

Research Article

Community of copepods in the peri-urban estuary Arroyo Moreno, Veracruz southwest Gulf of Mexico

Sergio Cházaro-Olvera¹ , María Fernanda Durán-Del Valle¹ , Ángel Morán-Silva¹ 
Jesús Montoya-Mendoza²  & Rafael Chávez-López¹ 

¹Laboratorio de Crustáceos, Facultad de Estudios Superiores Iztacala
Universidad Nacional Autónoma de México, Tlalnepantla, Estado de México, México

²Laboratorio de Investigación de Acuicultura Aplicada, Tecnológico Nacional de México
Instituto Tecnológico de Boca del Río, Boca del Río, Veracruz, México

Corresponding author: Sergio Cházaro-Olvera (schazaro@gmail.com)

ABSTRACT. Copepods represent between 70 and 90% of the planktonic biomass in the marine and coastal systems. The present study aims to increase knowledge about the abundance, distribution, and diversity of copepods in the Arroyo Moreno estuary, classified as a peri-urban system with high anthropogenic impact. We measured dissolved oxygen, water temperature, total dissolved solids, pH, and salinity *in situ*. The planktonic samples from six sites were collected during dry, cold fronts, and rainy weather conditions from the Arroyo Moreno estuary. The Arroyo Moreno estuary is a system with general hypoxic conditions ($1.37 \pm 1.89 \text{ mg L}^{-1}$). The temperature was $32.45 \pm 2.21^\circ\text{C}$. The values of total dissolved solids were greater than the maximum permissible limit ($2,276.67 \pm 621.7 \text{ ppm}$). The salinity presented values from 0.20 ± 0.07 to 15.95 ± 1.27 . In the study, 10 species of copepods were found. The highest abundance occurred in May with 4,717 ind (during the dry season). The species with higher abundance were *Acartia* (*Acanthcartia*) *tonsa* and *Paracalanus quasimodo*. The highest diversity value was found in March, with 0.75 bits ind⁻¹. The species *A. (A.) tonsa* represented 93% of the abundance of copepods found in the Arroyo Moreno estuary and was related to a euryoic response. The other species of copepods exhibited a coastal-marine affinity, spatially limiting their distribution to the Arroyo Moreno estuary. The diversity was significantly lower than what was recorded by other authors in other coastal systems. According to the results obtained, this study revealed a significant anthropocentric impact.

Keywords: *Acartia*; coastal system; environment impact; Gulf of Mexico; species richness

INTRODUCTION

Copepods constitute 70 to 90% of the planktonic biomass in neritic regions (Suárez-Morales & Gasca 2000, Cházaro-Olvera et al. 2019). This group of microcrustaceans is predominant in the zooplankton of estuarine coastal systems (Escamilla et al. 2011). Their

considerable diversity in forms and feeding behaviors results in a significant proportion of primary consumers and a lesser proportion of secondary consumers (Campos-Hernández & Suárez-Morales 1994).

Copepod species distribution and abundance are influenced by several abiotic and biotic factors, including temperature, salinity, and the quantity and/or

quality of food. All these factors fluctuate more in estuaries than in marine or freshwater systems (Uriarte & Villate 2005).

Estuaries provide valuable services that benefit humans, including supporting commercial shellfisheries and tourist activities. They also play a crucial role in regulating water quality, providing habitats for many different species, and serving as resources for cultural education and research (Wenninger et al. 2003, Cházaro-Martínez 2024). However, the discharge of chemical compounds and fecal matter into peri-urban areas disturbs estuaries, threatens human health, damages coastal areas, and negatively affects the diversity, stability, and resilience of biological communities (Paul & Meyer 2008, Petkova et al. 2015).

Estuaries are natural buffer zones between rivers and oceans, and they are among the aquatic ecosystems most significantly impacted by human activities. Impacts of urbanization on estuaries include increases in sediment, nutrient, and fecal microbial concentrations, which result in harmful algal blooms, changes in streamflow and salinity, and damage to the plankton inhabiting within the estuary systems (Paerl et al. 2014, Lemley et al. 2018).

