MASSIVE AGGREGATIONS BY THE INVASIVE SERPULID, *Hydroides sanctaecrucis* (POLYCHAETA: SERPULIDAE), IN A COASTAL LAGOON SYSTEM FROM THE SOUTHERN MEXICAN PACIFIC

J. Rolando Bastida-Zavala[1,*], J. Pablo Sánchez-Ovando[1,2], Mariela Ramos-Sánchez[1,3], Itzahí Silva-Morales[1,4], Julio D. Gómez-Vásquez[1,4] & María del Socorro García-Madrigal[1,5]

[1] *Laboratorio de Sistemática de Invertebrados Marinos (LABSIM), Universidad del Mar, campus Puerto Ángel, Ciudad Universitaria, Apdo. Postal 47, Puerto Ángel, Oaxaca, 70902, México.*
[*] *Corresponding author:rolando_bastida@yahoo.com.mx; https://orcid.org/0000-0003-4802-1348*

[2] *Laboratorio de Ecofisiología de Organismos Acuáticos, Departamento de Biotecnología Marina, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California, 22860, México.*
sanchezjp@cicese.edu.mx; https://orcid.org/0000-0001-6238-8934

[3] *Doctorado en Ciencias Biológico Agropecuarias, Área Ciencias Biológico Agropecuaria y Pesquera, Ciudad de la Cultura "Amado Nervo", Tepic, Nayarit, 63000, México.*
ramos-sanchez1@hotmail.com; https://orcid.org/0000-0001-8197-033X

[4] *Laboratorio de Poliquetos, Departamento de Sistemática y Ecología Acuática, El Colegio de la Frontera Sur, Chetumal, Quintana Roo, 77000, México.*
itzahi_marley.gwn@hotmail.com; https://orcid.org/0000-0002-0796-0667;
julio.gomez@posgrado.ecosur.mx; https://orcid.org/0000-0002-2185-0114

[5]*ms_garcia_m@hotmail.com; https://orcid.org/0000-0003-4279-9116*

ABSTRACT: The massive aggregations of serpulids have been studied in several regions of the world (Mediterranean, northern Gulf of Mexico, Argentina, California, Malaysia, Australia); however, there have been few studies on the Mexican coasts that record aggregations of small serpulids in the Gulf of California, as *Salmacina tribranchiata*. In this work, we recorded, for the first time, the massive aggregations of the invasive serpulid *Hydroides sanctaecrucis* Krøyer [in] Mörch, 1863 in a coastal lagoon system from Oaxaca, Southern Mexican Pacific. The serpulid is native to the Caribbean Sea; nevertheless, it was recorded as non-native in the Tropical Eastern Pacific 24 years ago, as solitary specimens or, less frequently, in small aggregations of some specimens, mainly associated with marinas and harbor facilities. With the spreading of this species in several localities of the Tropical Eastern Pacific and Western Pacific, both in ports and less human-impacted habitats, *H. sanctaecrucis* is considered an invasive species. This serpulid formed aggregations in a coastal lagoon system of Oaxaca; the aggregations have between 10 and 70 cm diameter, including thousands of calcareous tubes. The conditions of the lagoons during the sampling were hypersaline (42.37-44.19 ‰) in Superior Lagoon, and brackish (30.77 ‰) in Inferior Lagoon; the turbidity was high so visibility was almost null. The aggregations include three other native serpulids, *H. crucigera* Mörch, 1863, *H. panamensis* Bastida-Zavala & ten Hove, 2003, and *Spirobranchus minutus* (Rioja, 1941), but with less abundance. The flora and fauna associated with these serpulid aggregations included two macroalgae, other polychaetes, gastropods, bivalves, porcelain crabs, barnacles, amphipods, and isopods.

Key words: Gulf of Tehuantepec, *Hydroides crucigera*, *Hydroides panamensis*, *Spirobranchus minutus*, Oaxaca

