

## Research Article

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# Molluscs along a salinity gradient in a hypersaline coastal lagoon, southern Gulf of Mexico

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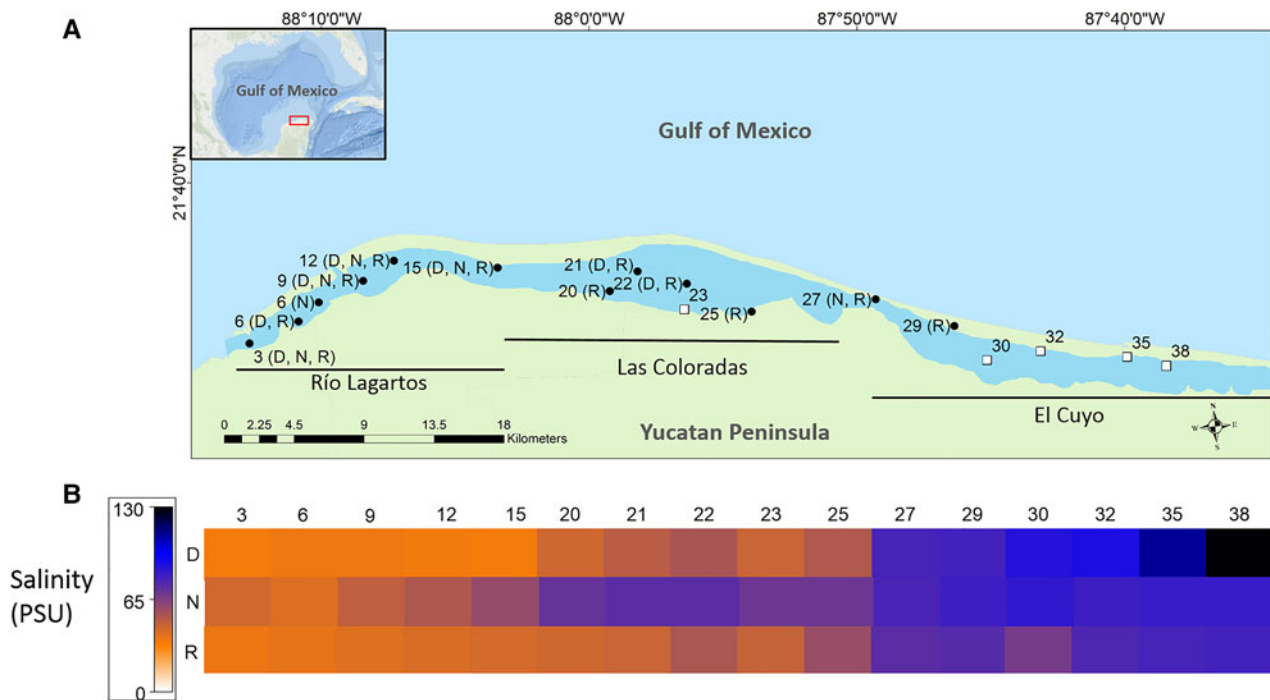
## Abstract

Molluscs are a diverse phylum in coastal lagoons because the numerous taxa collectively display broad ranges of optima and tolerance with respect to ambient conditions. We report on the taxonomic composition, habitat preferences and feeding guilds of molluscs from Río Lagartos coastal lagoon, Mexico. Molluscs were collected in the rainy season (September/October 2017), during the winter (*Nortes*) season (February 2018) and at the end of the warm, dry season (May 2018). Samples were taken using a Ponar dredge, a cylindrical PVC core barrel, or a beach seine. We studied the abiotic characteristics (sediment grain-size distributions, submersed aquatic vegetation abundance and salinity) to explore assemblage differences across the broad salinity gradient that characterizes the system (~30–78 PSU). Molluscs were represented by 39 species, 34 genera, 23 families and two classes. Stenohaline species were more numerous overall than euryhaline species, but their occurrence in samples was low (<20% of the samples). Stenohaline taxa lived primarily in environments characterized by marine salinity, and few were found under hypersaline conditions. We collected a smaller number of species than did studies carried out in the lagoon >35 years ago. Species accumulation curves revealed that the full species richness was not captured in our study. Euhaline environments displayed greater mollusc species richness and had a larger proportion of amount (mass) of submersed aquatic vegetation. In the hypersaline environments, species richness may be favoured by the lower dominance of sands. Suspension feeders were the most diverse group in both the euhaline and hyperhaline environments.

## Introduction

Mexico has ~1,567,300 ha of coastal wetlands, of which about 674,500 ha (43%) lie along the Gulf of Mexico (GoM) (including the Atlantic Ocean and the Caribbean Sea) (Contreras-Espinosa & Warner, 2004). These are represented by about 149 geomorphological forms, of which 59% are coastal lagoons (De La Lanza Espino *et al.*, 2013). Coastal lagoons are shallow, enclosed or semi-enclosed coastal wetlands, which are ephemeral or permanently flooded, and usually separated from the sea by a sand barrier (Lankford, 1977; Kjerfve, 1994). Coastal lagoons are often characterized by strong spatial salinity gradients (Lampthey & Armah, 2008) and temporal variations in salinity at different time scales, the latter related to intra-annual fluctuations in the precipitation–evaporation balance, tidal forces and wind stress, all of which regulate the hydrological balance (Kjerfve & Magill, 1989). Such lagoons are often highly productive aquatic systems that contain many habitat types (Herrera-Silveira & Morales-Ojeda, 2010) and therefore support numerous invertebrate phyla (Hernández-Guevara *et al.*, 2008).

Molluscs are an abundant and diverse phylum in coastal lagoons because the numerous taxa collectively display a broad range of optima with respect to ambient conditions, e.g. salinity and temperature, and some individual species display a broad tolerance with respect to those variables (Wingard & Surge, 2017). Temperature is perhaps the most important environmental variable that determines large-scale geographic distributions of marine organisms, whereas salinity exerts greater control at the local level (Turney & Perkins, 1972; Lampthey & Armah, 2008; Tunnell *et al.*, 2010; Selly *et al.*, 2018; De Jesús-Carrillo *et al.*, 2020, 2021). In addition to temperature and salinity, other environmental factors affect benthic mollusc distributions, such as water circulation (Tunnell *et al.*, 2010; Grenz *et al.*, 2017), substrate type (Abdelhady *et al.*, 2019), habitat complexity (De Duarte *et al.*, 2020) and oxygen concentration (De Jesús-Carrillo *et al.*, 2020).



**Fig. 1.** (A) Location of the Río Lagartos coastal lagoon on the northern Yucatán Peninsula, Mexico. The extents of the three main basins of the system are shown (Río Lagartos basin (mouth), Las Coloradas basin (middle) and El Cuyo basin (head)). Black dots indicate sites where molluscs were collected, open squares indicate sites without molluscs and letters denote the season when molluscs were collected (N: cool Nortes season (February sampling), R: rainy season (September/October sampling), D: warm and dry season (late May sampling)). (B) Heat map of the salinity values per station (shown at the top) and season (D: warm and dry, N: cool Nortes, R: rainy) (shown on the left).

Benthic mollusc taxa occupy many positions in the food web. Most bivalves are suspension feeders, whereas gastropods, which display infaunal and epifaunal benthic life habits, are primarily grazers, predators or scavengers (de Lucena *et al.*, 2012; Wingard & Surge, 2017). Molluscs are also a preferred food source for many other organisms (Arceo-Carranza *et al.*, 2013; Chi-Espinola & Vega-Cendejas, 2013; Hinojosa-Garro *et al.*, 2013).

Several investigations yielded lists of molluscs from the coastal GoM (Vokes & Vokes, 1983; García-Cubas & Reguero, 2004, 2007). For coastal lagoons, a great deal of information from the western and southern GoM was generated from the 1970s to 2000. It consists of taxonomic inventories, as well as studies on community structure and ecology (García-Cubas, 1970, 1971, 1981; Reguero & García-Cubas, 1989, 1991b, 1993, 1994; García-Cubas *et al.*, 1990, 1992, 1999). Recently, the assemblage structure and functional ecology of molluscs was addressed in Mecoacn Lagoon, also in the southern GoM (De Jesús-Carrillo *et al.*, 2020, 2021). An exhaustive evaluation of the malacological diversity associated with different habitats was performed in Los Petenes Biosphere Reserve, Campeche (Mexico), and in a suite of coastal lagoons along the western and south-eastern Mexican GoM (Lagunas Mandinga, Sontecomapan, Carmen-Machona, Mecoacán, Tupilco-Ostión, Terminos, Atasta, Santa Anita and Sabancuy) (Gonzalez *et al.*, 2018). Nevertheless, studies of molluscs in the eastern GoM (i.e. the Yucatán Peninsula and Caribbean coastal wetlands) are few. The geographic distribution patterns and species richness of bivalves and gastropods from 33 localities along the shoreline (including some coastal wetlands) and corals reefs of the Yucatán Peninsula were studied about 30 years ago, using specimens collected during the 1980s (Gonzalez *et al.*, 1991). In the last decade, a study addressing the entire macrobenthic fauna community in the Río Lagartos coastal lagoon, northern Yucatán Peninsula, yielded information on the presence, patterns of distribution, and physical-chemical controls on the dominant molluscs (Kuk-Dzul *et al.*, 2012).

Aside from those studies, however, we lack critical information, such as functional traits, updated inventories, or ecological preferences, about molluscs in coastal lagoons of the eastern GoM (Yucatán Peninsula).

The coastal zone of the Yucatán Peninsula is often recognized as a characteristic unit, with two subregions that have very different oceanographic characteristics: (i) the northern and western parts of the Yucatán Peninsula, which are part of the Gulf of Mexico, and (ii) the eastern coast of the Peninsula, which is part of the Caribbean Sea (Herrera-Silveira *et al.*, 2013 and references cited therein). The first subregion, also called the 'Campeche Bank' is an extension of the Peninsula that is a vast and shallow continental shelf, which, like the terrestrial portion of the Yucatán Peninsula is composed of porous, Karst limestone of high permeability. This enables direct communication between continental and marine waters (Valle-Levinson *et al.*, 2011). The shallow environment of this subregion promotes important heat gain and evaporation, which, in the coastal lagoons and along the coastal environment in general, contributes to the development of warm and very saline waters that enter the GoM (Enriquez *et al.*, 2013). Also, being part of the GoM, tides of this subregion are predominantly diurnal (Tenorio-Fernandez *et al.*, 2016), with maximum tidal ranges that reach 0.6 m during tropical tides, and minimum ranges of only 0.1 m during equatorial tides, when the tide can be semi-diurnal, as long as it does not coincide with neap tides (Valle-Levinson *et al.*, 2022). The second subregion is different, as the water depth increases abruptly very close to the coast, where the intense oceanic Yucatán Current flows northward through the Yucatán Channel into the GoM. Tides in this subregion are semi-diurnal and also micro-tidal (<0.6 m range). Both regions are greatly influenced by the dominant trade winds (easterlies) and by substantial continental submarine fresh groundwater discharges. The north-eastern corner of the Yucatán Peninsula is a peculiar transition zone, which is influenced by both the Caribbean Sea and GoM. The region

receives nutrient-rich upwelling water that arises from the Yucatán Current and moves onto the shallow Yucatán Shelf, interacting with the continental border (western boundary current) (Enriquez *et al.*, 2010; Reyes-Mendoza *et al.*, 2016). Linked to this transitional character of the Yucatán Peninsula, particular biological communities, including molluscs, are observed in near-coastal areas, including the coastal lagoons. Those communities differ from communities in the southern GoM to the west and in the Caribbean Sea to the east (Gonzalez *et al.*, 1991; Herrera-Silveira *et al.*, 2013; Aguilar-Medrano & Vega-Cendejas, 2021).

Given the distinctive geographic characteristics of the northern Yucatán Peninsula and the paucity of mollusc research in the area, we undertook this study to evaluate mollusc community composition in the second largest coastal lagoon on the northern Yucatán Peninsula, i.e. the Río Lagartos coastal lagoon. Considering the marked spatial salinity gradient in this system, we also explored how mollusc species and functional groups are distributed with respect to salinity.