In Mexico, studies have been conducted on the specific richness of copepod communities in certain coastal systems of the Gulf of Mexico. For instance, López-Salgado et al. (2000) identified 106 species of copepods in the Plain of Tamaulipas, while Cházaro-Olvera et al. (2019) identified 62 species of copepods in the Veracruz reef system from surface collections. In the Caribbean Sea, Suárez-Morales & Gasca (2000) identified 201 species of pelagic copepods. However, research in estuarine systems has been limited. For example, Álvarez-Silva & Gómez-Aguirre (2000) provided a list of only 23 species found in six estuarine systems with low anthropogenic impact. They noted that the common species in those estuarine systems were *Acartia* (*Odontacartia*) *lilljeborgii* Giesbrecht, 1889, *A. (Acanthacartia) tonsa*, *Pseudodiaptomus pelagicus* Herrick, 1884, and *Temora turbinata* (Dana, 1849-1852). The present study aims to increase knowledge about the abundance, distribution, and diversity of copepods in the Arroyo Moreno estuary, which is classified as a peri-urban system with high anthropogenic impact.

MATERIALS AND METHODS

Study area

The Arroyo Moreno estuary is part of the Protected Natural Area that bears the same name. It is located at

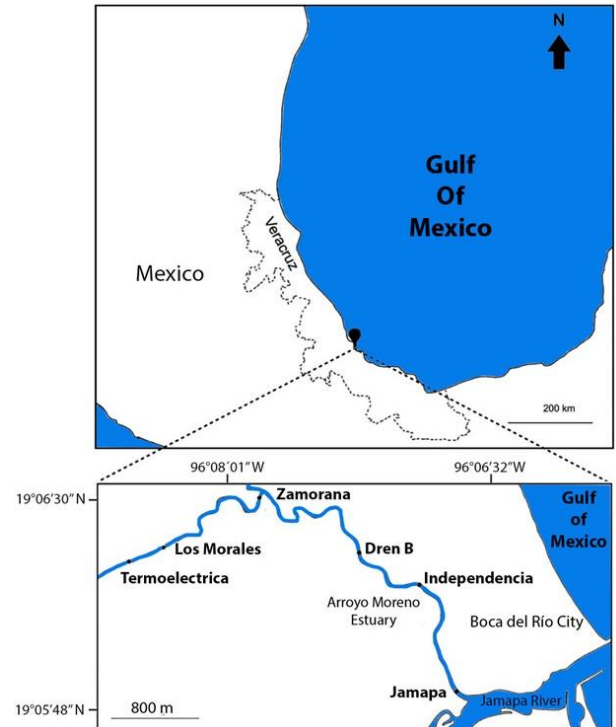


Figure 1. Location of the sampling stations in the Arroyo Moreno estuary (modified from Nolasco-Flores 2024).

19°05'-19°08'N and 96°06'-96°09'W, covering a designated area of 287 ha (Gaceta Oficial 2008). Most of the estuary is located within the boundaries of the municipality of Boca del Río. At the same time, a smaller portion lies in the municipality of Medellín de Bravo (Fig. 1). To the north, the estuary is bordered by the Miguel Alemán, Plan de Ayala, and housing unit General Workers Peasants and Popular Union Company (UGOCEP); to the east by the La Joya subdivision, El Morro, and Graciano Sánchez; and to the south by the La Tampiquera colonies. The Arroyo Moreno receives fresh water from the Jamapa River and seawater through tidal exchanges with the Gulf of Mexico, exhibiting a mixed diurnal tidal pattern (López-Portillo et al. 2009). The area is climatically subject to three climatic seasons: cold fronts from November to March, characterized by little precipitation, low air temperature, and frequent arrivals of cold boreal air; the dry season from April to June, which may extend until August and is marked by higher temperatures, minimal rainfall, and lower water volumes in the channels; and the rainy season from August to October, during which the area experiences the largest rainfall discharges that can cause floods (Martínez-Gómez 1996).