RESUMEN: Las agregaciones masivas de serpúlidos han sido estudiadas en varias regiones del mundo (Mediterráneo, norte del golfo de México, Argentina, California, Malasia, Australia); sin embargo, han sido pocos los estudios en las costas mexicanas que registran agregaciones en el golfo de California de serpúlidos pequeños como *Salmacina tribranchiata*. En este trabajo, registramos, por primera vez, las agregaciones masivas del serpúlido invasor *Hydroides sanctaecrucis* Krøyer [In] Mörch, 1863 en un sistema lagunar costero de Oaxaca, Pacífico sur de México. El serpúlido es nativo del Caribe; sin embargo, hace 24 años fue registrado como no-nativo en el Pacífico oriental tropical, como ejemplares solitarios o, con menor frecuencia, pequeñas agregaciones de algunos ejemplares, principalmente asociados a marinas e instalaciones portuarias. Con la propagación de esta especie en varias localidades del Pacífico oriental tropical y del Pacífico occidental, tanto en puertos como en hábitats menos impactados por el hombre, *H. sanctaecrucis* es considerada una especie invasora. Este serpúlido formó agregaciones en un sistema lagunar costero de Oaxaca; las agregaciones tienen 10-70 cm de diámetro, incluyendo miles de tubos calcáreos. Las lagunas durante el muestreo presentaron condiciones hipersalinas (42.37-44.19 ‰) en la Laguna Superior, y salobres (30.77 ‰) en la Laguna Inferior; la turbidez fue elevada por lo que la visibilidad fue casi nula. Las agregaciones incluyeron otros tres serpúlidos nativos, *H. crucigera* Mörch, 1863, *H. panamensis* Bastida-Zavala & Ten Hove, 2003 y *Spirobranchus minutus* (Rioja, 1941), pero con menor abundancia. La flora y fauna asociada a estas agregaciones de serpúlidos incluyeron dos macroalgas, otros poliquetos, gasterópodos, bivalvos, cangrejos porcelánidos, balanos, anfípodos e isópodos.

Palabras clave: Golfo de Tehuantepec, *Hydroides crucigera*, *Hydroides panamensis*, *Spirobranchus minutus*, Oaxaca.

INTRODUCTION

The Southern Mexican Pacific is an extensive region (in the political and territorial sense) with more than 1350 km of shores, including three Mexican states: Guerrero, Oaxaca, and Chiapas. Of these, Oaxaca and Chiapas have the highest biodiversity in México (García-Mendoza *et al.* 2004; Conabio 2013). The Southern Mexican Pacific includes two ecoregions (*sensu* Spalding *et al.* 2007), Mexican Tropical Pacific and Chiapas-Nicaragua, both belonging to the Tropical East Pacific Province.

Likewise, among the main drivers of modern species extinctions are the invasive species (Sodhi *et al*. 2009), which deserve attention in a region such as the Southern Mexican Pacific, which has a great species richness, with more than 3300 species of marine and coastal animals (Bastida-Zavala *et al*. 2013; Bastida-Zavala & García-Madrigal 2022).

The serpulids are benthic and suspension-feeder worms, that build their calcareous tubes of calcite and/or aragonite (Ten Hove & Van den Hurk 1993). Almost all serpulids inhabit marine and brackish habitats, and some species exhibit a wide tolerance range of salinity (0-55 ‰) among other variables (Ten Hove 1979; Bastida-Zavala & Ten Hove 2002, 2003; Bastida-Zavala & García-Madrigal 2012; Bastida-Zavala *et al.* 2017).

Serpulidae is one of the polychaete families with the greatest species richness, as well as most non-native and invasive species recorded because their tubes embed themselves in hard substrates, both natural and anthropogenic. When the substrate is a ship hull or floating structures (buoys, nets, ropes, piers), the species can travel with them and are inadvertently introduced into areas far from their native distributions (Ruiz *et al*. 2011).

The phenomenon of mass aggregations in serpulids has been studied in several localities around of world (Ten Hove 1979; Ten Hove & Van den Hurk 1993; Bianchi & Morri 2001;

Hoeksema & Ten Hove 2011; Sandonnini *et al*. 2021; Montefalcone *et al*. 2022). Ten Hove (1979) concluded that this phenomenon "occurs in unstable environments, by euryoecious serpulids only". Montefalcone *et al*. (2022) made a global revision of the serpulid reefs and proposed a classification of these reefs into seven groups, "according to the building modality and the type of habitat they occupy".

On Mexican coasts, there have been few studies recording serpulid aggregations in the Gulf of California, for instance, the native serpulid *Salmacina tribranchiata* (Moore, 1923) in marinas and bays of Baja California Sur (Bastida-Zavala *et al*. 2016), or the invasive serpulid, *Ficopomatus miamiensis* (Treadwell, 1934), in "shrimp culture containers and small aggregates on the mangrove roots" in Mazatlán, Sinaloa (Tovar-Hernández *et al*. 2009). Another *Ficopomatus* species, *F. uschakovi* (Pillai, 1960), has a wide coverage in mangrove roots in a coastal lagoon in Chiapas, although it has not yet been observed to form reefs (Bastida-Zavala & García-Madrigal 2022).