## Materials and methods

### Study area

The Río Lagartos coastal lagoon is located on the north-east coast of the Yucatán Peninsula (21°26′–21°38′N 87°30′–88°5′W), Mexico, and is part of the Ría Lagartos Biosphere Reserve. This east–west-oriented lagoon is ~80 km long and has a total surface area of ~98 km<sup>2</sup>. The lagoon is divided into three hydrologically connected basins: Río Lagartos basin (mouth), Las Coloradas basin (middle) and El Cuyo basin (head (interior)) (Quesadas-Rojas *et al.*, 2021) (Figure 1A). It is generally shallow (~0.4–1.0 m) (Valdes & Real, 2004; Quesadas-Rojas *et al.*, 2021), with some deeper locations, up to 3.5 m in channels or between zones (Quesadas-Rojas *et al.*, 2021). The lagoon is hypersaline throughout much of its length, with a gradient from the head near El Cuyo (>70) to the seaward region near Río Lagartos (33–38) (Herrera-Silveira & Ramírez-Ramírez, 1998) (Figure 1B). Hypersaline conditions are a consequence of low rainfall (<500 mm/year), high evaporation (~2000 mm/year), absence of overland freshwater inputs, long residence times, and physical/geomorphological characteristics (Valdes & Real, 2004; Peralta-Meixueiro & Vega-Cendejas, 2011).

### Field sampling and data collection

#### Sampling strategy

Samples were collected in the Río Lagartos coastal lagoon system (Figure 1A) as part of the Salinity Gradient Energy project of the Centro Mexicano de Innovación en Energía Océano (CEMIE Océano). Samples were obtained from 16 stations distributed along the lagoon, in the three main basins of the system: Río Lagartos basin to the mouth, in the west (stations: 3, 6, 9, 12, 15), Las Coloradas basin, in the middle (stations: 20, 21, 22, 23, 25) and El Cuyo basin to the head of the lagoon, in the east (stations: 27, 29, 30, 32, 35, 38) (Figure 1A; Table 1). Spatial distribution of the stations was based on previous studies of abiotic and biotic variables, which indicated that the three basins can be considered environmentally and biologically distinct (Ortegón-Aznar *et al.*, 2001; Valdes & Real, 2004; Vega-Cendejas & Hernández De Santillana, 2004; Peralta-Meixueiro & Vega-Cendejas, 2011; Dávila-Jiménez *et al.*, 2019). The lagoon was sampled during three periods that coincided with the end of the three seasons in the region: the rainy season (September/October 2017), the cool *Nortes* season (February 2018) and the warm, dry season (May 2018) (Table 1). This was done to capture seasonal

differences in the mollusc fauna throughout the year. Samples were collected at water depths ranging from 0.5–1.5 m.

#### Mollusc sampling

Molluscs were collected using three methods. Samples of macrobenthic molluscs were obtained using a standard Ponar dredge (9" × 9" or 22.9 × 22.9 cm; 0.052 m<sup>2</sup> sampling area), or a cylindrical PVC core tube (6" diameter; 0.018 m<sup>2</sup> sampling area), the latter in the event that the substrate was too hard and the dredge did not penetrate the sediment. Duplicate samples were obtained at each station, and sediments were sieved through a 500-µm mesh to separate the macrofauna. Megabenthic molluscs were collected using a 40-m-long and 1-m-high beach seine with half-inch mesh size, covering an area of 400 m<sup>2</sup>. Molluscs on the roots of red mangrove (*Rhizophora mangle* Linnaeus, 1753) were also obtained in some cases, by gently scraping them from the root surface over a 20 × 20 cm<sup>2</sup> area, at mid-depth in the water column. Details about the sampling locations and gear used are found in Supplementary Material 1. Specimens from one replicate at each station were initially anaesthetized with magnesium chloride, and then preserved in 4% formaldehyde. The other replicate was frozen for future chemical analyses. In the laboratory, the formaldehyde samples were transferred to 70% ethanol, after which all molluscs were sorted and identified, usually to species level, under a stereo- or a compound microscope.

Taxonomic classification largely followed Bouchet *et al.* (2010) for Bivalvia, and Bouchet *et al.* (2017) for Gastropoda, though some classifications were updated using Mikkelsen & Bieler (2008), Redfern (2013) and Tunnell *et al.* (2010). Molluscs were identified to the lowest possible taxonomic level, using multiple sources (García-Cubas, 1981; García-Cubas & Reguero, 2007; Mikkelsen & Bieler, 2008; Tunnell *et al.*, 2010; Espinosa *et al.*, 2012; Redfern, 2013), and photographed. The term specimen generally refers to live-collected animals with soft parts intact. Bivalve shells are described as 'paired', and only articulated individuals were photographed. Only for the species of gastropod *Cerithium atratum* photographs were obtained from a dead specimen with a sipunculid worm inside, but for numerical analyses only live animals were considered. Each specimen was assigned a catalogue number and deposited in the 'Colección de Moluscos de la Península de Yucatán' (CMPY), Unidad Multidisciplinaria de Docencia e Investigación Campus Sisal, Universidad Nacional Autónoma de México.

#### Salinity measurement

At each station, salinity was measured in the water column at depths between 0.15–0.35 m, using a multiparameter Aquaprobe AP-5000. A refractometer was used to measure salinity when values exceeded 60, and a Baume hydrometer was used when salinity was >80.

#### Sediment sampling

Sediments were sampled with the same dredge or PVC core barrel used for biological sampling and collected material was stored at –20°C for grain-size analysis. In the laboratory, sediments were dried at 60°C to a constant weight, and later, proportions of gravel (>2 mm), sand (0.063–2 mm) and silt/clay (<0.063 mm) (Wentworth, 1922) were obtained by sieving sediments with a sieve agitator for 20 min.

#### Submersed vegetation

The macroscopic vegetation collected in each macrobenthos sample was separated from the sediment after thorough inspection under the microscope to separate the organisms. Wet weights of the vegetation and sediments were obtained after drying with blotting paper, and the gravimetric contribution of vegetation

**Table 1.** Sampling locations where molluscs were collected in the hypersaline Río Lagartos coastal lagoon, Yucatán Peninsula, Mexico

Survey code	Site	Latitude N	Longitude W	Date of collection	Season	Basin	Salinity (PSU)
RL1709	3	21.574	-88.231	2017-10-03	R	RL	36.7
RL1709	6	21.581	-88.199	2017-10-03	R	RL	38.2
RL1709	12	21.608	-88.135	2017-10-03	R	RL	41.6
RL1709	15	21.596	-88.071	2017-10-04	R	RL	42.5
RL1709	20	21.575	-88.003	2017-10-04	R	CO	44.1
RL1709	21	21.592	-87.985	2017-10-04	R	CO	45.8
RL1709	22	21.581	-87.955	2017-10-05	R	CO	53.0
RL1709	25	21.563	-87.916	2017-10-05	R	CO	58.1
RL1709	27	21.560	-87.838	2017-10-02	R	CU	74.0
RL1709	29	21.535	-87.791	2017-10-02	R	CU	75.0
RL1709	9c1	21.603	-88.156	2017-09-29	R	RL	40.0
RL1709	9c2	21.603	-88.156	2017-09-29	R	RL	40.0
RL1709	9c3	21.603	-88.156	2017-09-29	R	RL	37.7
RL1709	9c4	21.603	-88.156	2017-09-30	R	RL	40.0
RL1802	3	21.574	-88.230	2018-02-27	N	RL	43.5
RL1802	6	21.592	-88.185	2018-02-27	N	RL	40.5
RL1802	12	21.608	-88.136	2018-02-27	N	RL	52.3
RL1802	15	21.596	-88.071	2018-02-28	N	RL	58.9
RL1802	27	21.560	-87.838	2018-02-23	N	CU	78.0
RL1802	9c2	21.603	-88.156	2018-02-26	N	RL	37.2
RL1802	9c3	21.603	-88.156	2018-02-26	N	RL	36.9
RL1805	3	21.574	-88.230	2018-05-19	D	RL	34.5
RL1805	6	21.580	-88.198	2018-05-19	D	RL	36.0
RL1805	12	21.608	-88.135	2018-05-19	D	RL	35.2
RL1805	15	21.596	-88.071	2018-05-19	D	RL	34.3
RL1805	21	21.592	-87.985	2018-05-21	D	CO	49.8
RL1805	22	21.581	-87.955	2018-05-20	D	CO	53.8
RL1805	9c1	21.603	-88.156	2018-05-17	D	RL	36.2
RL1805	9c2	21.603	-88.156	2018-05-17	D	RL	37.2
RL1805	9c3	21.603	-88.156	2018-05-18	D	RL	35.4
RL1805	9c4	21.603	-88.156	2018-05-18	D	RL	35.3

Survey letters 'RL' indicate Río Lagartos and survey numbers indicate the year of sampling and month when the sampling survey started. Site numbers are as indicated in Figure 1A and locations are designated by latitude (north) and longitude (west). Date is collection date (year-month-day). Season of collection is indicated by R: rainy season (September/October sampling), N: cool *Nortes* season (February sampling), and D: warm and dry season (late May sampling). Basin of the lagoon system (RL: Río Lagartos (mouth), CO: Las Coloradas (middle), CU: El Cuyo (head)), and value of salinity in Practical Salinity Units (PSU) also indicated.

(macroalgae and seagrasses) to the whole sample (i.e. vegetation and sediments) was calculated as a proxy for the amount of vegetation in the sample.

## Data analysis

### Community composition analysis

A sample presence-absence matrix was constructed. Presence of the species in each basin and during each sampling period was examined and the total number of species was obtained. Organisms were classified according to their taxonomic class (Bivalvia or Gastropoda), habitat (infaunal or epifaunal) and feeding guild (suspension feeders, carnivores, deposit consumers or grazers), following the classification scheme of García-Cubas (1981) and García-Cubas & Reguero (2007), and the number of species in each group was determined. These three classifications

were related in an alluvial diagram with the online software Raw graphs 2.0.

### Species vs salinity analysis

Samples were classified into two groups based on salinity (euhaline (30–40) and hyperhaline (>40)), following the classification of Wingard *et al.* (2012), and the salinity range occupied by each species was explored. Next, species were classified into two groups based on salinity tolerance, i.e. stenohaline (occurring in <20% of the total salinity range in the lagoon) and euryhaline (occurring in >20% of the total salinity range in the lagoon). The per cent contribution to the total number of species and the frequency of occurrence (FO% = number of samples in which a class was present/total number of samples × 100) of each taxonomic class, habitat group and feeding guild were calculated for the euhaline and hyperhaline environments. Mean

values and standard deviations of the different sediment grain-size classes and of the submersed vegetation gravimetric percentages were also estimated for both environments.

Species accumulation curves were constructed for each salinity environment with interpolation-extrapolation of Hill Numbers of order  $q$ : species number ( $q = 0$ ) to compute diversity estimates and the associated 95% (0.95) confidence intervals for the two groups, based on salinity. Analyses were performed using the online package iNEXT (Chao *et al.*, 2016). A data summary is provided in Supplementary Material 2.

## Results

### Taxonomic composition

A total of 2598 mollusc specimens from the Río Lagartos coastal lagoon, representing 39 species (Table 2), 34 genera, 23 families (Figures 2–5), and two classes, were enumerated. Molluscs were found at seven stations in the dry season, six stations in the cold (Nortes) season and 11 stations in the rainy season. Species *Carditamera floridana*, *Meioceras nitidum*, *Modulus modiolus* and *Crepidula convexa* were present during all three seasons (Table 2). Nine species were collected during the cold season, 22 species in the rainy season and 28 species in the warm dry season. Thirty-seven species were collected in the Río Lagartos basin (mouth) (RL), six species in the Las Coloradas basin (middle) (CO) and five species in the El Cuyo basin (head) (CU) (Table 2). The most ubiquitous species were *Prunum apicinum* (Menke, 1828), encountered at 14 stations, *Anomalocardia auberiana*, encountered at nine stations, and *Meioceras nitidum* (Stimpson, 1851), *Angulus paramerus* (Boss, 1964), *Modulus modiolus* (Linnaeus, 1758), *Crepidula convexa* (Say, 1822) and *Carditamera floridana* (Conrad, 1838), encountered at eight stations. Thirty-three species were collected with the dredge, 12 species with the beach seine and four species with the cylindrical PVC tube. Twenty species (51%) belonged to the class Gastropoda, and 19 (49%) to the Bivalvia (Figure 6). Twenty-two species (56%) were epifaunal and 17 (44%) were infaunal (Table 2, Figure 6). Nine species (23%) were carnivores, 14 (36%) were suspension feeders, seven (18%) were deposit consumers and nine (23%) grazers (Table 2, Figure 6).