Field work

The collection of specimens was conducted at six stations along the Arroyo Moreno estuary from March to December 2021. Horizontal surface hauls were made using a 1.5 m long conical net (WP2) with a mouth diameter of 0.5 m and a mesh opening of 330 μm . The hauls were conducted from a boat equipped with an outboard motor and lasted for 5 min, averaging a speed of 1.5 ms^{-1} . Samples were concentrated and fixed in 500 mL flasks with 96% alcohol. *In situ* measurements included dissolved oxygen (mg L^{-1}), surface water temperature ($^{\circ}\text{C}$), total dissolved solids (ppm), and salinity, which were measured using a portable multiparameter water quality 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. In brief, the sample was placed in 100 mL of 70% alcohol, and then 12.5 mL aliquots were taken with a Motodo (1959) subsampler. For identification, a Motic stereoscopic microscope model SMZ-168 and a Leica DM750 microscope were used. The criteria of Campos-Hernández & Suárez-Morales (1994) and Conway (2012) were followed. The following databases on diversity were consulted: the Geographic Distribution of Marine Planktonic Copepods (Razouls et al. 2017), World of Copepods (Walter & Boxshall 2019), and the World Register of Marine Species (WoRMS 2024). To obtain the density of copepods, the total number of individuals per species was counted and standardized to the number of copepods per 100 m^3 .

Statistical analysis

The generalized least squares (GLS) model was used to compare dissolved oxygen, total dissolved solids, salinity, pH, and temperature across different sampling months and sites (Zuur et al. 2007). GLS was performed using SPSS v.25. The generalized linear model (GLM) was used to determine the relationships between the abundance of copepod species and sites, months, and environmental factors. A Poisson log-linear model was used to count, with the abundance of each species serving as the dependent variable in each month, and sampling sites and variables related to environmental factors serving as independent variables. 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 an arcsine, and the abundance values of the species were transformed to $\log(n+1)$

(Zuur et al. 2007). The Shannon diversity (H') and specific richness (S) indexes were also obtained (Magurran 1988). The diversity values among months and sites were compared with the Hutcheson (1970) test. These characteristics were analyzed using PAST software (Harmer et al. 2001).

RESULTS

Environmental factors

The results of the analysis of environmental factors across the sampling months are presented below (Table 1). The dissolved oxygen levels presented an average of between $1.37 \pm 1.89 \text{ mg L}^{-1}$ (December) and $3.78 \pm 1.74 \text{ mg L}^{-1}$ (March). The temperature presented an average interval between $29.58 \pm 3.4^{\circ}\text{C}$ (March) and $32.45 \pm 2.21^{\circ}\text{C}$ (August). The total dissolved solids presented an average of between $2,276.67 \pm 621.7 \text{ ppm}$ (July) and $16,773.33 \pm 4,805.68 \text{ ppm}$ (March). The salinity presented an average interval between 0.20 ± 0.07 (July) and 15.95 ± 1.27 (March). The pH presented an average interval between 7.3 ± 0.14 (December) and 7.67 ± 0.11 (May).

The results of the environmental factor analysis at the sampling sites are presented below (Table 1). The dissolved oxygen levels ranged from 0.1 to 6.68 mg L^{-1} . The temperature varied from 25.56°C at the Jamapa site to 36.14°C at the Los Morales site. The total dissolved solids ranged from 1,300 to 20,270 ppm, observed at both locations in the Los Morales site. The salinity presented an average interval between 0.1 and 17.01, recorded at the Termoelectrica site. The pH ranged between 7.15 at the Dren B site to 7.83 at the Jamapa site.

The dissolved oxygen, total dissolved solids, salinity, and pH presented statistically significant differences among the sampling months according to the GLS test ($F_{9,4; 0.05} = 4.40$, $P = 0.01$; $F_{9,4; 0.05} = 26.63$, $P < 0.001$; $F_{9,4; 0.05} = 52.99$, $P < 0.001$; $F_{9,4; 0.05} = 8.26$, $P < 0.001$, respectively). The temperature presented statistically significant differences among the sampling sites ($F_{9,5; 0.05} = 7.76$, $P < 0.001$) (Table 2). Tukey's test of the temporal analysis showed statistically significant differences in environmental factors. Dissolved oxygen was statistically significantly different in December compared to June and March ($P < 0.05$). The difference was statistically significant in total dissolved solids in December, with all months sampled except May; however, March presented significant differences with all months sampled ($P < 0.05$). Salinity levels were significantly different among most months ($P < 0.05$). The pH levels were significantly different in December

Table 1. Values, average, and standard deviation (SD) of environmental factors registered for the months and sampling sites in the Arroyo Moreno estuary. DO: dissolved oxygen, Temp: temperature, TDS: total solids dissolved, Sal: salinity, and pH from sites and months of sampling.

