 236$  mysis 100 m<sup>-3</sup> in the south central-Fs transect during cold front weather conditions in 2011 (Table 2). According to the PERMANOVA results, the *P. aztecus* mysis density changed according to weather conditions ( $F_{(5,54)} = 2.73$ ,  $p = 0.025$ ) considering the distance off the coastline. The pairwise comparison test revealed that differences in mysis density were apparent among 2013 cold front season and 2012 and 2013 rainy seasons ( $p < 0.05$ ).

Respect to the transects, changes were found among weather conditions ( $F_{(3,48)} = 5.18$ ,  $p = 0.004$ ) and transects too ( $F_{(5,48)} = 3.38$ ,  $p = 0.009$ ). The pairwise comparisons revealed that mysis density was different among 2013 cold fronts and 2012 and 2013 rainy season conditions, also among the 2011 cold fronts season conditions and 2012 rainy season conditions ( $p < 0.05$ ). Furthermore, the pairwise comparisons showed differences among northern transect, southern transect and south-central transect; another difference was among north-central transect and the southern transect ( $p < 0.05$ ) (Table 3).

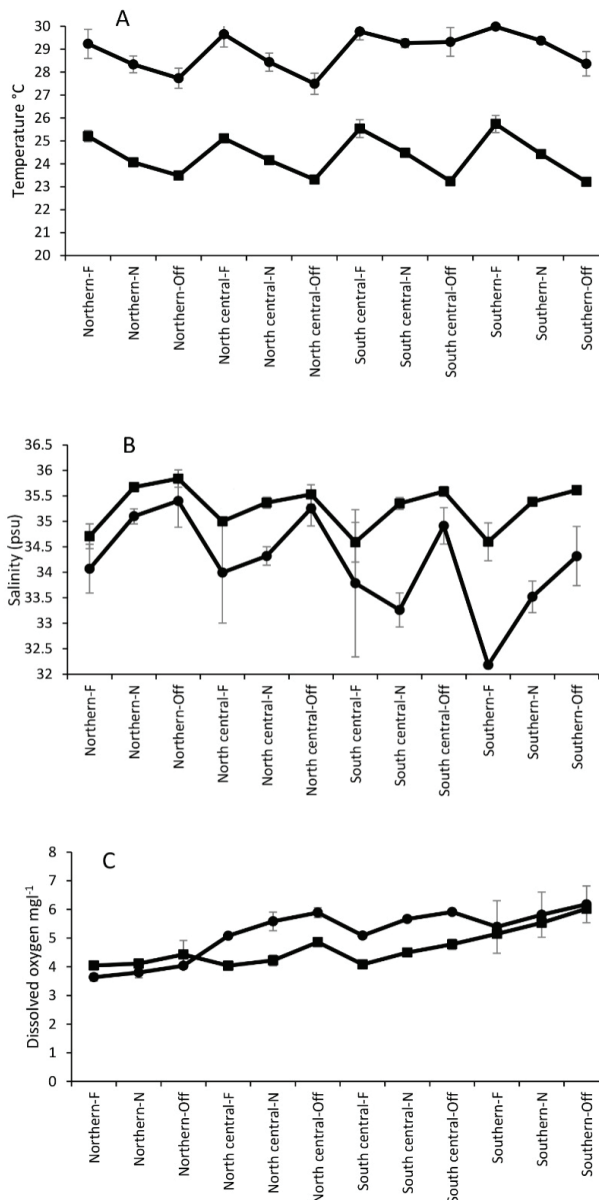


Fig. 2. Relation between the zone of sampling and environmental factors. A, temperature °C; B salinity (psu); C, dissolved oxygen mgL<sup>-1</sup>. Black circles, rainy weather conditions; Black squares, cold fronts weather conditions.

Table 1. Model Generalized Least Squares applied to compare the temperature (°C), salinity (psu) and dissolved oxygen (mgL<sup>-1</sup>) from transects (Tr) and shore zones (Sz) under weather conditions (Wc) for each sampling year. \*, significant differences. Cf, cold fronts; Comp, comparison between transects, weather conditions and shore zones; Fs, foreshore; Offs, offshore; N, northern; Nc, north central; Ns, nearshore; R, rainy; S, southern; Sc, south central.