On the other hand, *Hydroides sanctaecrucis* Krøyer [in] Mörch, 1863 was described from Saint Croix Island, U.S. Virgin Islands, and has a wide distribution in the Caribbean Sea (Bastida-Zavala & Ten Hove 2002), Florida, and the southern part of Gulf of Mexico (Bastida-Zavala *et al*. 2017). This species was first recorded in the Eastern Pacific in 2002, with samples from the Pacific of Panamá dated April 1972 (Bastida-Zavala & Ten Hove 2002). It was then recorded for the first time in the Mexican Pacific with specimens collected from Marina Chahué, Huatulco, in May 2000 (Bastida-Zavala & Ten Hove 2003). Subsequently, the species was recorded in Santa Cruz Bay, in November 2003 (Bastida-Zavala 2008), and later in Salina Cruz Port in May 2011, where it was found as fouling on a pier and a ship hull. The most recent record was in San Dionisio del Mar, Inferior Lagoon, in August 2014 (Bastida-Zavala *et al.* 2016).

This work informs for the first time the massive aggregations of the serpulid *H. sanctaecrucis*, an invasive species (Çinar 2013; Bastida-Zavala *et al.* 2016; Conabio 2017).

MATERIAL AND METHODS

The Huave Lagoon System is located in the northernmost part of the ecoregion Chiapas-Nicaragua, which belongs to Oaxaca State (Fig. 1). The Huave Lagoon System comprises six interconnected lagoons, covering an area of 738 km^2 and divided into six lagoons, which are important for human fishing activities, mostly of penaeid shrimps, portunid crabs, mollusks and fishes (Tapia-García & Gutiérrez 1998; Serrano-Guzmán 2004). Two of these lagoons, Superior Lagoon (380 km^2) and Inferior Lagoon (311 km^2), are the larger lagoons (Serrano-Guzmán 2004).

Superior Lagoon is considered hypersaline, exhibiting significant salinity variation throughout the year, with maxima of 54.89 ‰ in winter and minima of 44.69 ‰ in summer; the bottom of the lagoon is composed of coarse to medium silt in the margin lagoon and fine to very fine sand in the southern area of the lagoon; temperature range from 23.5 and 31°C; dissolved oxygen levels range from 2.84 to 9.80 ml/l (Ortiz-Gallarza *et al.* 1991). Inferior Lagoon, particularly in San Dionisio del Mar, has a lesser salinity (30.77 ‰) in summer; while the temperature is 30.62°C (present study). Superior and Inferior lagoons are interconnected, and the common exit to the sea is often closed (Serrano Guzmán 2004).

Several samples were collected from Superior and Inferior lagoons (Fig. 1) between August 2014 and January 2017 (TABLE 1). In some cases, the samples were found in the supralittoral after strong winds, the aggregations were dried, and the serpulids were in decay. Live specimens of serpulids, other invertebrates, and macroalgae, were found in two samples collected into the water. The only location where we dived to look for more aggregations, was Playa Vicente (Superior Lagoon), the visibility was less than 5 cm, making it impossible to observe anything.

RESULTS

Description of the aggregation samples

1) In San Dionisio del Mar (Inferior Lagoon), the first samples were collected, in August 2014, and included some dried aggregations found in the supralittoral, on the sandy beach (Fig. 3B), and some fragments in the intertidal (0.5 m). The bigger dried aggregation in this sample had a size of 18 cm in diameter, a smaller diameter of 15 cm, and a height of 11 cm, with a dry weight of 514 g (Fig. 2A). Ten specimens of *H. sanctaecrucis* and two specimens of *Spirobranchus minutus* (Rioja, 1941) were collected. The superficial temperature was 30.62°C and the salinity 30.77 ‰; no dissolved oxygen data were obtained (TABLE 1).

2) Playa Vicente (Superior Lagoon), sampled on April 15, 2016, included small aggregations of empty tubes found in shallow water (0.5 m). The bigger aggregation in this sample had a diameter larger than 5.5 cm, a smaller diameter of 3.5 cm, and a height of 3 cm. Their weight was