### Molluscs and salinity in the Río Lagartos coastal lagoon

The Río Lagartos coastal lagoon is inhabited by both stenohaline (27 species; 69%) and euryhaline (12 species; 31%) species (Figure 7). Stenohaline species displayed lower occurrence (<20%), and some species were collected exclusively under euhaline (15 species) or hypersaline conditions (6 species). Twelve species tolerate a broad salinity range (euryhaline). The species distributed in the largest salinity range were: *Melongena corona* (37–78), *Anomalocardia auberiana* (34–58), *Meioceras nitidum* (36–74) and *Odostomia laevigata*, which was collected at only two stations with very different salinity (35 and 78).

Abiotic characteristics and fauna composition differed between the two salinity environments (Table 3). In the euhaline sites, sediments were mostly sandy, and gravel and silt/clay were notably scarce (<10%) (Table 3). Percent submersed vegetation was  $15.25 \pm 29\%$ . Thirty-five species were collected in euhaline sites. Gastropoda and epifaunal molluscs occurred in all stations (FO = 100%). With respect to feeding guild, suspension feeders and grazers (FO = 79%) and carnivores (FO = 68%) appeared in more than half the samples. Suspension feeders were the most diverse group (40% of the species), followed by carnivores and grazers, each representing 23% of the species. In the hyperhaline sites, sediments were again mostly sandy, but the percentage

contributions of gravel (7.8%) and silt/clay (11.3%) were greater than in the euhaline sites, and the sediments were more variable (Table 3). The percentage of submersed vegetation was lower ( $4.9 \pm 7.9\%$ ). We found 22 species associated with hyperhaline sites, and of those, infauna (FO = 79%) and the class Bivalvia (FO = 79%) were distributed extensively in the samples. With respect to feeding guilds, suspension feeders appeared in more than half of the samples (FO = 64%), and the rest of the guilds were distributed in <50% of the samples. The most diverse groups in the hypersaline environments were suspension feeders (36% of the species) and carnivores (32% of the species).

For comparison of diversity between the euhaline and hyperhaline environments, sample-size-based sampling curves were constructed, using reference sample sizes of 33 and 24 (considering each replicate), respectively. Extrapolation was carried out to >40 samples in both cases (Figure 8A). In all cases, sample completeness was <1 (0.8 for the hyperhaline environment and 0.7 for the euhaline environment) (Figure 8B), which indicates a deficit in the detection of species of about 20%. Comparisons of coverage-based sampling curves, up to a base coverage, revealed higher diversity than expected in euhaline environments (Figure 8C).

## Discussion

### Taxonomic composition

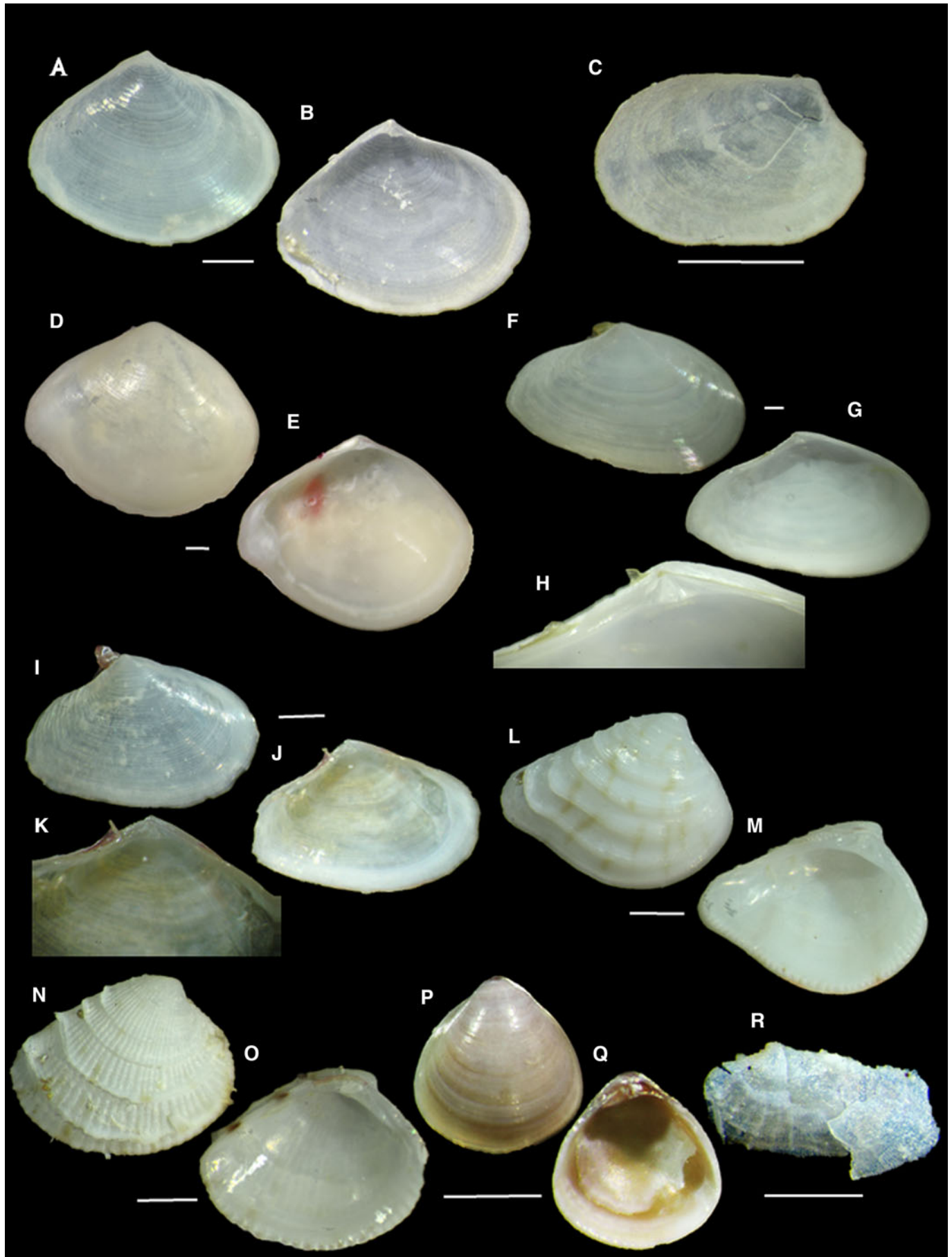
This work updates and expands upon previous mollusc studies in the Río Lagartos coastal lagoon. We encountered 37 species in the Río Lagartos basin (mouth), six in the Las Coloradas basin (middle) and five in the El Cuyo basin (head). The numbers differ substantially from those obtained by Gonzalez *et al.* (1991), who reported the presence of 71 species in the Río Lagartos basin, four in the Las Coloradas basin, and one in the El Cuyo basin. Furthermore, only nine of the species found in this study overlap with those reported by Gonzalez *et al.* (1991) (*Anodontia alba*, *Carditamera floridana*, *Chione cancellata*, *Anomalocardia auberiana*, *Modulus modiolus*, *Cerithium atratum*, *C. eburneum*, *Melongena corona* and *Bulla occidentalis*), all of which were collected from the Río Lagartos basin, only one from the Las Coloradas basin (*Melongena corona*) and none from the El Cuyo basin. The difference in number and composition of species between the two studies may be a consequence of several factors, some related to changes in the environmental conditions, and others related to sampling and sample-processing methods. Regarding the environment, it is unlikely that the effects of recent climate change, which have been detected on the Yucatán Peninsula during the last 60 years (Carnero-Bravo *et al.*, 2018; Andrade-Velázquez *et al.*, 2021), affected the mollusc community composition inside the lagoon, as detected long-term variations are small compared with short-term (diel, fortnightly or seasonal) variations that occur in the waterbody. For instance, no directional change in lagoon salinity has been detected during the last 40 years (Wojtarowski *et al.*, 2021). Given the rapid population growth and increased human activities around the lagoon during that same period, it is more plausible that the differences in faunal composition between the two studies are related to greater recent anthropogenic activities. For example, microplastics have been found in large quantities in recent lagoon sediments, and have been linked to human activity in the area (Quesadas-Rojas *et al.*, 2021). Nevertheless, interannual differences in abiotic conditions related to, for example, changes in precipitation or impacts of individual extreme events such as tropical storms and hurricanes (De la Barreda *et al.*, 2020), or longer-term climate variations (e.g. El Niño–Southern Oscillation; Fichez *et al.*, 2017), may also be responsible for such fauna differences

**Table 2.** Species presence by season (N: cool and dry *Nortes season* (February sampling), R: rainy season (September/October sampling), D: warm and dry season (late May sampling)), basin (RL – Río Lagartos (mouth), CO – Las Coloradas (middle), CU – El Cuyo (head)), and sampler used (dredge, beach seine and PVC tube). Feeding guild (SF: suspension feeder, DC: deposit consumers, G: grazer, C: carnivore) and habitat (E: epifaunal, I: infaunal) of each species also indicated

N°	Species	Season			Basin			Sampler			Feeding guild	Habitat
		N	R	D	RL	CO	CU	Dredge	Beach seine	PVC Tube		
<b>Bivalvia</b>												
1	<i>Brachidontes exustus</i>		x		x	x		x		x	SF	E
2	<i>Musculus lateralis</i>			x	x			x			SF	E
3	<i>Anodontia alba</i>		x	x	x			x			SF	I
4	<i>Ctena orbiculata</i>	x			x			x			SF	I
5	<i>Luciniscia nassula</i>		x	x	x			x			SF	I
6	<i>Parvilucina crenella</i>			x	x			x			SF	I
7	<i>Carditamera floridana</i>	x	x	x	x			x	x		SF	I
8	<i>Crassinella</i> sp.			x	x			x			SF	I
9	<i>Lasaeidae</i> sp.			x	x			x			SF	I
10	<i>Angulus merus</i>		x		x			x			DC	I
11	<i>Angulus paramerus</i>		x	x	x	x		x			DC	I
12	<i>Angulus sybariticus</i>			x	x			x			DC	I
13	<i>Macoma cerina</i>			x	x			x			DC	I
14	<i>Macoma tenta</i>		x				x	x			DC	I
15	<i>Merisca</i> sp.			x	x			x			DC	I
16	<i>Anomalocardia auberiana</i>		x	x	x	x		x	x		SF	I
17	<i>Chione cancellata</i>		x	x	x			x			SF	I
18	<i>Parastarte triquetra</i>		x		x	x		x			SF	I
19	<i>Lyonsia</i> sp.			x	x			x			SF	I
<b>Gastropoda</b>												
20	<i>Eulithidium adamsi</i>	x			x				x		G	E
21	<i>Cerithiidae</i> sp.		x		x			x			G	E
22	<i>Cerithium atratum</i>	x		x	x				x		G	E
23	<i>Cerithium eburneum</i>		x	x	x			x	x		G	E
24	<i>Cerithium lutosum</i>		x		x					x	G	E
25	<i>Modulus modulus</i>	x	x	x	x			x	x		G	E
26	<i>Vermetidae</i> sp.		x	x	x			x		x	DC	E
27	<i>Caecum donmoorei</i>			x	x			x			G	E
28	<i>Meioceras nitidum</i>	x	x	x	x		x	x		x	G	E
29	<i>Zebina browniana</i>		x		x			x			G	E
30	<i>Crepidula convexa</i>	x	x	x	x			x	x		SF	E
31	<i>Granulina</i> sp.			x	x			x			C	E
32	<i>Prunum apicinum</i>		x	x	x	x		x	x		C	E
33	<i>Astyris antares</i>			x	x			x			C	E
34	<i>Melongena corona</i>	x		x	x	x	x		x		C	E
35	<i>Nassarius vibex</i>		x		x				x		C	E
36	<i>Henrya henryi</i>		x				x	x			C	E
37	<i>Bulla occidentalis</i>		x	x	x				x		C	E
38	<i>Haminoea succinea</i>			x	x			x	x		C	E
39	<i>Odostomia laevigata</i>	x		x	x		x	x			C	E
	Total species	9	22	28	37	6	5	33	12	4		



**Fig. 2. Mytilidae:** *Brachidontes exustus*: (A, B). *Musculus lateralis*: (C–D). **Lucinidae:** *Anodontia alba*: (E–G). *Ctena orbiculata*: (H–J). *Luciniscia nassula*: (K–M). *Parvilucina crenella*: (N–P). **Carditidae:** *Carditamera floridana*: (Q–S). **Crassatellidae:** *Crassinella* sp.: (T). **Lasaeidae:** *Lasaeidae* sp.: (U, V). **Tellinidae:** *Angulus merus*: (W–Y) Scale bars = 1 mm.