Month	Sampling site	DO (mg L ⁻¹)	Temp (°C)	TDS (ppm)	Sal	pH
March	Jamapa	6.68	25.75	8670	13.5	7.51
	Independencia	4.52	26.04	13060	16.5	7.41
	Dren B	3.11	28.12	19350	15.71	7.59
	Zamorana	2.21	31.18	20220	16.56	7.45
	Los Morales	4.13	33.19	20270	16.39	7.24
	Termoelectrica	2.03	33.17	19070	17.01	7.23
	Average ± SD	3.78 ± 1.74	29.58 ± 3.4	16773.33 ± 4805.68	15.95 ± 1.27	7.41 ± 0.15
May	Jamapa	3.04	30.16	6417	7.31	7.83
	Independencia	1.62	30.67	12550	15.17	7.78
	Dren B	1.61	31.28	10380	12.31	7.65
	Zamorana	1.4	33.2	6815	7.77	7.62
	Los Morales	2.74	36.14	4144	4.52	7.62
	Termoelectrica	1	33.16	2425	2.56	7.52
	Average ± SD	1.9 ± 0.8	32.45 ± 2.21	7121.83 ± 3784.16	8.27 ± 4.73	7.67 ± 0.11
June	Jamapa	5.72	25.56	1250	0.17	7.79
	Independencia	3.57	28.51	2870	0.28	7.75
	Dren B	2.62	31.07	4510	0.44	7.59
	Zamorana	1.9	31.76	3310	0.32	7.56
	Los Morales	5.27	33.27	1300	0.12	7.53
	Termoelectrica	3.52	33.12	1830	0.17	7.53
	Average ± SD	3.77 ± 1.48	30.55 ± 2.99	2511.67 ± 1287.14	0.25 ± 0.12	7.63 ± 0.12
July	Jamapa	3.16	28.08	1880	0.17	7.69
	Independencia	0.86	30.78	3240	0.3	7.65
	Dren B	1.53	31.42	2460	0.21	7.29
	Zamorana	2.14	31.39	2250	0.2	7.36
	Los Morales	1.95	31.06	2440	0.23	7.33
	Termoelectrica	3.48	29.24	1390	0.1	7.33
	Average ± SD	2.19 ± 0.99	30.33 ± 1.36	2276.67 ± 621.7	0.2 ± 0.07	7.44 ± 0.18
December	Jamapa	0.1	29.69	11910	6.4	7.18
	Independencia	0.26	29.93	11240	13.45	7.22
	Dren B	0.22	29.94	11280	13.51	7.15
	Zamorana	0.36	30.06	10710	12.75	7.42
	Los Morales	2.53	31.39	8723	10.11	7.5
	Termoelectrica	4.75	31.94	7403	8.51	7.35
	Average ± SD	1.37 ± 1.89	30.49 ± 0.93	10211 ± 1757.06	10.79 ± 2.94	7.3 ± 0.14

compared to May and June, and May differed significantly from all other months sampled ($P < 0.05$). Tukey's test of spatial analysis revealed significant differences in the temperature of the sampling sites. The Independencia site presented differences compared to the Los Morales site; the Jamapa site differed from the Los Morales, Termoelectrica, and Zamorana sites ($P < 0.05$) (Table 3).