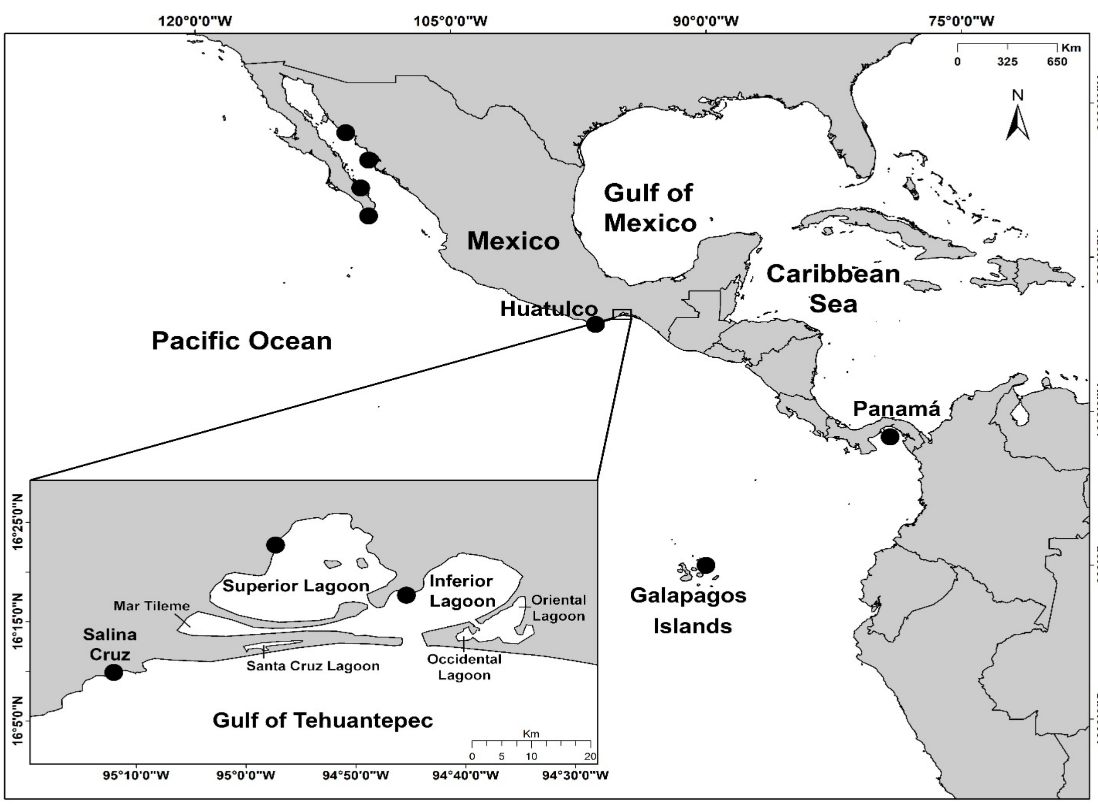

Figure 1. Distribution of *Hydroides sanctaecrucis* in the Tropical Eastern Pacific (black dots) with the new records in the Huave Lagoon System (Superior and Inferior lagoons).