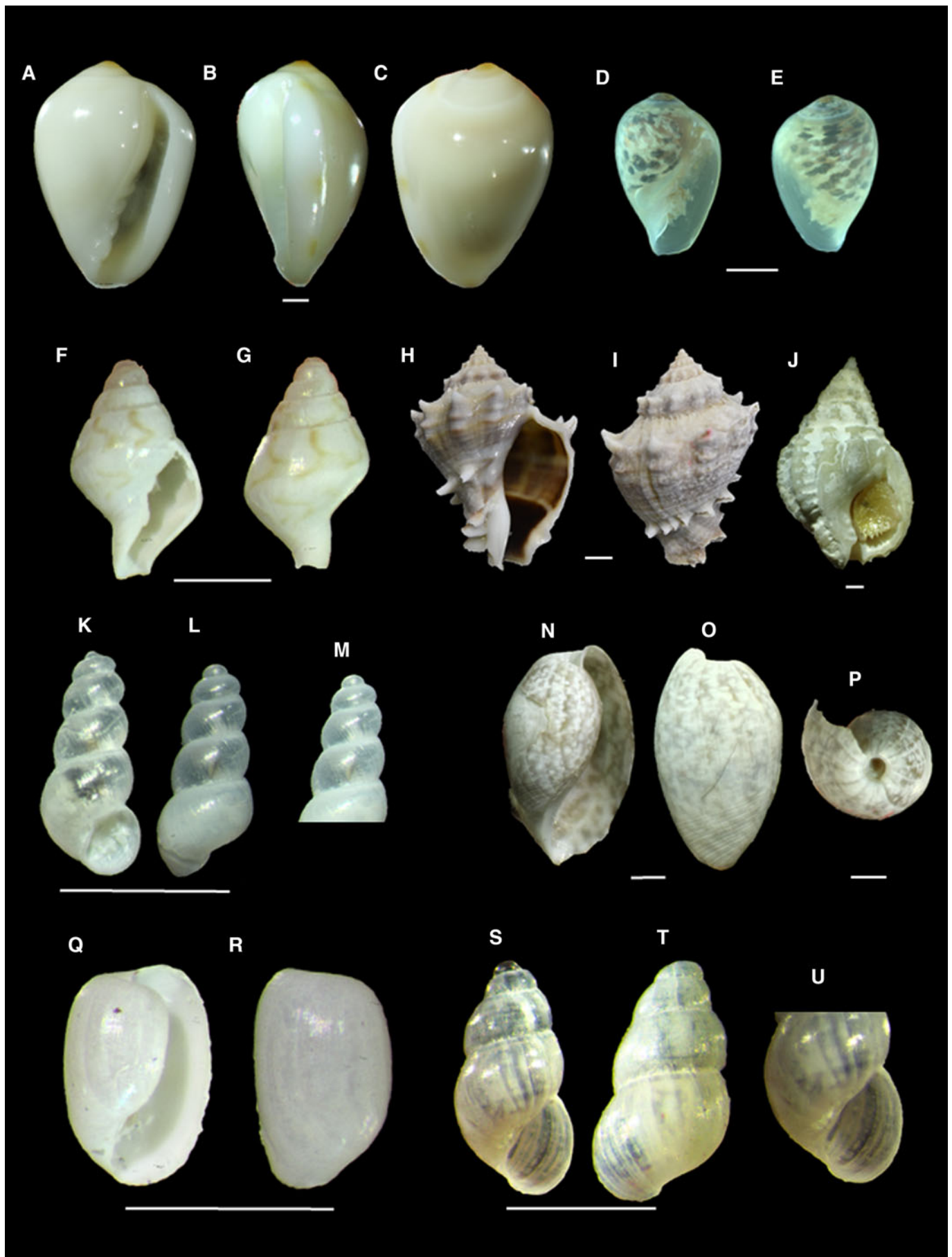


**Fig. 3.** Tellinidae: *Angulus paramerus*: (A, B). *Angulus sybariticus*: (C). *Macoma cerina*: (D, E). *Macoma tenta*: (F–H). *Merisca* sp.: (I–K). Veneridae: *Anomalocardia auberiana*: (L, M). *Chione cancellate*: (N, O). *Parastarte triquetra*: (P, Q). Lyonsiidae: *Lyonsia* sp.: (R). Scale bars = 1 mm.

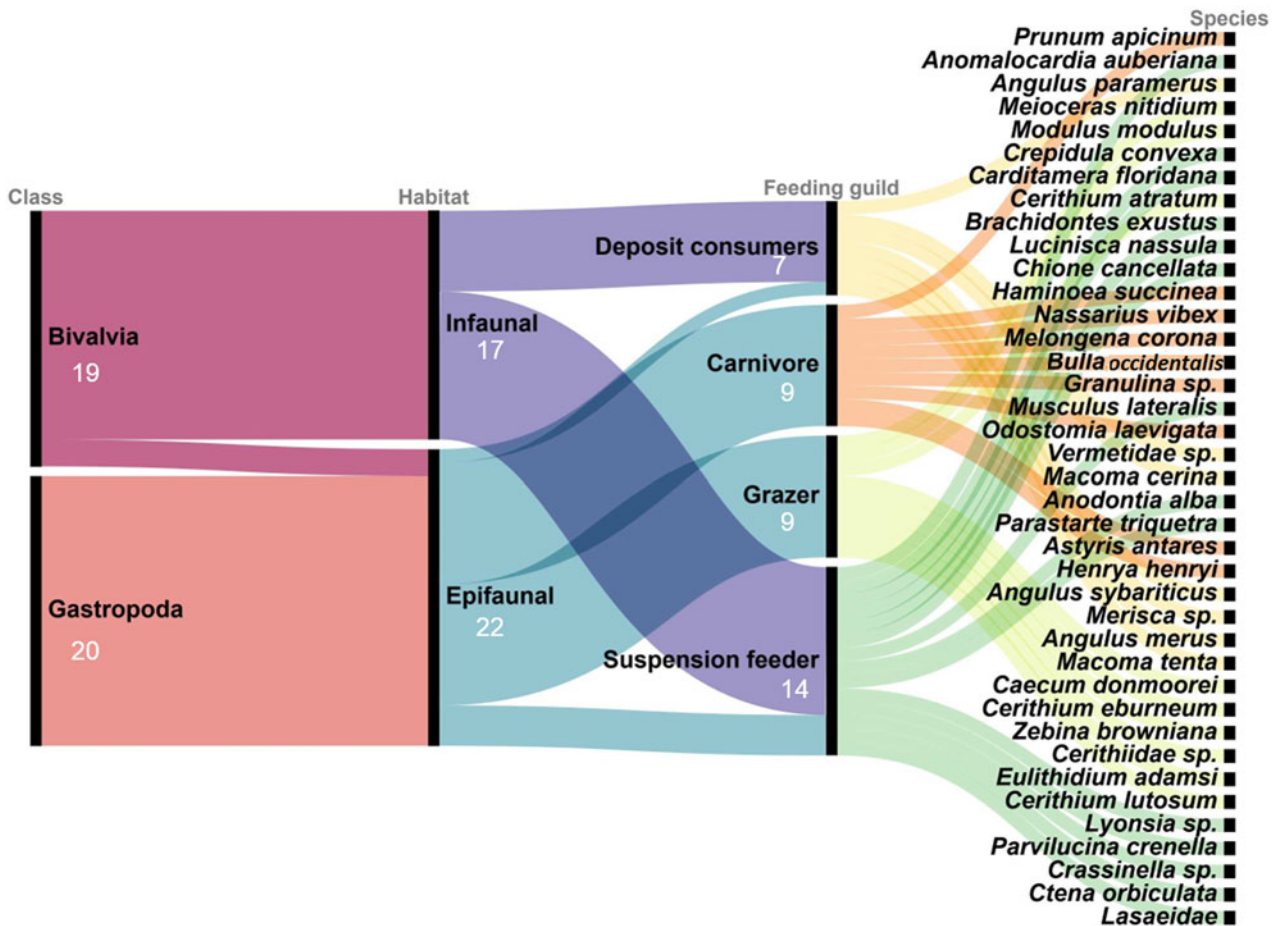




**Fig. 4.** Phasianellidae: *Eulithidium adamsi*: (A, B). Cerithiidae: Cerithiidae sp.: (C, D). *Cerithium atratum*: (E, F) (with Sipuncula). *Cerithium eburneum*: (G). *Cerithium lutosum*: (H, I). Modulidae: *Modulus modulus*: (J, K). Vermetidae: Vermetidae sp.: (L, M). Caecidae: *Caecum donmoorei*: (N, O). *Meioceras nitidum*: (P, Q). Zebinidae: *Zebina browniana*: (R–T). Calyptraeidae: *Crepidula convexa*: (U–W). Marginellidae: *Granulina* sp.: (X–Z). Scale bars = 1 mm.



**Fig. 5.** **Marginellidae:** *Prunum apicinum*: (A–E). **Columbellidae:** *Astyris antares*: (F, G). **Melongenidae:** *Melongena corona* (H, I) (scale bar = 5 mm). **Nassariidae:** *Nassarius vibex*: (J). **Murchisonellidae:** *Henrya henryi*: (K–M). **Bullidae:** *Bulla occidentalis*: (N–P). **Haminoeidae:** *Haminoea succinea*: (Q, R). **Pyramidellidae:** *Odostomia laevigata*: (S–U). Scale bars = 1 mm.



**Fig. 6.** Alluvial plot depicting the relationship between classes and species for two different functional traits: habitat and feeding guild. The species numbers are provided for each category.

between the two studies. Although all these explanations are plausible, we cannot rule out the possibility that differences between the two studies are attributable to sampling and sample-processing differences. Those methodological differences relate to: (1) the timing of sampling during the year, as suggested by the seasonal changes in species richness detected in our results, with the highest number of species (28) found in the dry season; (2) the types of samplers used, as the selectivity of each sampler is related to the net mesh size and the mode of operation (Raz-Guzman & Grizzle, 2001) – in this study, the dredge retained more species (33) than did the other samplers (Supplementary Material 3); and (3) the use of both empty shells and live specimens in counts in the previous study. Determination of the true cause(s) of long-term temporal patterns in mollusc fauna composition in the lagoon would require regular monitoring and use of standardized methods, which are expensive and difficult to sustain. Such large-scale efforts, which use standardized protocols (MBON Pole to Pole, 2019; Obst *et al.*, 2020; Ashton *et al.*, 2022), can be employed to detect shifts in community composition going forward. Such programmes, however, cannot shed light on past community changes. To document such past changes, it will be necessary to undertake palaeoecological studies, like those that have been done to examine changes in marine fauna communities during the last century, in both coastal (Armenteros *et al.*, 2016) and open-ocean contexts (Cartes *et al.*, 2017, 2022).