Abundance, specific richness, and diversity

In the Arroyo Moreno estuary, a total of 10 species were found: *Acartia* (O.) *lilljeborgii*, *A. (A.) tonsa*,

Acrocalanus longicornis Giesbrecht, 1888, *Clausocalanus furcatus* (Brady, 1883), *Dioithona oculata* (Farran, 1913), *Labidocera aestiva* Wheeler, 1900, *Megacalanus princeps princeps* Wolfenden, 1904, *Oithona nana* Giesbrecht, 1893, *Paracalanus aculeatus aculeatus* Giesbrecht, 1888, and *P. Quasimodo* Bowman, 1971. The species with the highest abundance were *A. (A.) tonsa*, which totaled 11,493 ind and had a density of 1 to 3,240 ind 100 m⁻³, and *P. quasimodo*, with a total of 300 ind and a density of 3 to 210 ind 100 m⁻³ (Table 4).

Table 2. Model generalized least squares applied to compare dissolved oxygen (DO, mg L⁻¹), temperature (Temp, °C), total solids dissolved (TDS, ppm), salinity (Sal), and pH from sites and months of sampling (a). *Significant differences; *r*: correlation coefficient.

Source	DO		Temp		TDS		Sal		pH	
	F	P	F	P	F	P	F	P	F	P
Model	3.17	0.02	5.56	< 0.001	12.50	< 0.001	24.74	< 0.001	4.65	0.00
Interception	119.64	< 0.001	11796.49	< 0.001	221.86	< 0.001	283.93	< 0.001	97503.54	< 0.001
Month	4.40	0.01*	2.81	0.053	26.63	< 0.001*	52.99	< 0.001*	8.26	< 0.001*
Site	2.19	0.10	7.76	< 0.001*	1.20	0.34	2.14	0.10	1.76	0.17
	<i>r</i> = 0.76		<i>r</i> = 0.84		<i>r</i> = 0.92		<i>r</i> = 0.96		<i>r</i> = 0.82	

Table 3. Model generalized least squares, *post-hoc* comparison with the Tukey test, results only where there were significant differences.

Environmental Factor	Comparison		P
Dissolved oxygen (mg L ⁻¹)	December	June	0.03
	December	March	0.03
TDS (ppm)	December	July	< 0.001
	December	June	< 0.001
	December	March	0.01
	July	March	< 0.001
	June	March	< 0.001
	May	March	< 0.001
Salinity	December	July	< 0.001
	December	June	< 0.001
	December	March	0.01
	July	March	< 0.001
	July	May	< 0.001
	June	March	< 0.001
	June	May	< 0.001
	March	May	< 0.001
pH	December	June	0.00
	December	May	0.00
	July	May	0.05
	March	May	0.02
Temperature (°C)	Independencia	Los Morales	0.01
	Jamapa	Los Morales	< 0.001
	Jamapa	Termoelectrica	< 0.001
	Jamapa	Zamorana	0.01

The highest species richness occurred in May, with 7 species identified. In the remaining months, 5 to 6 species were found. The highest abundance also occurred in May, with 4,717 ind, followed by June, with 3,340 ind. According to the Shannon diversity index, the highest diversity value was found in March, with 0.75 bits ind⁻¹, followed by July, with 0.74 bits ind⁻¹. The highest equitability of Pielou occurred in March, with 0.32, and in July, with 0.29 (Table 5). In terms of spatial analysis, the highest species richness and abundance were found in the Independencia site, with

8 species and 3,892 ind, respectively, followed by the Jamapa site, with 7 species and 3,277 ind. The greatest diversity and equitability were found at the Los Morales site, with 0.67 bits ind⁻¹ and 0.35, respectively, followed by the Termoelectrica site, with 0.49 bits ind⁻¹ and equity of 0.31, respectively (Table 6).

Abundance and environmental factors relationship

The results of the GLM showed a statistically significant relationship between the abundance of *A. (O.) lilljeborgii* and salinity ($P < 0.001$); the β value

Table 4. Abundance and density (ind 100 m⁻³) of copepods collected in the Arroyo Moreno estuary, Boca del Río, Veracruz. Bold shows the highest abundances. *A. lill*: *Acartia* (*Odontacartia*) *lilljeborgii*, *A. lon*: *Acrocalanus longicornis*, *A. ton*: *Acartia* (*Acanthacartia*) *tonsa*, *C. fur*: *Clausocalanus furcatus*, *D. ocu*: *Dioithona oculata*, *L. aes*: *Labidocera aestiva*, *M. prin*: *Megacalanus princeps princeps*, *O. nan*: *Oithona nana*, *P. acu*: *Paracalanus aculeatus aculeatus*, *P. qua*: *Paracalanus quasimodo*.