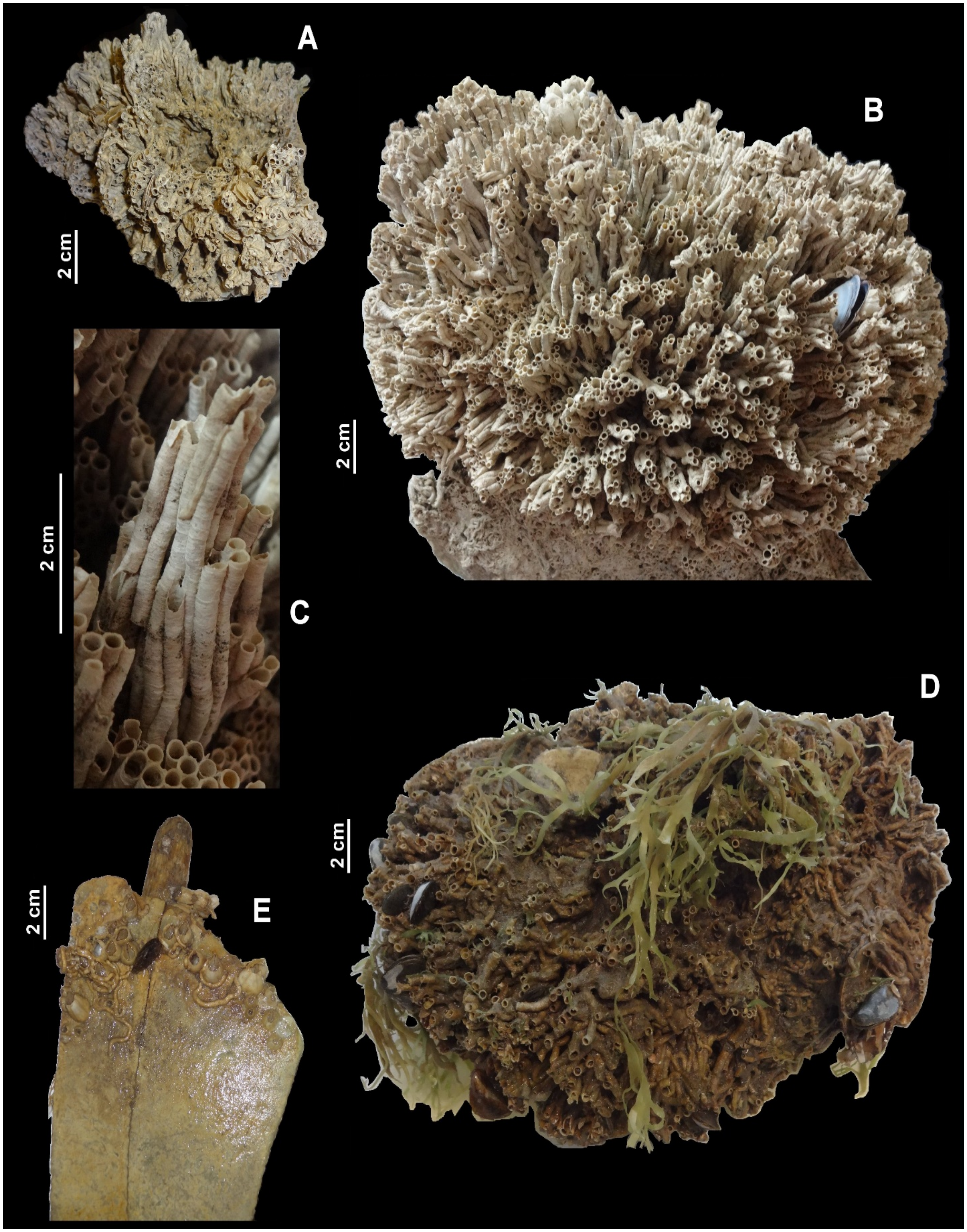

Figure 2. Serpulid aggregations. A. From San Dionisio del Mar, Inferior Lagoon, Oaxaca (August 2014); B. dried aggregation from Playa Vicente, Superior Lagoon, Oaxaca (January 2017); C. serpulid tubes in detail; D. immersed aggregation from Playa Vicente, Oaxaca (January 2017); E. turtle rib with serpulid tubes and barnacles (January 2017).

not measured, and no specimens of serpulids were found. The superficial temperature was 30.82°C and the salinity 43.13 ‰; no dissolved oxygen data were obtained (TABLE 1).

3) Playa Vicente, sampled on January 20, 2017 (Fig. 3A), included several dried aggregations found in the supralittoral of a sandy-limo beach. The bigger aggregation in this sample had a larger diameter of 25 cm, a smaller diameter of 22.5 cm, and a height of 15 cm, with a dry weight of approximately 1500 g, because this aggregation is attached to a heavy rock, it is impossible to separate without destroying the tubes (Fig. 2B). The serpulid tubes are the largest among the samples, with 4-5 cm of length (Fig. 2D). The superficial temperature was 29.27°C, the salinity 42.37 ‰, and dissolved oxygen 41.6% (TABLE 1).

4) Playa Vicente, sampled on January 21, 2017, which included some aggregations, a marine turtle rib with some serpulid tubes, and several barnacles attached to that (Fig. 2E), all found in shallow water (0.5-1 m). The bigger aggregation in this sample had a diameter larger than 18 cm, a smaller diameter of 13 cm, and a height of 10 cm, with a wet weight of 1023 g (Fig. 2D). Some macroalgae tuffs were present: *Gracilaria parvispora* I.A. ABBOT, 1985 and *Hypnea musciformis* (WULFEN) J.V. LAMOUROUX, 1813. The superficial temperature was 26.51°C, salinity 44.19 ‰, and dissolved oxygen 40.0% (TABLE 1).

5) The last aggregation was found close to the previous sample (January 21, 2017), but it was not possible to extract it due to high turbidity (Fig. 3A). Its dimensions (~70 cm diameter) and weight (~50 kg) are approximate. A small fragment was obtained to confirm that it was a serpulid aggregation. No water parameters were obtained here.

The aggregation collected from Playa Vicente (sample 4) was broken to obtain the specimens. The polychaetes were counted: 2644 empty tubes, 220 live specimens of *H. sanctaecrucis*, 20 specimens of *H. crucigera* MÖRCH, 1863, and one specimen of *H. panamensis* BASTIDA-ZAVALA & TEN HOVE 2003. Additionally, other invertebrate fauna was found, such as eight specimens of other polychaetes, nine gastropods, 57 bivalves (Fig. 2B), 168 porcelain crabs, 75 barnacles, 37 amphipods, and 29 isopods. In the sample from the turtle-rib, we found 10 live specimens of *H. sanctaecrucis*, five empty tubes, one nereidid, five bivalves, and 166 barnacles.

TABLE 1. Data of the samples collected from Superior and Inferior Lagoons, Oaxaca.