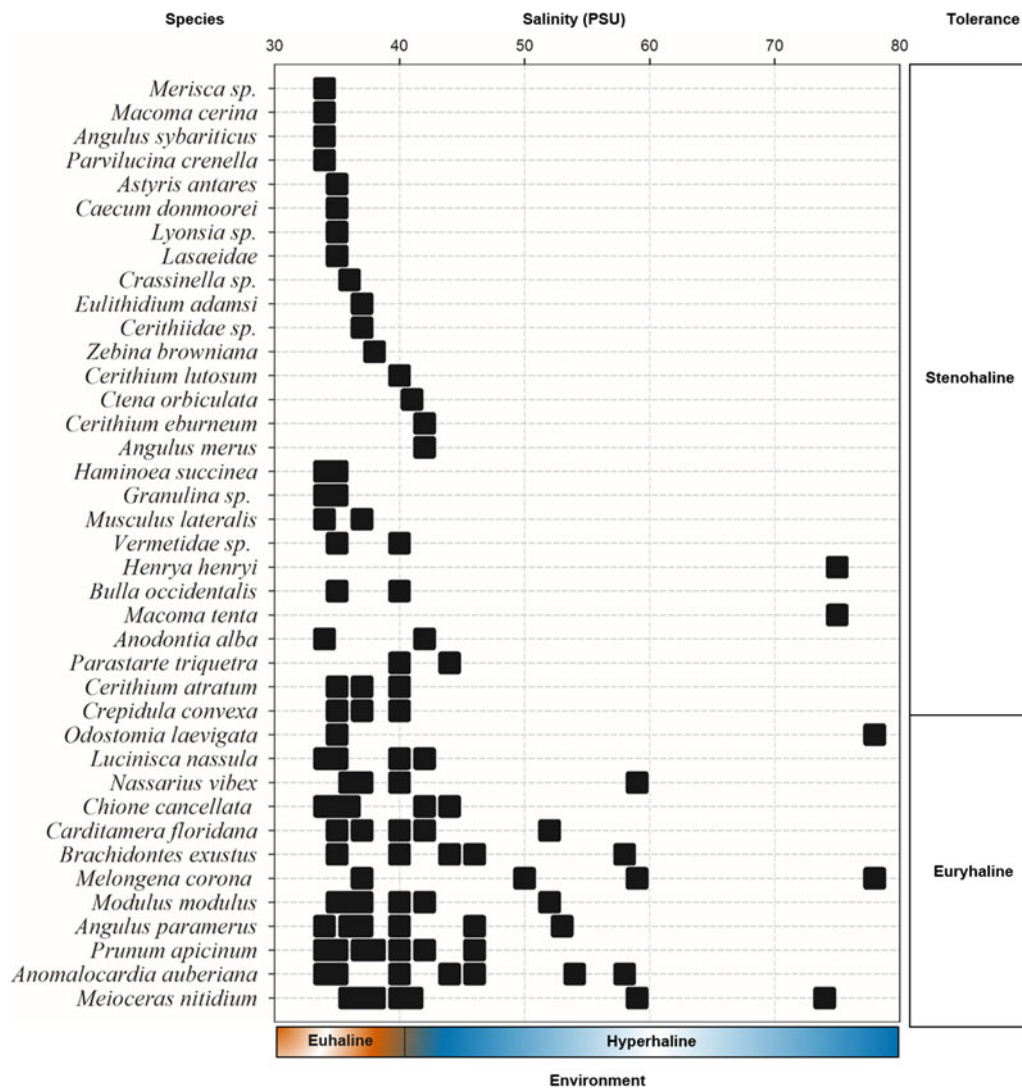
In any case, the large disparity in the diversity between the two studies, together with the revealed deficit in the detection of species in this study, as seen in the species accumulation curves, reinforces the idea that, despite the great sampling effort, the Río

Lagartos coastal lagoon has greater mollusc diversity, and likely spatio-temporal heterogeneity, than reported in this or previous studies. This highlights the lack of information from the region that will be necessary to achieve solid ecological baseline knowledge (Guerra-Castro *et al.*, 2020).

All the species found in the Río Lagartos coastal lagoon have been reported previously from other lagoons around the Gulf of Mexico (Figure 9) and 22 species were reported earlier from the Caribbean (García-Cubas & Reguero, 2004, 2007; Rosenberg *et al.*, 2009; Turgeon *et al.*, 2009). The high number of shared species between the Gulf of Mexico and the Caribbean is attributable to the dispersal of larvae by the Yucatán Current. Larvae may be carried from the Caribbean onto the continental shelf, particularly by upwelling events that occur seasonally, typically from April to September (Sanvicente-Añorve *et al.*, 2014; Reyes-Mendoza *et al.*, 2016; Kurczyn *et al.*, 2021). Once in the northern coastal region of the Yucatán Shelf, the main current is directed westward along the coast mainly by winds, and enhanced by westward pulses of the Yucatán Current, which flows to the north (Enriquez *et al.*, 2013). The Trade Winds (easterlies) are locally deflected southward by intense diurnal onshore breezes, which keep the westward-flowing waters close to the coast. This transport favours connectivity among populations (Herrera-Silveira *et al.*, 2013).

#### Abiotic and biotic patterns

This study demonstrates that mollusc species richness in the Río Lagartos coastal lagoon is influenced by salinity. Species richness was higher under euhaline than hypersaline conditions, and no animals were collected at salinities >78. A decrease in species



**Fig. 7.** Occurrence of mollusc species vs salinity. Ranges for euhaline (marine, 30–40 PSU) and hyperhaline environments (40–80 PSU) are indicated at the bottom of the figure. Salinity tolerance groups, i.e. stenohaline and euryhaline, are shown on the right. Terminology follows Wingard *et al.* (2012).

richness above hypersaline values in aquatic environments is common (Deaton, 2019) and in the Río Lagartos coastal lagoon it is reflected by the substantially lower numbers of species in the Las Coloradas (middle) and El Cuyo (head) basins. Such a pattern was also detected by Gonzalez *et al.* (1991), and, in fact, the authors reported that the Las Coloradas and El Cuyo basins behaved as entities independent from the Río Lagartos basin, in terms of species richness.

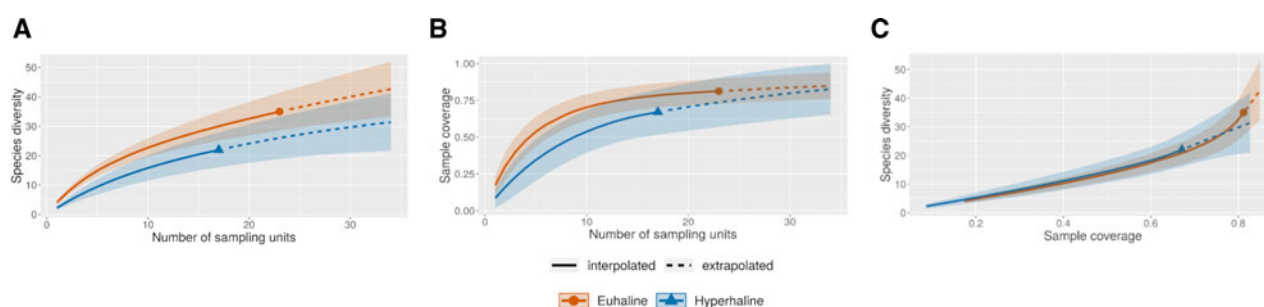
Experimental studies on salinity tolerances of mollusc species and the mechanisms that underlie salinity limitation are notably scarce and mainly limited to species of economic interest (Calabrese & Davis, 1970; Nell & Gibbs, 1986; Deaton *et al.*, 1989; Yang *et al.*, 2018), and a few others (Berger & Kharazova, 1997; Przeslawski, 2004). Most of those studies considered salinities less than hypersaline, and little or nothing is yet known about the osmoregulatory physiology of hypersaline molluscs (Berger & Kharazova, 1997; Deaton, 2019). Khlebovich & Kondratenkov (1973) reported the high-salinity acclimation threshold for the snail *Hydrobia ulvae* at values between 75 and 80, and for other macrobenthic invertebrates such as polychaetes, survival was restricted to salinity values <70. Thus, absence of molluscs at salinities >78 may indicate that is a threshold value for this taxonomic group. Below 78, bivalves were more diverse and widespread under hypersaline conditions than were gastropods, the latter of which prevailed under euhaline conditions.

Bivalves can withstand stressful conditions and respond to changes in environmental salinity by closing their shells (Vlašić *et al.*, 2018). In the case of gastropods, extreme values of salinity and temperature slow development and/or increase embryonic mortality (Przeslawski, 2004). On the other hand, the low incidence of gastropods could be a consequence of a low availability of food and reduced feeding activity under stressful conditions.

The bivalve *Anomalocardia auberiana* and the gastropods *Meioceras nitidum* and *Melongena corona* were among the species distributed across the largest salinity ranges and the first two were among the most ubiquitous species in the Río Lagartos coastal lagoon. The large salinity tolerance ranges and the capacity to live under very high salinities, up to 58 for *A. auberiana*, 74 for *M. nitidum* and 78 for *M. corona*, explains their widespread distribution in the lagoon. Tolerance of hypersaline conditions was reported for *A. auberiana* in the Baffin Bay estuary (south Texas, USA) (Rubio *et al.*, 2018), and *Melongena* spp. inhabit different ecosystems (i.e. shallow, low-energy embayments, lagoons, salt marshes, mangrove swamps and oyster bars) (Hayes, 2003), which suggests a wide salinity tolerance of the genus. Instead, *M. nitidum* has usually been found in shallow habitats where the salinity is close to that of the ocean (Lester-Coll, 2017). This suggests strong physiological plasticity and may point to high capacity for acclimation, as reported for other marine snails (Berger & Kharazova, 1997). A similar yet less marked tolerance

**Table 3.** Salinity ranges, number of sites (including samples in each season), proportions of sediment size-classes (gravel, sand, silt/clay) and submersed vegetation gravimetric contribution to the surface sediment samples (mean value  $\pm$  SD). The total number of species (S) per environment and species number range per site (in parenthesis) in the environment also shown. The percentage contribution to the total number of species (S) and frequency of occurrence (FO% = number of samples in which a class was present/total number of samples  $\times$  100) in the mollusc groups by class (Gastropoda and Bivalvia), habitat (epifauna and infauna), or feeding guild (suspension feeders, carnivores, deposit consumers and grazers) in the euhaline and hyperhaline environments of the Río Lagartos coastal lagoon are on the bottom

	Euhaline		Hyperhaline	
Abiotic characteristics				
Salinity (PSU)	30–40		>40 $\leq$ 78	
Number of sites	19		14	
Mean gravel %	6.3 $\pm$ 4.5		7.8 $\pm$ 10.5	
Mean sand %	90.8 $\pm$ 6.4		80.8 $\pm$ 21.2	
Mean silt/clay %	2.9 $\pm$ 5.2		11.3 $\pm$ 16.5	
Mean vegetation %	15.25 $\pm$ 29		4.9 $\pm$ 7.9	
Fauna composition				
Species number (S)	35 (1–9)		22 (1–8)	
	S (%)	FO (%)	S (%)	FO (%)
Class				
Bivalvia %	49	63	55	79
Gastropoda %	51	100	45	64
Habitat				
Epifauna %	57	100	55	79
Infauna %	43	58	45	79
Feeding guild				
Suspension feeders %	40	79	36	64
Carnivores %	23	68	32	43
Deposit consumers %	14	37	18	36
Grazers %	23	79	14	36