Sampling sites	Month/species	<i>A. lil</i>	<i>A. long</i>	<i>A. ton</i>	<i>C. fur</i>	<i>D. ocu</i>	<i>L. aes</i>	<i>M. prin</i>	<i>O. nan</i>	<i>P. acu</i>	<i>P. qua</i>	Total
Jamapa	March			510					1		4	515
	May	7		1619			1					1627
	Jun		17						24			41
	July			859					13	15	5	892
	December			177							25	202
Independencia	March	1	108						1			110
	May			215								215
	Jun	20		3240					1		30	3291
	July					2			1		3	6
	December			124			33			113		270
Dren B	March			1								1
	May			1840							210	2050
	Jun								1			1
	July								13			13
	December	40		1020							20	1080
Zamorana	March			25								25
	May			624								624
	July				2				5			7
	December	2		460								462
Los Morales	March		2									2
	May	1		168						1	3	173
	Jun								4			4
	July			1					1			2
	December			33			24		7			64
Termoelectrica	May			16	1			10		1		28
	Jun								3			3
	July								85	1		86
	December			561								561
	Total	71	127	11493	3	2	58	10	160	131	300	12355

was negative. The GLM for *A. (A.) tonsa* showed a statistically significant relationship between the abundance and the five environmental factors ($P < 0.001$); the β values were negative for temperature and salinity and positive for dissolved oxygen, total dissolved solids, and pH. The abundance of *A. longicornis* showed a statistically significant relationship with temperature and dissolved oxygen ($P < 0.05$); the β values for both environmental factors were negative. The GLM for *L. aestiva* showed a statistically significant relationship only with temperature ($P = 0.001$), with a negative β value. The abundance of *O. nana* showed a statistically significant

relationship with dissolved oxygen, total dissolved solids, salinity, and pH ($P < 0.05$); the β values were negative for dissolved oxygen and pH, and positive for total dissolved solids and salinity. The abundance of *P. aculeatus* showed a statistically significant relationship with temperature, total dissolved solids, and salinity ($P < 0.05$); the β values were negative for temperature and positive for total dissolved solids and salinity. The abundance of *P. quasimodo* showed statistically significant relationships with dissolved oxygen, temperature, and pH ($P < 0.001$); the β values of dissolved oxygen and temperature were negative, and the β value for pH was positive (Table 7).

Table 5. Species richness, Shannon diversity, and equitability of Pielou of copepods in the Arroyo Moreno estuary, months.

Community parameter	March	May	June	July	December
Richness specific	5	7	5	6	6
Abundance	653	4717	3340	1006	2639
Shannon diversity	0.75	0.32	0.25	0.74	0.67
Equitability	0.32	0.11	0.11	0.29	0.26

Table 6. Species richness, Shannon diversity, and equitability of Pielou of copepods in the Arroyo Moreno estuary, site of sampling.

Community parameter	Jamapa	Independencia	Dren B	Zamorana	Los Morales	Termoeléctrica
Richness specific	7	8	4	4	7	5
Abundance	3277	3892	3145	1118	245	678
Shannon diversity	0.2	0.4	0.36	0.05	0.67	0.49
Equitability	0.1	0.19	0.26	0.04	0.35	0.31

DISCUSSION

The average concentration of dissolved oxygen ranged from 1.37 ± 1.89 to 3.78 ± 1.74 mg L⁻¹, which is lower than the levels reported near the Arroyo Moreno estuary (Castañeda-Chávez et al. 2017), where values ranged from 5.35 to 5.63 mg L⁻¹. This lower concentration of dissolved oxygen leads to hypoxic conditions (Hayami et al. 2020), resulting in mortality events, particularly for organisms residing in the surface layer, such as zooplankton. Conversely, the highest concentrations of dissolved oxygen were recorded in the Jamapa River, attributed to its proximity to the river and the mouth of the thermoelectric tributary, where oxygenation occurs due to the waterfall that pours water into this zone.