Locality	Coordinates	Date	Depth	°C	Salinity ‰	Dissolved oxygen %	Collector
San Dionisio del Mar (Inferior Lagoon)	16°18’7.92”N 94°44’56.39”W	Aug 30, 2014	Supralittoral and intertidal	30.62	30.77	No data	COTSIKAYALA PACHECO-RAMÍREZ
Playa Vicente (Superior Lagoon)	16°22’9.12”N 94°57’34.9”W	Apr 15, 2016	0.5 m	30.82	43.13	No data	MARIELA RAMOS-SÁNCHEZ
Playa Vicente (Superior Lagoon)	16°22’9.8”N 94°57’35.1”W	Jan 20, 2017	Supralittoral	29.27	42.37	41.6	ITZAHÍ SILVA-MORALES & JULIO GÓMEZ-VÁSQUEZ
Playa Vicente (Superior Lagoon)	16°22’9.9”N 94°57’35”W	Jan 21, 2017	0.5-1 m	26.51	44.19	40.0	J. ROLANDO BASTIDA-ZAVALA

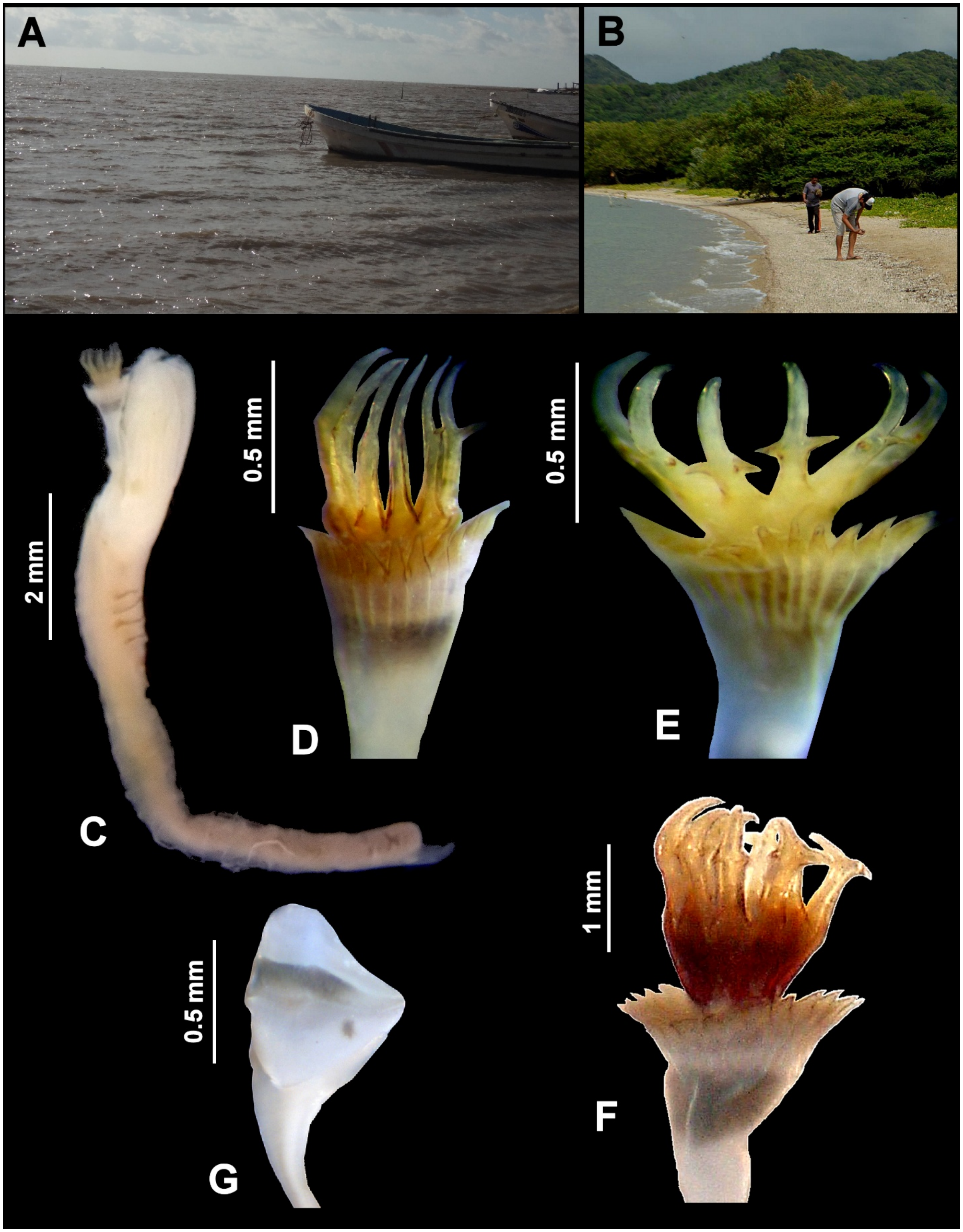

Figure 3. Localities sampled: A. Superior Lagoon during the survey (January 2017); B. Inferior Lagoon during the survey (August 2014, photo by Marcela Bastida-García). Serpulid species from Superior and Inferior lagoons. Opercula: C-D. *Hydroides sanctaecrucis*, body and operculum; E. *H. crucigera*, operculum; F. *H. panamensis*, operculum; G. *Spirobranchus minutus*, operculum.

Taxonomic account

The serpulid species recorded in this work are summarized. Only original descriptions and recent records were mentioned, because two previous works updated the synonyms list (Bastida-Zavala *et al.* 2016, 2017).

Family Serpulidae Rafinesque, 1815

Genus *Hydroides* Gunnerus, 1768

Hydroides sanctaecrucis Krøyer [in] Mörch, 1863

Figure 3C-D

Hydroides (Eucarphus) sanctae-crucis Krøyer [in] Mörch, 1863: 378-379, pl. 11, fig. 12. Type locality: Saint Croix Island, Caribbean Sea.

Hydroides sanctaecrucis.— For a last updated synonyms list see Bastida-Zavala *et al.* 2017: 38-40, figs. 4J, 6 (Florida, United States; fouling plates); Ferrario & Minchin 2017: 1-4, fig. 2A-C (Kaohsiung Harbour, Taiwan; on quaysides and immersed ropes; alongside the black striped mussel *Mytilopsis sallei* (Récluz, 1849)).

Material examined. Ten specimens from San Dionisio del Mar, Oaxaca (intertidal; August 2014); 220 specimens from Playa Vicente, Oaxaca (shallow-water, 0.5-1 m; January 21, 2017).