<b>Temperature</b>							
<b>Source</b>	<b>SC</b>	<b>GI</b>	<b>Mc</b>	<b>F</b>	<b>p</b>	<b>Comp</b>	<b>p (Tukey)</b>
Corrected model	178.22 <sup>a</sup>	10	17.82	179.15	< 0.001*	N-Nc	1.000
Intersection	69363.56	1	69363.56	697255.67	< 0.001*	N-Sc	0.004*
Tr	2.18	3	0.73	7.31	< 0.001*	N-Sc	0.016*
Sz	15.87	2	7.93	79.76	< 0.001*	Nc-Sc	0.005*
Wc	160.17	5	32.03	322.02	< 0.001*	Nc-S	0.021*
Residual	6.07	61	0.09			Sc-S	0.956
Total	69547.85	72				Cf-R	<0.001*
Corrected total	184.29	71				Fs-Ns	<0.001*
$r^2 = 0.97$						Fs-Offs	<0.001*
						Ns-Offs	<0.001*

<b>Salinity</b>							
<b>Source</b>	<b>SC</b>	<b>GI</b>	<b>MC</b>	<b>F</b>	<b>p</b>	<b>Comp</b>	<b>p (Tukey)</b>
Corrected model	18.01 <sup>a</sup>	10	1.80	17.87	< 0.001*	N-Sc	0.014*
Intersection	93851.66	1	93851.66	931188.30	< 0.001*	N-S	<0.001*
Tr	2.82	3	0.94	9.32	< 0.001*	Nc-Sc	0.246
Sz	6.19	2	3.09	30.71	< 0.001*	Nc-S	0.003*
Wc	8.99	5	1.8	17.86	< 0.001*	Sc-S	0.287
Residual	6.15	61	0.10			Cf-R	0.001*
Total	93875.82	72				Fs-Ns	<0.001*
Corrected total	24.16	71				Fs-Offs	<0.001*
$r^2 = 0.75$						Ns-Offs	<0.001*

<b>Dissolved oxygen</b>							
<b>Source</b>	<b>SC</b>	<b>GI</b>	<b>MC</b>	<b>F</b>	<b>p</b>	<b>Comp</b>	<b>p (Tukey)</b>
Corrected model	66.91 <sup>a</sup>	10	6.69	20.77	< 0.001*	N-Nc	<0.001*
Intersection	11720.09	1	11720.09	36378.88	< 0.001*	N-Sc	<0.001*
Tr	45.88	3	15.29	47.47	< 0.001*	N-S	<0.001*
Sz	10.42	2	5.21	16.16	< 0.001*	Nc-S	<0.001*
Wc	10.61	5	2.12	6.59	< 0.001*	Sc-S	<0.001*
Residual	19.652	61	0.32			Cf-R	<0.001*
Total	11806.65	72				Fs-Ns	0.019*
Corrected total	86.56	71				Fs-Offs	<0.001*
$r^2 = 0.773$						Ns-Offs	0.014*

The NMDS results identified two groups in rainy seasons, separated by transects (stress = 0.117); one group comprising the northern and north central zones, with low densities and average temperature of  $28.68 \pm 0.76$  °C, salinity of  $34.58 \pm 0.64$  and dissolved oxygen concentration of  $4.43 \pm 0.86$  mgL<sup>-1</sup>; the second group, with higher densities, was comprised by the southern and south central transects, with average temperature  $29.35 \pm 0.56$  °C, salinity of  $33.66 \pm 0.94$  and dissolved oxygen levels of  $5.68 \pm 0.39$  mgL<sup>-1</sup> (Fig. 3a). The NMDS anal-

ysis also separated two groups (stress = 0.043) in cold front weather conditions: a group in the northern and north central zones, with low densities and average temperature of  $24.41 \pm 0.73$  °C, salinity  $35.32 \pm 0.47$ , and dissolved oxygen levels of  $4.16 \pm 0.17$  mgL<sup>-1</sup>; the second group, with higher densities, was formed by the southern and south central transects, with average temperature of  $24.44 \pm 1.08$  °C, salinity of  $35.19 \pm 0.47$ , and dissolved oxygen concentration of  $5.01 \pm 0.71$  mgL<sup>-1</sup> (Fig. 3b).

Table 2. *Penaeus aztecus*. Density of mysis  $100\text{ m}^{-3}(\pm\text{SD})$  in the PNSAV during rainy and cold fronts of 2011, 2012 and 2013. Cold fronts, Cf; Shore zone, Sz; Rainy, R. Bold highest density.