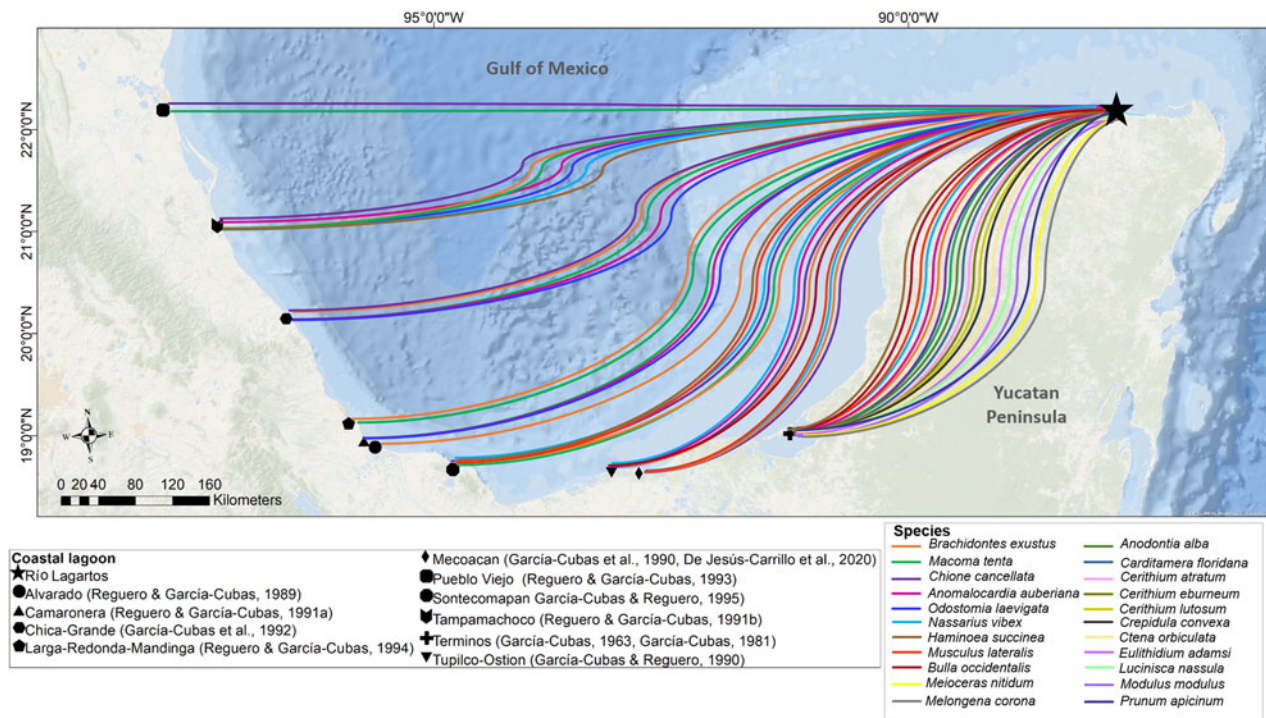


**Fig. 8.** Interpolation and extrapolation curves of mollusc species in samples from the Río Lagartos coastal lagoon under euhaline (red line) and hyperhaline (blue lines) conditions. (A) Species accumulation curves based on the occurrence of species. (B) Sample-coverage accumulation curve. (C) Sample completeness curves, linking curve 8A and 8B. The solid lines represent interpolation, whereas the dashed lines depict extrapolation.

for high salinity (to 50 PSU) caused by exposure to high salinity values, can be deduced for the most frequently encountered mollusc species in the Río Lagartos coastal lagoon, the gastropod *Prunum apicinum*. This species was previously found inhabiting environments with salinity up to 40, with a preferred range of about 15–25 (Cain, 1972; Roessler & Tabb, 1974; Tampa Bay Water & Janicki Environmental Inc., 2003; Jiménez-Ramos & Acosta-Balbás, 2020). The very high and unstable salinity conditions that prevail in the Río Lagartos coastal lagoon probably favour the adaptation of species, which represents an adaptive advantage, given the predicted salinity increase associated with ongoing climate change (Curry *et al.*, 2003; Boyer *et al.*, 2005). This is especially relevant in this type of lagoon, where limited

freshwater inputs and high evaporation rates drive salinity increases.

Salinity may not be the only factor responsible for the spatial distribution patterns of molluscs. Rather, substrate type, sediment grain size, hydrodynamics and salinity likely interact to create such patterns. Furthermore, the effects of salinity on molluscs may be direct, by acting on their osmotic and ionic equilibrium, or indirect, by affecting the distribution of other factors that in turn regulate mollusc distribution. For example, in the Río Lagartos coastal lagoon, the distribution of submersed vegetation, which serves as habitat or a food source for many macrobenthic taxa, is strongly influenced by salinity (Ortegón-Aznar *et al.*, 2001). In this sense, higher species richness and frequency of



**Fig. 9.** Comparison of molluscs recorded in the Río Lagartos coastal lagoon (present study) and in other coastal lagoons around the Gulf of Mexico, Mexico (García-Cubas, 1963, 1981; García-Cubas *et al.*, 1990, 1992; García-Cubas and Reguero, 1990, 1995; Reguero and García-Cubas, 1993, 1994, 1989, 1991b, 1991c; De Jesús-Carrillo *et al.*, 2020).

occurrence of gastropods in the euhaline environment may be associated with the greater amount of submersed vegetation. The macrophytes provide a range of habitat types for epifaunal organisms and food for grazers, both functional groups being represented by gastropods in the Río Lagartos coastal lagoon. Accordingly, the widespread distribution of *Meioceras nitidum*, an epifaunal grazer, is enhanced by both its euryhaline character and a considerable capacity to inhabit a diverse array of substrates, as live specimens have been found on mangrove roots, algae from the intertidal to subtidal zone, and seagrass beds (Tunnell *et al.*, 2010; Redfern, 2013; Pereira Costa *et al.*, 2021). Conversely, higher occurrence and diversity of bivalves, which are predominantly infaunal, in the hypersaline environments, may be favoured by lower amounts of vegetation on the bottom, and the presence of a broader array of sediment grain sizes that are suitable for a large number of burrowing species (Alexander *et al.*, 1993), or for suspension and deposit feeders.

Complex hydrodynamics and geomorphology of the lagoon favour high sediment heterogeneity. This may explain the presence of large denuded areas, even in the euhaline sites, which may trigger the spread of *A. auberiana*, an opportunistic species with a high capacity to rapidly invade newly available habitat, and soon after appear in large numbers (Grizzle, 1984; Kuk-Dzul *et al.*, 2012). Although tides have little influence throughout the entire lagoon, except near the mouth of the Río Lagartos basin, the local dynamics are important in the middle and upper basins because of their sizes, depths and processes therein. Possessing vast shallow areas, these basins are subject to the effects of wind and waves, which mix the whole water column and enhance resuspension of sediment particles throughout the area, providing food for the suspension feeders that dominate the lagoon's mollusc community.

Most of the stenohaline species in this study were rare, having been captured at only one or two stations. Although the sampling limitations mentioned previously cannot be ruled out as having caused the low recovery of these species (Lyons *et al.*, 2005), low

salinity tolerance, together with impaired dispersal or colonizing ability linked to the small-scale environmental heterogeneity of the system also seems a plausible explanation (Cao *et al.*, 2001). For example, *Parastarte triquetra* was found at only two stations and in a narrow salinity range, consistent with the very localized distribution of the species recorded in other systems (Grizzle, 1984; Morelos-Villegas *et al.*, 2018). This species has been correlated with high values of trichlorobenzene in the Yucatán Peninsula coastal lagoons, and in this study it appeared at stations where high levels of pollution were reported previously (Kuk-Dzul *et al.*, 2012).

This work revealed that the current state of knowledge regarding the abiotic and biotic controls on mollusc distributions in the eastern GoM is poor. Information from this study serves as a starting point ('baseline') for studies of future impacts on the Río Lagartos coastal lagoon, for example, changes in salinity regime and consequent redistribution of organisms. Our study also raises an important question: what factor or factors account for the lower (45.1%) number of mollusc species found in this study, relative to the number encountered in a similar study carried out almost four decades ago? The relative roles of natural variation and anthropogenic activities on mollusc diversity changes remain to be distinguished and are crucial to understand the potential effects of ongoing global change on mollusc diversity. This question needs to be addressed cautiously, as factors independent from environmental variables, such as the types of samplers used, sampling intensity and time of the year, and high numbers of rare species, can all affect the number of species collected. We encourage colleagues who undertake similar future studies to collaborate with large-scale networks that use standardized protocols (MBON Pole to Pole, 2019; Obst *et al.*, 2020; Ashton *et al.*, 2022). In addition, to better understand past changes and effects on the fauna since the 'Great Acceleration' of human impacts, we propose palaeoecological studies be undertaken. Such investigations can provide a historical perspective on changing mollusc species diversity in coastal lagoons over the last

century or more. Lastly, to fully understand the drivers of recent shifts in mollusc community composition, knowledge of the environmental optima and tolerances for each taxon is required.

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1017/S0025315423000085>.

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**Author contributions.** NYSM wrote the first draft of the manuscript, identified the molluscs, and prepared tables, figures and plates. VP and MB revised and edited successive drafts of the manuscript. VP participated in interpretation of results. VP and CE contributed to the conception and design of the study, and were responsible for funding acquisition and project administration. NS and CE revised and provided advice on the last draft of the manuscript. All authors contributed to manuscript revision, and have read and agreed to the submitted version.