Remarks. Our specimens (Fig. 3C-D) agree with the redescription by Bastida-Zavala & Ten Hove (2002). *Hydroides sanctaecrucis* is native to the Caribbean Sea (Zibrowius 1971; Bastida-Zavala & Ten Hove 2002; Bastida-Zavala *et al.* 2017) and has an extensive record in several localities from the Tropical Eastern Pacific (Bastida-Zavala & Ten Hove 2003; Tovar-Hernández *et al.* 2014; Bastida-Zavala *et al.* 2016; Keppel *et al.* 2019), and Western Pacific (Lewis *et al.* 2006; Sun *et al.* 2012, 2015; Ferrario & Minchin 2017).

Each tube of *H. sanctaecrucis* has a length of 4-5 cm and a width of 2-3 mm; however, the aggregations are formed by hundreds to thousands of tubes arranged perpendicularly to the substrate, with tubes cemented to each other forming dense clumps, reaching of 25 to 70 cm of height (Fig. 2B-C). According to Montefalcone *et al.* (2022), these aggregations of *H. sanctaecrucis* could be considered reefs, since these serpulids can build rigid, wave-resistant topographic structures. According to their classification, the reefs from the Huave Lagoon System would correspond to type IV, which are reefs in coastal lakes and ports, and type V, for being brackish water reefs.

The introduction via and date of *H. sanctaecrucis* to the Huave Lagoon System is unknown. However, the nearest site where this was previously recorded (in 2011) is the port of Salina Cruz (Bastida-Zavala*et al.* 2016). This port is located 48 km from the entrance to the Huave Lagoon System, so passive entry of larvae would be the most likely means of introduction (Fig. 1).

Hydroides crucigera Mörch, 1863

Figure 3E

Hydroides (Eucarphus) crucigera Mörch, 1863: 378, pl. 11, fig. 8. Type locality: Puntarenas, Pacific side of Costa Rica, 26 m.

Hydroides crucigera.— For the last updated synonyms list see Bastida-Zavala *et al.* 2016: 426, figs 6, 12E (Sonora, Baja California, Baja California Sur and Guerrero, México, and Panamá; fouling on man-made structures).

Material examined. Twenty specimens from Playa Vicente, Oaxaca (shallow-water, 0.5-1 m; January 21, 2017).

Remarks. Our specimens (Fig. 3E) agree with the redescription by Bastida-Zavala & Ten Hove (2003). *Hydroides crucigera* is a native species of the Eastern Pacific, from the Gulf of California to the Pacific of Colombia and Hawaii (Bastida-Zavala *et al.* 2016).