The highest water temperature recorded in this study was within the maximum permissible limit of 35°C, as defined by the official Mexican standard (NOM-001-SEMARNAT-2021). The elevated temperature values were closely related to the water discharge from the artificial tributary of the Dos Bocas thermoelectric plant, which uses water from the Jamapa River to cool its turbines. Instead, the highest temperature values were associated with the climatic seasons, as they were recorded during the dry and rainy seasons. In this regard, some authors have reported values of 23 to 25°C during cold fronts (Avendaño-Álvarez 2013, Contreras-Espinoza 2016, Castañeda-Chávez et al. 2017) and 29.4°C during the rainy season in the estuary of the Jamapa River (Contreras-Espinoza 2016).

The concentration of total dissolved solids was very high, exceeding nine times those established by the official Mexican standard (NOM-127-SSA1-2021); a maximum permissible limit of 1,000 ppm on environmental health, water for human use and consumption, and the permissible limits of quality and treatments to which the water must be subjected for its purification. These elevated concentrations of dissolved solids are linked to discharges from urban tributaries that do not undergo treatment at a wastewater facility.

The pH values were slightly alkaline and similar to those reported by Houbon (2010), indicating that a buffering effect is present in the study area, which prevents the water from becoming overly acidic (Bates 1973). These alkalinity values enable the system to mitigate the acidification caused by organic matter from urban water discharges.

Salinity was lowest in June and July, corresponding to the rainy season. González-Vázquez et al. (2019) recorded values of 2 in September, which is also the rainy season, and this finding is consistent with the results of the present study.

The average abundance for the Arroyo Moreno estuary was 123.6 ind 100 m⁻³, similar to the report by Suárez-Morales (1994), which noted 114.6 ind 100 m⁻³ in Chetumal Bay. The diversity values (0.25 to 0.75 bits ind⁻¹) were lower than those reported by Ruíz-Pineda et al. (2016), which ranged from 1.64 to 1.73 bits ind⁻¹. These diversity values were significantly lower than those recorded in the neritic zone of the Veracruz reef system, adjacent to the study area, which was 3.71 bits ind⁻¹ (Cházaro-Olvera et al. 2019).

Table 7. Generalized linear model. Relationship between the density of copepod species (B) with months, sampling sites, and environmental factors in the Arroyo Moreno estuary, Boca del Río, Veracruz, Mexico.

Specie		B	Wald chi-square	P
<i>Acartia (Odontacartia) lilljeborgii</i> Giesbrecht, 1889	Interception	101.84	1.30	0.255
	Salinity	-0.40	20.02	< 0.001
<i>Acrocalanus longicornis</i> Giesbrecht, 1888	Interception	23.24	34.38	< 0.001
	Dissolved oxygen	-0.68	8.13	0.004
	Temperature	-0.59	28.19	< 0.001
	Interception	-1.98	23.70	< 0.001
<i>Acartia (Acanthacartia) tonsa</i> Dana, 1849	Dissolved oxygen	0.02	10.46	0.001
	Temperature	-0.13	778.86	< 0.001
	Total dissolved solids	0.01	159.1	< 0.001
	Salinity	-0.05	169.42	< 0.001
	pH	1.62	1005.42	< 0.001
	-	-	-	-
<i>Clausocalanus furcatus</i> (Brady, 1883)	-	-	-	-
<i>Dioithona oculata</i> (Farran, 1913)	-	-	-	-
<i>Labidocera aestiva</i> Wheeler, 1900	Interception	30.96	13.65	< 0.001
	Temperature	-0.93	11.06	0.001
<i>Megacalanus princeps princeps</i> Wolfenden, 1904	-	-	-	-
<i>Oithona nana</i> Giesbrecht, 1893	Interception	44.36	58.99	< 0.001
	Dissolved oxygen	-0.22	9.60	0.002
	Total dissolved solids	0.01	27.72	< 0.001
	Salinity	0.23	9.04	0.003
	pH	-4.96	56.04	< 0.001
<i>Paracalanus aculeatus aculeatus</i> Giesbrecht, 1888	Interception	29.63	60.10	< 0.001
	Temperature	-0.74	12.58	< 0.001
	Total dissolved solids	0.01	4.42	0.035
	Salinity	2.25	5.58	0.018
<i>Paracalanus quasimodo</i> Bowman, 1971	Interception	-15.68	3.29	0.040
	Dissolved oxygen	-0.89	14.28	< 0.001
	Temperature	-0.45	12.76	< 0.001
	pH	4.61	47.12	< 0.001