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## References

- Abdelhady AA, Khalil MM, Ismail E, Fan J, Zhang S and Xiao J (2019) Water chemistry and substrate type as major determinants of molluscan feeding habit and life—mode in lagoon sediments. *Estuarine, Coastal and Shelf Science* **220**, 120–130.
- Aguilar-Medrano R and Vega-Cendejas ME (2021) Ichthyological sections of the coastal-wetland ecosystem of the Yucatan Peninsula and Campeche Bank. *Regional Studies in Marine Science* **47**, 101932.
- Alexander RR, Stanton RJ and Dodd JR (1993) Influence of sediment grain size on the burrowing of bivalves: correlation with distribution and stratigraphic persistence of selected Neogene clams. *Palaeos* **8**, 289–303.
- Andrade-Velázquez M, Medrano-Pérez OR, Montero-Martínez MJ and Alcuía-Aguilar A (2021) Regional climate change in Southeast Mexico-Yucatan Peninsula, Central America and the Caribbean. *Applied Sciences* **11**, 8284.
- Arceo-Carranza D, Vega-Cendejas ME and Hernández de Santillana M (2013) Day and night trophic variations of dominant fish species in a lagoon influenced by freshwater seeps. *Journal of Fish Biology* **82**, 54–68.
- Armenteros M, Díaz-Asencio M, Fernández-Garcés R, Hernández CA, Helguera-Pedraza Y, Bolaños-Alvarez Y, Agraz-Hernández C and Sanchez-Cabeza JA (2016) One-century decline of mollusk diversity as consequence of accumulative anthropogenic disturbance in a tropical estuary (Cuban Archipelago). *Marine Pollution Bulletin* **113**, 224–231.
- Ashton GV, Freestone AL, Duffy JE, Torchin ME, Sewall BJ, Tracy B, Albano M, Altieri AH, Altwater L, Bastida-Zavala R, Bortolus A, Brante A, Bravo V, Brown N, Buschmann AH, Buskey E, Barrera RC, Cheng B, Collin R, Coutinho R, De Gracia L, Dias GM, DiBacco C, Flores AAV, Haddad MA, Hoffman Z, Erquiaga BI, Janiak D, Campeán AJ, Keith I, Leclerc JC, Lecompte-Pérez OP, Longo GO, Matthews-Cascon H, McKenzie CH, Miller J, Munizaga M, Naval-Xavier LPD, Navarrete SA, Otálora C, Palomino-Alvarez LA, Palomo MG, Patrick C, Pegau C, Pereda SV, Rocha RM, Rumbold C, Sánchez C, Sanjuan-Muñoz A, Schlöder C, Schwindt E, Seemann J, Shanks A, Simoes N, Skinner L, Suárez-Mozo NY, Thiel M, Valdivia N, Velez-Zuazo X, Vieira EA, Vildoso B, Wehrmann IS, Whalen M, Wilbur L and Ruiz GM (2022) Predator control of marine communities increases with temperature across 115 degrees of latitude. *Science* **376**, 1215–1219.
- Berger VJ and Kharazova AD (1997) Mechanisms of salinity adaptations in marine molluscs. *Hydrobiologia* **355**, 115–126.
- Bouchet P, Rocroi J-P, Bieler R, Carter JG and Coan EV (2010) Nomenclator of Bivalve families with a classification of Bivalve families. *Malacologia* **52**, 1–184.
- Bouchet P, Rocroi J-P, Hausdorf B, Kaim A, Kano Y, Nützel A, Parkhaev P, Schrödl M and Strong EE (2017) Revised classification, nomenclator and typification of gastropod and monoplacophoran families. *Malacologia* **61**, 1–526.
- Boyer TP, Levitus S, Antonov JI, Locarnini RA and Garcia HE (2005) Linear trends in salinity for the World Ocean, 1955–1998. *Geophysical Research Letters* **32**, 1–4.
- Cain TD (1972) Additional epifauna of a reef off North Carolina. *Journal of the Elisha Mitchell Scientific Society* **88**, 79–82.
- Calabrese A and Davis HC (1970) Tolerances and requirements of embryos and larvae of bivalve molluscs. *Helgoländer Wissenschaftliche Meeresuntersuchungen* **20**, 553–564.
- Cao Y, Larsen DP and Thorne RS-J (2001) Rare species in multivariate analysis for bioassessment: some considerations. *Journal of the North American Benthological Society* **20**, 144–153.
- Carnero-Bravo V, Sanchez-Cabeza JA, Ruiz-Fernández AC, Merino-Ibarra M, Corcho-Alvarado JA, Sahli H, Hélie JF, Preda M, Zavala-Hidalgo J, Diaz-Asencio M and Hillaire-Marcel C (2018) Sea level rise sedimentary record and organic carbon fluxes in a low-lying tropical coastal ecosystem. *Catena* **162**, 421–430.
- Cartes JE, Díaz-Viñolas D, Schirone A, Lombarte A, Barsanti M, Delbono I, Salas C, Gofas S, Serrano A and Santos-Echeandía J (2022) How the reconstruction of faunal communities in a marine protected area (Columbretes Reserve, western Mediterranean) evidence human and natural impacts on fauna. *Ecological Indicators* **142**, 109209.
- Cartes JE, Schirone A, Barsanti M, Belbono I, Martínez-Aliaga A and Lombarte A (2017) Recent reconstruction of deep-water macrofaunal communities recorded in continental margin sediments in the Balearic Basin. *Deep-Sea Research Part I* **125**, 52–64.
- Chao A, Ma KH and Hsieh TC (2016) iNEXT (iNterpolation and EXTrapolation) Online: Software for Interpolation and Extrapolation of Species Diversity.
- Chi-Espínola AA and Vega-Cendejas ME (2013) Hábitos alimenticios de *Spherooides testudineus* (Perciformes: Tetraodontidae) en el sistema lagunar de Ría Lagartos, Yucatán, México. *Revista de Biología Tropical* **61**, 849–858.
- Contreras-Espinosa F and Warner BG (2004) Ecosystem characteristics and management considerations for coastal wetlands in Mexico. *Hydrobiologia* **511**, 233–245.
- Curry R, Dickson B and Yashayaev I (2003) A change in the freshwater balance of the Atlantic Ocean over the past four decades. *Nature* **426**, 826–829.
- Dávila-Jiménez Y, Papiol V, Hernández-Alcántara P, Enriquez C, Sauma-Castillo L and Chiappa-Carrara X (2019) Polychaete assemblages in a tropical hypersaline coastal lagoon of the southeastern Gulf of Mexico during the rainy season. *Revista de Biología Tropical* **67**, S136–S156.
- Deaton L (2019) Osmotic and ionic regulation in molluscs. In Evans DH (ed.), *Osmotic and Ionic Regulation: Cells and Organisms*. Boca Raton, FL: CRC Press, pp. 107–133.
- Deaton L, Derby JGS, Subhedar N and Greenberg MJ (1989) Osmoregulation and salinity tolerance in two species of bivalve mollusc: *Limnoperna fortunei* and *Mytilopsis leucophaeta*. *Journal of Experimental Marine Biology and Ecology* **133**, 67–79.
- de Duarte RCS, Mota ELS and Dias TLP (2020) Algal complexity positively affects the abundance, richness and diversity of molluscan assemblages of a semiarid hypersaline mangrove. *Aquatic Ecology* **54**, 1001–1013.
- De Jesús-Carrillo RM, Ocaña FA and Barba-Macias E (2021) Functional variations of mollusks along an environmental gradient in a coastal lagoon of

- the Southern Gulf of Mexico. *Regional Studies in Marine Science* **44**, 101723.
- De Jesús-Carrillo RM, Ocaña FA, Hernández-Ávila I, Mendoza-Carranza M, Sánchez AJ and Barba-Macias E (2020) Mollusk distribution in four habitats along a salinity gradient in a coastal lagoon from the Gulf of Mexico. *Journal of Natural History* **54**, 1257–1270.
- De la Barreda B, Metcalfe SE and Boyd DS (2020) Precipitation regionalization, anomalies and drought occurrence in the Yucatan Peninsula, Mexico. *International Journal of Climatology* **40**, 4541–4555.
- De La Lanza Espino G, Pérez MAO and Pérez JLC (2013) Diferenciación hidrogeomorfológica de los ambientes costeros del Pacífico, del Golfo de México y del Mar Caribe. *Investigaciones Geográficas* **81**, 33–50.
- de Lucena MJ, Oliveira de Meirelles CA and Matthews-Cascon H (2012) Feeding behavior of *Nassarius vibex* (Gastropoda: Nassariidae). *Arquivos de Ciências Do Mar* **45**, 60–67.
- Enriquez C, Mariño-Tapia IJ and Herrera-Silveira JA (2010) Dispersion in the Yucatan coastal zone: implications for red tide events. *CSR* **30**, 127–137.
- Enriquez C, Mariño-Tapia I, Jeronimo G and Capurro-Filograsso L (2013) Thermohaline processes in a tropical coastal zone. *Continental Shelf Research* **69**, 101–109.
- Espinosa J, Ortea J, Sánchez R and Gutiérrez J (2012) *Moluscos marinos Reserva de la Biosfera de la Península de Guanahacabibes*. La Habana, Cuba: Instituto Oceanología, Ministerio de Ciencia, Tecnología Ambiente, y Medio.
- Fichez R, Archundia D, Grenz C, Douillet P, Gutiérrez Mendieta F, Origel Moreno M, Denis L, Contreras Ruiz Esparza A and Zavala-Hidalgo J (2017) Global climate change and local watershed management as potential drivers of salinity variation in a tropical coastal lagoon (Laguna de Terminos, Mexico). *Aquatic Sciences* **79**, 219–230.
- García-Cubas A (1963) *Sistemática y distribución de los micromoluscos de la laguna de Terminos, Campeche, México* (Universida). Mexico D.F.
- García-Cubas A (1970) Ecología y distribución de los micromoluscos recientes de la Laguna Madre, Tamaulipas, México. *Anales Del Instituto de Geología, UNAM* **86**, 1–44.
- García-Cubas A (1971) Ecología y distribución de los micromoluscos de la Laguna de Tamiagua, Veracruz, Mexico. *Boletín Del Instituto de Geología* **91**, 1–53.
- García-Cubas A (1981) *Moluscos de un sistema lagunar tropical en el sur del Golfo de México (Laguna de Términos, Campeche)*. Instituto de Ciencias del Mar y Limnología. Universidad Nacional Autónoma de México. *Publicación especial*. (1. ed.). México, D.F.
- García-Cubas A, Escobar F and Reguero M (1999) Gastrópodos marinos de la península de Yucatán, México. *Revista de La Sociedad Mexicana de Historia Natural* **49**, 127–146.
- García-Cubas A, Escobar F, Gonzalez Ania LV and Reguero M (1990) Moluscos de la laguna de Mecoaacán, Tabasco, México: sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología. Universidad Nacional Autónoma de México* **17**, 1–30.
- García-Cubas A and Reguero M (1990) Moluscos del sistema lagunar Tupilco-Ostión, Tabasco, México: Sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **1**, 309–343.
- García-Cubas A and Reguero M (1995) Moluscos de la laguna de Sontecomapan, Veracruz, México: sistemática y ecología. *Hidrobiológica* **5**, 1–24.
- García-Cubas A and Reguero M (2004) *Catálogo ilustrado de moluscos gasterópodos del Golfo de México y Mar Caribe*. Mexico, D.F., Mexico: Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México.
- García-Cubas A and Reguero M (2007) *Catálogo ilustrado de moluscos bivalvos del Golfo de México y Mar Caribe*. Mexico, D.F., Mexico: Instituto en Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México.
- García-Cubas A, Reguero M and Elizarrarás R (1992) Moluscos del sistema lagunar Chica-Grande, Veracruz, México: sistemática y ecología. *Anales Centro de Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **19**, 1–121.
- Gonzalez MA, Chávez EA, de la Cruz G and Torruco D (1991) Patrones de Distribución de gasterópodos y bivalvos en la Península de Yucatán, México. *Ciencias Marinas* **17**, 147–172.
- Gonzalez M, Chávez E, de la Cruz G and Torruco D (2018) Comparative analysis of mollusks in the Los Petenes Biosphere Reserve and coastal lagoons in southeastern Mexico. *Boletín de Investigaciones Marinas y Costeras* **47**, 25–44.
- Grenz C, Fichez R, Silva CÁ, Benítez LC, Conan P, Esparza ACR, Denis L, Ruiz SD, Douillet P, Martínez MEG, Ghiglione JF, Mendieta FJG, Origel-Moreno M, García AZM, Caravaca AM, Pujo-Pay M, Alvarado RT and Zavala-Hidalgo J (2017) Benthic ecology of tropical coastal lagoons: environmental changes over the last decades in the Términos Lagoon, Mexico. *Comptes Rendus – Geoscience* **349**, 319–329.
- Grizzle R (1984) Pollution indicator species of macrobenthos in a coastal lagoon. *Marine Ecology Progress Series* **18**, 191–200.
- Guerra-Castro E, Hidalgo G, Castillo-Cupul RE, Muciño-Reyes M, Noreña-Barroso E, Quiroz-Deaquino J, Mascaro M and Simoes N (2020) Sandy beach macrofauna of Yucatán state (Mexico) and oil industry development in the Gulf of Mexico: first approach for detecting environmental impacts. *Frontiers in Marine Science* **7**, 913.
- Hayes KA (2003) Phylogeography and Evolution of the Florida Crown Conch (*Melongena corona*). Thesis, FSU, University of South Florida. Available at <https://digitalcommons.usf.edu/etd/1385>.
- Hernández-Guevara NA, Pech D and Ardisson PL (2008) Temporal trends in benthic macrofauna composition in response to seasonal variation in a tropical coastal lagoon, Celestun, Gulf of Mexico. *Marine and Freshwater Research* **59**, 772–779.
- Herrera-Silveira JA, Comin FA and Filograsso LC (2013) Landscape, land use, and management in the coastal zone of Yucatan Peninsula. In Day JW and Yáñez-Arancibia A (eds), *Gulf of Mexico Origin, Waters, and Biota: Volume 4, Ecosystem-Based Management*. Harte Research Institute for Gulf of Mexico Studies Series. Texas A&M University-Corpus Christi. College Station, TX: Texas A&M University Press, pp. 225–242.
- Herrera-Silveira JA and Morales-Ojeda SM (2010) Subtropical karstic coastal lagoon assessment, Southeast Mexico: the Yucatan Peninsula case. In Kennish MJ and Paerl HW (eds), *Coastal Lagoons: Critical Habitats of Environmental Change*. Boca Raton, FL: CRC Press, pp. 307–333.
- Herrera-Silveira JA and Ramírez-Ramírez J (1998) Salinity and nutrients in the coastal lagoons of Yucatan, Mexico. *SIL Proceedings, 1922–2010* **26**, 1473–1478.
- Hinojosa-Garro D, Arceo-Gómez J, Zambrano L and Escalera-Vázquez LH (2013) Fish diet composition in permanent and semi-permanent pools in tropical wetlands of the Yucatan Peninsula. *Neotropical Ichthyology* **11**, 881–890.
- Jiménez-Ramos E and Acosta-Balbás V (2020) Benthic macroinvertebrates associated with *Thalassia testudinum* (Hydrocharitaceae), in northeastern Venezuela. *Hidrobiológica* **30**, 73–92.
- Khlebovich VV and Kondratenkov AP (1973) Stepwise acclimation – a method for estimating the potential euryhalinity of the gastropod *Hydrobia ulvae*. *Marine Biology* **18**, 6–8.
- Kjerfve B (ed.) (1994) *Coastal lagoons*. In *Coastal Lagoon Processes*, vol. **60**. Amsterdam: Elsevier Science, pp. 1–8.
- Kjerfve B and Magill KE (1989) Geographic and hydrodynamic characteristics of shallow coastal lagoons. *Marine Geology* **88**, 187–199.
- Kuk-Dzul JG, Gold-Bouchot G and Ardisson PL (2012) Benthic infauna variability in relation to environmental factors and organic pollutants in tropical coastal lagoons from the northern Yucatan Peninsula. *Marine Pollution Bulletin* **64**, 2725–2733.
- Kurczyn JA, Duran R, Beier E and Souza AJ (2021) On the advection of upwelled water on the Western Yucatan shelf. *Frontiers in Marine Science* **8**, 1450.
- Lamprey E and Armah AK (2008) Factors affecting macrobenthic fauna in a tropical hypersaline coastal lagoon in Ghana, West Africa. *Estuaries and Coasts* **31**, 1006–1019.
- Lankford RR (1977) Coastal lagoons of Mexico their origin and classification. In Wiley M (ed.), *Estuarine Processes II*. Cambridge, MA: Academic Press, pp. 182–215.
- Lester-Coll AS (2017) *Caecidae (Mollusca: Gastropoda) in Broward County*. HCNSO Student Theses and Dissertations. Florida. Available at [https://nsu-works.nova.edu/occ\\_stuetd/436](https://nsu-works.nova.edu/occ_stuetd/436).
- Lyons KG, Brigham CA, Traut BH and Schwartz MW (2005) Rare species and ecosystem functioning. *Conservation Biology* **19**, 1019–1024.
- MBON Pole to Pole (2019) Sampling protocol for assessment of marine diversity on rocky shores. *Marine Biodiversity Observation Network Pole to Pole of the Americas*, 14 pp.
- Mikkelsen PM and Bieler R (2008) *Seashells of Southern Florida: Living Marine Mollusks of the Florida Keys and Adjacent Regions*. Princeton, NJ: Princeton University Press.