Transect	Sz	R-2011	Cf-2011	R-2012	Cf-2012	R-2013	Cf-2013
Northern	Foreshore		208 ± 36				40 ± 12
Northern	Noeshore		72 ± 15		28 ± 8	184 ± 22	660 ± 113
North central	Foreshore					35 ± 7	80 ± 25
North central	Noeshore	8 ± 2	9	43 ± 18			72 ± 21
North central	Offshore		40 ± 12		33 ± 10	225 ± 25	2704 ± 356
South central	Foreshore	49 ± 14	<b>3056 ± 236</b>		56 ± 16	56 ± 14	113 ± 26
South central	Noeshore	256 ± 36	666 ± 125		159 ± 21		1439 ± 189
South central	Offshore	139 ± 17			272 ± 56		3321 ± 339
Southern	Foreshore	1682 ± 125	20 ± 6	26 ± 6	248 ± 65	13 ± 3	464 ± 89
Southern	Noeshore	<b>6938 ± 326</b>	112 ± 26	59 ± 12	728 ± 112		555 ± 145
Southern	Offshore	64 ± 11	59 ± 16		55 ± 18	88 ± 12	872 ± 258

## DISCUSSION

Changes in environmental conditions in the PNSAV region during periods of weather associated with a cold front, rainy weather, tropical storms, and hurricanes cause a mixed layer in the water column, incorporating nutrients into the photic zone (Zavala-Hidalgo *et al.*, 2006, 2014), which can be used by phytoplankton, zooplankton such as mysis that feed on the algae (Schwamborn *et al.*, 2001). In cold front weather conditions winds along Tamaulipas and Veracruz coasts produce cyclonic currents in a southerly direction, while those in the states of Campeche Bank

and Yucatán form anticyclonic currents. These currents converge at the southern end of the Gulf of Mexico, forming flows, perpendicular to the coast, from the neritic-oceanic zone to the oceanic zone (Zavala-Hidalgo *et al.*, 2006). Furthermore, the subtropical water underlying the Campeche Bank enhances the resuspension of nutrient-rich sediments in the southern part of the PNSAV. Rodríguez-Gómez *et al.* (2015) found that the highest levels of chlorophyll and, consequently, of gross primary productivity in the PNSAV begin to appear in September and at the end of October to April. Thus, the highest mysis density obtained in this study under rainy weather conditions could be associated to the

Table 3. Permutational multivariate analysis of variance (PERMANOVA) on the density of mysis of *Penaeus aztecus* from PNSAV reef, based on an orthogonal two-factors model. Cf, cold fronts; Comp, comparison between transects, weather conditions and shore zones; N, northern; Nc, north central; S, southern; Sc, south central; Sz, Shore zones; R, Rainy; Tr, Transects; Wc, Weather conditions. \*, significant differences ( $p < 0.05$ ).

Shore zones							
Source	SS	df	MS	F	P	Comp	p (Tukey)
Sz	0.52	2	0.26	1.12	0.312	Cf2013-R2012	0.001*
Wc	3.14	5	0.63	2.73	0.025*	Cf2013-R2013	0.031*
Interaction	1.54	10	0.15	0.67	0.766		
Residual	12.43	54	0.23				
Total	17.63	71					
Transects							
Source	SS	df	MS	F	P	Comp	p (Tukey)
Tr	2.8918	3	0.96394	5.18	0.004*	N-S	<0.001*
Wc	3.1443	5	0.62885	3.38	0.009*	N-Sc	0.016*
Interaction	2.655	15	0.177	0.95	0.513	Nc-S	0.011*
Residual	8.9383	48	0.18621			Cf2011-R2012	0.039*
Total	17.629	71					

values of dissolved oxygen, due to the increase in chlorophyll (Álvarez-Cadena *et al.*, 2007), and a response to nutrient input by the estuarine plume of the Jamapa River during rainy conditions (Horta-Puga *et al.*, 2016). However, Landeira & Lozano-Soldevilla (2018), commented that valuable information is obtained from knowing the place and potential spawning season for a species, and the temporal distribution of decapod larvae suggests a larval hatching period for many species with peaks of abundance associated with seasonality. So, peak spawning from December through April (Zimmerman & Minello, 1984; Rozas & Reed, 1993; Matthews, 2008) and a second peak that occurs during late summer and early fall (Rogers *et al.*, 1993) is consistent with the peak of abundance obtained in this study in rainy weather and the continuous presence of high mysis abundance in cold front weather conditions.

The GLS and PERMANOVA tests allow the distinction of two zones: northern zone and southern zone, related to the freshwater inflows and sediment loadings from Jamapa river. However, is important to point out that during cold fronts weather conditions, the inshore marine current turns to a southward direction and Jamapa river plume reaches its highest influence over the nearest reefs to Anton Lizardo coast; in contrast, during dry weather conditions the inshore marine currents go northward and the Jamapa river plume change its influence over the reefs ubicated in front of Veracruz Port (Krutak *et al.*, 1980).

The multivariate analysis (NMDS) results also distinguished two zones, based on dissolved oxygen concentration, since the northern zone had low concentrations (up to  $4 \text{ mgL}^{-1}$ ) while the northern zone had higher values (up to  $5 \text{ mgL}^{-1}$ ). According to the EPA (1986) and the ecological Criteria of the European Community (1989), the concentration of dissolved oxygen needed for the protection of aquatic life in both fresh water and marine water is  $5 \text{ mg L}^{-1}$ . Some aquatic animals can tolerate a lower concentration of dissolved oxygen for a period; however, this has negative effects on biodiversity, growth, and reproduction.