The species *A. (A.) tonsa* accounted for 93% of the copepods' abundance in the Arroyo Moreno estuary. Ruíz-Pineda et al. (2016) reported that this species accounted for 83% of the copepod abundance in Chetumal Bay. The abundance of *A. (A.) tonsa* could be to the broad tolerance to salinity changes from oligohaline (Suárez-Morales 1994) to hypersaline (Britton & Morton 1989), and they are tolerant to high turbidity (Derisio et al. 2014). The low salinity values in the Arroyo Moreno estuary favor the reproductive success of *A. (A.) tonsa* (Calliari et al. 2006) and explains the higher abundance values of the species. According to the results obtained in this study using GLM, although the relationship with salinity was significant, the value of β was the lowest compared to the other species, as were the values of β for the dissolved oxygen, temperature, total dissolved solids, and pH.

The species *A. (A.) tonsa* and *A. (O.) lilljeborgi* coexist in estuarine coastal systems; however, *A. (O.)*

lilljeborgi prefers areas with higher salinity (Ruíz-Pineda et al. 2016). The GLM analysis indicated that the β values were positive for salinity, reaching even the highest levels. In contrast, Elliott et al. (2013) reported that *A. (A.) tonsa* exhibits a high tolerance to low oxygen levels, capable of surviving in conditions as low as 2.3 mL L⁻¹. However, the results obtained in the present study suggest that the tolerance range for hypoxic conditions may be broader for the species, as the lowest average concentration recorded was 1.37 ± 1.89 mg L⁻¹. Conversely, the low abundance of *A. (O.) lilljeborgi* can be linked to the decreased concentration of dissolved oxygen (Escamilla et al. 2011).

The species *A. (A.) tonsa*, *A. longicornis*, *C. furcatus*, *D. oculata*, *L. aestiva*, *M. princeps princeps*, *O. nana*, *P. aculeatus aculeatus*, and *P. quasimodo*, as noted by Ruíz-Pineda et al. (2016), show coastal-marine affinity that restricts their distribution to the Arroyo Moreno estuary, resulting in a group with low diversity.

In conclusion, the Arroyo Moreno estuary is a peri-urban system that generally presents hypoxic conditions. The highest temperature values occurred in May, which corresponds to the dry season. Then again, the maximum temperature approached the permissible limit established by the official Mexican standard. Likewise, the concentration of total dissolved solids was very high, exceeding the official Mexican standard by more than nine times. The pH values were slightly alkaline, allowing the system to function like a buffer. Salinity levels decreased in June and July, coinciding with the onset of the rainy season. The average abundance observed in this estuary aligned with findings from other studies. However, the diversity was significantly lower than reported previously. The species *A. (A.) tonsa* represented 93% of the total copepod abundance found in the Arroyo Moreno estuary, reflecting the euryoic response of the species. The other species showed coastal-marine affinity, which spatially restricted their distribution in the Arroyo Moreno estuary, resulting in a group with low diversity.

ACKNOWLEDGMENTS

We appreciate the support received from the Boca del Río Veracruz Technological Institute for this study. We thank the reviewers for their work and the time they dedicated to reviewing this study.

Credit the author's contribution

S. Cházaro-Olvera: data curation, formal analysis, investigation, methodology, software, writing-original draft, writing-review and editing; M.F. Durán-Del Valle: investigation, formal analysis methodology, validation, and visualization; Á. Morán-Silva: validation, visualization, writing-review and editing; J. Montoya-Mendoza: investigation, methodology, supervision, validation, writing-review and editing; R. Chávez-López: conceptualization, investigation, supervision, validation, visualization and writing-review. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest.

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Received: July 2, 2025; Accepted: August 1, 2025