- Morelos-Villegas A, Condal AR and Ardisson PL (2018) Spatial heterogeneity and seasonal structure of physical factors and benthic species in a tropical coastal lagoon, Celestun, Yucatan Peninsula. *Regional Studies in Marine Science* **22**, 136–146.
- Nell JA and Gibbs PJ (1986) Salinity tolerance and absorption of L-methionine by some Australian bivalve molluscs. *Marine and Freshwater Research* **37**, 721–727.
- Obst M, Exter K, Allcock AL, Arvanitidis C, Axberg A, Bustamante M, Cancio I, Carreira-Flores D, Chatzinikolaou E, Chatzigeorgiou G, Chrismas N, Clark MS, Comtet T, Dailianis T, Davies N, Deneudt K, de Cerio OD, Fortiç A, Gerovasileiou V, Hablützel PI, Keklikoglou K, Kotoulas G, Lasota R, Leite BR, Loisel S, Lévêque L, Levy L, Malachowicz M, Mavrič B, Meyer C, Mortelmans J, Norkko J, Pade N, Power AM, Ramšak A, Reiss H, Solbakken J, Staehr PA, Sundberg P, Thyrring J, Troncoso JS, Viard F, Wenne R, Yperifanou EI, Zbawicka M and Pavloudi C (2020) A marine biodiversity observation network for genetic monitoring of hard-bottom communities (ARMS-MBON). *Frontiers in Marine Science* **7**, 1031.
- Ortegón-Aznar I, González-González J and Granados AS (2001) Estudio ficológico de la laguna de Río Lagartos, Yucatán, México. *Hidrobiológica* **11**, 97–104.
- Peralta-Meixueiro MA and Vega-Cendejas ME (2011) Spatial and temporal structure of fish assemblages in a hyperhaline coastal system: Ría Lagartos, Mexico. *Neotropical Ichthyology* **9**, 673–682.
- Pereira Costa FM, Setubal Pires-Vanin AM and Barbosa Lima SF (2021) Caecidae (Gastropoda: Truncatelloidea) associated with unconsolidated carbonate substrates of the Abrolhos Coral Bank (Bahia State, Brazil). *American Malacological Bulletin* **38**, 83–88.
- Przeslawski R (2004) A review of the effects of environmental stress on embryonic development within intertidal gastropod egg masses. *Molluscan Research* **24**, 43–63.
- Quesadas-Rojas M, Enriquez C and Valle-Levinson A (2021) Natural and anthropogenic effects on microplastic distribution in a hypersaline lagoon. *Science of the Total Environment* **776**, 145803.
- Raz-Guzman A and Grizzle RE (2001) Techniques for quantitative sampling of infauna and small epifauna in seagrass. In Short F and Coles RG (eds), *Global Seagrass Research Methods*. Amsterdam: Elsevier, pp. 237–253.
- Redfern C (2013) *Bahamian Seashells: 1161 species from Abaco, Bahamas*. Boca Raton, FL: Bahamianseashells.com.
- Reguero M and García-Cubas A (1989) Moluscos de la laguna de Alvarado, Veracruz: sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **16**, 279–306.
- Reguero M and García-Cubas A (1991a) Moluscos de la laguna camaronera, Veracruz, México: sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **18**, 1–23.
- Reguero M and García-Cubas A (1991b) Moluscos de la laguna de Tampamachoco, Veracruz, México: Sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **18**, 289–328.
- Reguero M and García-Cubas A (1993) Moluscos de la laguna Pueblo Viejo, Veracruz, México: sistemática y ecología. *Anales Del Instituto Ciencias Del Mar y Limnología, Universidad Nacional Autónoma de México* **20**, 77–104.
- Reguero M and García-Cubas A (1994) Moluscos del complejo lagunar larga-redonda-mandinga, Veracruz, México: sistemática y ecología. *Hidrobiológica* **3**, 41–70.
- Reyes-Mendoza O, Mariño-Tapia I, Herrera-Silveira J, Ruiz-Martínez G, Enriquez C and Larcier JL (2016) The effects of wind on upwelling off Cabo Catoche. *Journal of Coastal Research* **32**, 638–650.
- Roessler MA and Tabb DC (1974) Studies on effects of thermal pollution in Biscayne Bay, Florida. *Ecol Res Ser EPA*. U.S. Govt. Printing Office. Available at <https://doi.org/10.3/JQUERY-UI.JS>.
- Rosenberg G, Moretzsohn F and García EF (2009) Gastropoda (Mollusca) of the Gulf of Mexico. In Felder DL and Camp DK (eds), *Gulf of Mexico: Origins, Waters, and Biota. Vol. 1. Biodiversity*. College Station, TX: Texas A&M University Press, pp. 579–699.
- Rubio KS, Ajemian M, Stunz GW, Palmer TA, Lebreton B and Beseres Pollack J (2018) Dietary composition of black drum *Pogonias cromis* in a hypersaline estuary reflects water quality and prey availability. *Journal of Fish Biology* **93**, 250–262.
- Sanvicente-Añorve L, Zavala-Hidalgo J, Allende-Arandía ME and Hermoso-Salazar M (2014) Connectivity patterns among coral reef systems in the southern Gulf of Mexico. *Marine Ecology Progress Series* **498**, 27–41.
- Selly T, Hale KE, Schiffbauer JD, Clapp DA and Huntley JW (2018) The influence of environmental gradients on molluscan diversity, community structure, body size, and predation in a carbonate tidal creek, San Salvador (The Bahamas). *American Journal of Science* **318**, 246–273.
- Tampa Bay Water and Janicki Environmental Inc. (2003) *Salinity Tolerances for the Major Biotic Components Within the Anclote River and Anchorage and Nearby Coastal Water*. Tampa Bay Water: Clearwater, Florida.
- Tenorio-Fernandez L, Gomez-Valdes J, Marino-Tapia I, Enriquez C, Valle-Levinson A and Parra SM (2016) Tidal dynamics in a frictionally dominated tropical lagoon. *Continental Shelf Research* **114**, 16–28.
- Tunnell JW Jr, Andrews J, Barrera NC and Moretzsohn F (2010) *Encyclopedia of Texas Seashells: Identification, Ecology, Distribution, and History*. College Station, TX: Texas A&M University Press. 512 pp.
- Turgeon DD, Lyons WG, Mikkelsen P, Rosenberg G and Moretzsohn F (2009) Bivalvia (Mollusca) of the Gulf of Mexico. In Felder DL and Camp DK (eds), *Gulf of Mexico: Origins, Waters, and Biota. Vol. 1. Biodiversity*. College Station, TX: Texas A&M University Press, pp. 711–744.
- Turney WJ and Perkins BF (1972) *Molluscan Distribution in Florida Bay. Sedimenta (Vol. III)*. Miami, FL: University of Miami.
- Valdes DS and Real E (2004) Nitrogen and phosphorus in water and sediments at Ria Lagartos coastal lagoon, Yucatan, Gulf of Mexico. *Indian Journal of Marine Sciences* **33**, 338–345.
- Valle-Levinson A, Enriquez C and Mariño I (2022) Competition between atmospheric and tidally attenuated forcing in an elongated coastal lagoon. *Estuaries and Coasts* **45**, 49–62.
- Valle-Levinson A, Mariño-Tapia I, Enriquez C and Waterhouse AF (2011) Tidal variability of salinity and velocity fields related to intense point-source submarine groundwater discharges into the coastal ocean. *Limnology and Oceanography* **56**, 1213–1224.
- Vega-Cendejas ME and Hernández De Santillana M (2004) Fish community structure and dynamics in a coastal hypersaline lagoon: Rio Lagartos, Yucatan, Mexico. *Estuarine, Coastal and Shelf Science* **60**, 285–299.
- Vlašić M, Glavić N, Bolotin J, Hrustić E and Radić ID (2018) Influence of salinity on physiological response of the bearded horse mussel *Modiolus barbatus* and Noah's ark shell *Arca noae*. *Ekologia Bratislava* **37**, 345–357.
- Vokes HE and Vokes EH (1983) *Distribution of shallow-water marine Mollusca, Yucatan Peninsula, Mexico*. Middle American Research Institute, vol. 54. New Orleans, LA: Mesoamerican Ecology Institute, Middle American Research Institute, Tulane University.
- Wentworth CK (1922) A scale of grade and class terms for clastic sediments. *Journal of Geology* **30**, 377–392.
- Wingard GL, Hudley JW, Bay F and National E (2012) Application of a weighted-averaging method for determining paleosalinity: a tool for restoration of South Florida's estuaries. *Estuaries and Coasts* **35**, 262–280.
- Wingard GL and Surge D (2017) *Application of Molluscan Analyses to the Reconstruction of Past Environmental Conditions in Estuaries*. Dordrecht: Springer, pp. 357–387.
- Wojtarowski A, Matrinez ML, Silva R, Vázquez G, Enriquez C, López-Portillo J, García-Franco JG, MacGregor-Fors I, Lara-Domínguez AL and Lithgow D (2021) Renewable energy production in a Mexican biosphere reserve: assessing the potential using a multidisciplinary approach. *Science of the Total Environment* **776**, 145823.
- Yang S, Zhong JR, Zhao LL, Wu H, Du ZJ, Liu Q, Zhang JE, Yan TM and Huang XL (2018) The salinity tolerance of the invasive golden apple snail (*Pomacea canaliculata*). *Molluscan Research* **38**, 90–98.