Regarding density, Cházaro-Olvera *et al.* (2009), found values of 146,530 postlarvae  $100 \text{ m}^{-3}$  in the tidal flow of an estuarine lagoon inlet; Wenner *et al.* (2005) found that the density of *L. setiferus* ranged from 1,300 postlarvae  $100 \text{ m}^{-3}$  to 29,900 postlarvae  $100 \text{ m}^{-3}$  in surface hauls during night-time flow tides. In the present study we obtained approximately 7,000 mysis  $100 \text{ m}^{-3}$  in the nearshore zone in daytime surface hauls. Thus, in open coastal systems dispersion of larvae and postlarvae is higher than in channels where larvae enter estuarine systems.

Finally, with respect to *P. aztecus* life history, Darnell *et al.* (1983) and Neal *et al.* (1983) mentioned that adults reproduce in marine environmental conditions beyond the 18 m depth, and the spawning sites are deeper and far away from shore (Williams, 1984). But the larval distribution, nauplii, protozoa, and mysis stages are found nearby the coast (Sick, 1970; Zimmerman & Minello, 1984), mainly from September to April (Sandifer, 1973; Williams, 1984). The results showed in this study are consistent evidence of previous reports, referred to highest density of *P. aztecus* mysis was found during rains and cold fronts weather conditions and in the foreshore zone, in this case in the south area of the PNSAV.

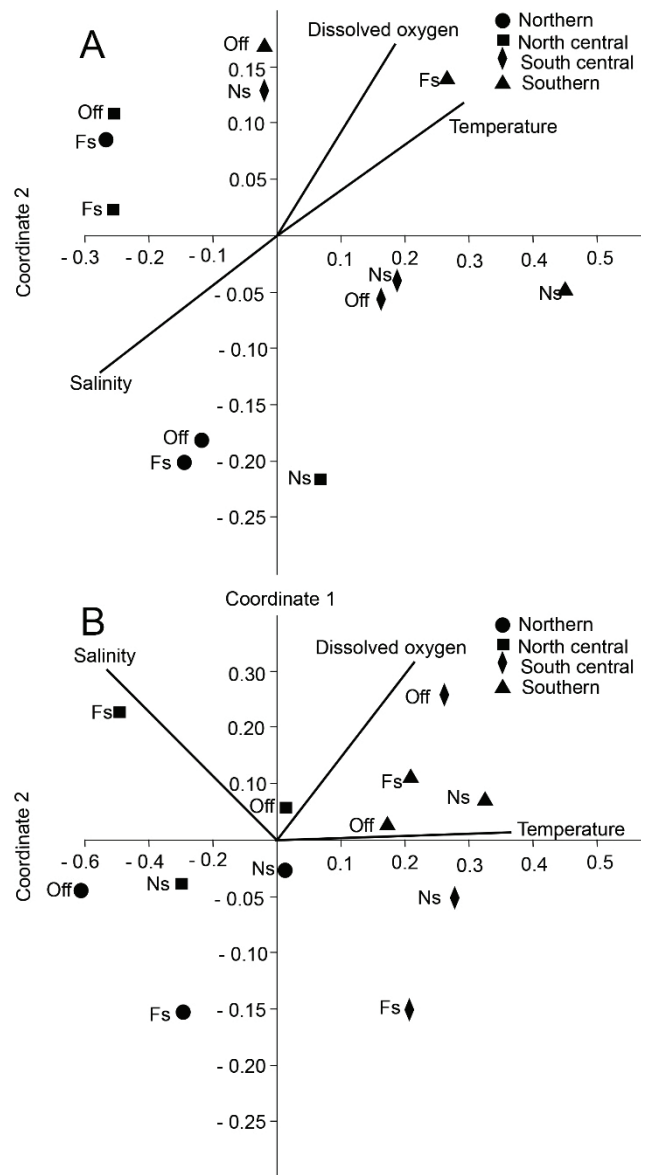


Fig. 3. *Penaeus aztecus* mysis stage. Non-metric multidimensional scaling (NMDS) for the ordination of density as a function of the weather conditions (A, rainy; B, cold fronts). Fs, foreshore; Ns, nearshore; Offs, offshore).

## ACKNOWLEDGEMENTS

Senior author appreciate the support of CONACYT National Sabbatical Program 2018; the authors express their gratitude towards SEMARNAT, CONANP and CONAPESCA-DGOPA (SAGARPA) authorities for their administrative and permits support for the realization of field work and to the students of the Crustacean Laboratory of FES Iztacala, UNAM, who participated in the processing of samples.

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