Hydroides panamensis Bastida-Zavala & Ten Hove, 2003

Figure 3F

Hydroides panamensis Bastida-Zavala & Ten Hove, 2003: 97-99, figs 18A-N. Type locality: Paitilla Beach, Pacific side of Panamá; also from La Libertad, Ecuador (0-9 m).

Hydroides panamensis.— BastidaZavala *et al.* 2016: 426, figs 6, 12E (Michoacán and Oaxaca, on sabellariid tubes, rocks and fouling on angler pier).

Material examined. One specimen from Playa Vicente, Oaxaca (shallow-water, 0.5-1 m; January 21, 2017).

Remarks. Our specimen (Fig. 3F) agrees with the original description by Bastida-Zavala & Ten Hove (2003). *Hydroides panamensis* is a native species of the Eastern Pacific, from Michoacán (México) to Panamá and Ecuador (Bastida-Zavala *et al.* 2016).

Genus *Spirobranchus* Blainville, 1818

Spirobranchus minutus (Rioja, 1941)

Figure 3G

Pomatoceros minutus Rioja, 1941: 734-738, pl. 9, figs 15-26. Type locality: Acapulco, Guerrero, México.

Spirobranchus minutus.— Pillai 2009: 146-148 (new combination, synonymy of the genera *Pomatoceros* Philippi, 1844 and *Pomatoleios* Pixell, 1913 with *Spirobranchus*); for the last updated synonyms list see Bastida-Zavala *et al.* 2017: 54-56, figs 9F-G, 10 (northern Gulf of México, United States; fouling plates).

Material examined. Two specimens from San Dionisio del Mar, Oaxaca (intertidal; August 2014).

Remarks. Our specimens (Fig. 3G) agree with the original description by Rioja (1941). *Spirobranchus minutus* is a native specie of the Eastern Pacific, from Baja California Sur (México) to Perú; however, was recorded as an non-native specie in Brazil, the Gulf of México, Sydney (Australia), and Hawaii (Bastida-Zavala *et al.* 2016, 2017).

DISCUSSION

Hydroides sanctaecrucis is a Caribbean species recorded as invasive in the Eastern Pacific: Panamá (Bastida-Zavala & Ten Hove 2002), México (Bastida-Zavala & Ten Hove 2003; Tovar-Hernández*et al.* 2012, 2014; Bastida-Zavala *et al.* 2016) and Galápagos islands (Keppel *et al.* 2019); in the central Pacific: Hawaii (Long 1974); and in the Western Pacific: Australia and Singapore (Lewis *et al.* 2006; Sun *et al.* 2015), Hong Kong (Sun *et al.* 2012) and Taiwan (Ferrario & Minchin 2017).

On the other hand, Lakshmana-Rao (1969: 8-9) described *Hydroides vizagensis* Lakshmana-Rao, 1969, from Visakhapatnam and Madras (now Chennai), India; however, observing his Figure 6a, this species resembles *H. sanctaecrucis*. To verify that *H. vizagensis* is a junior synonym of *H. sanctaecrucis*, type or topotypical specimens should be reviewed and molecular analysis performed, as Kupriyanova *et al*. (2023) suggested.

The hull fouling of vessels and yachts is considered the most probable vector for the dispersion of *H. sanctaecrucis* in the invaded areas (Lewis *et al.* 2006; Sun *et al.* 2012; Bastida-Zavala *et al.* 2016); generally, has been limited to polluted harbors in the sites recorded (Bastida-Zavala *et al.* 2017); however, in its native range, it has also been recorded on mangrove roots, mollusk shells, and corals (Rioja 1958; Dueñas 1981). Occasionally their presence has been together with other invasive species, such as the Caribbean false mussel *Mytilopsis sallei* (Lewis *et al.* 2006; Ferrario & Minchin 2017).

Before *H. sanctaecrucis*, only two species of *Hydroides* were recorded as reef-forming: *Hydroides dianthus* (Verrill, 1873), which built disconnected reefs of 0.5-1 km in Delaware Bay, east coast of USA (Haines & Maurer 1980), or in Italy, where this species built reef systems covering 0.4 km^2 (Bianchi & Morri 2001); the second species, *H. elegans* (Haswell, 1883), when become very abundant, may build clusters of tubes on any hard substrates submerged (Bianchi 1981; Bastida-Zavala *et al*. 2016; Sandonnini *et al*. 2021; De León-González, pers. comm.). In the case of *H. sanctaecrucis*, it may potentially build small reefs in hypersaline and hyposaline coastal lagoons. Therefore, sites where the species has been recorded in the Gulf of California should be studied, especially if coastal lagoons are close to the introduction sites.

The presence of *H. sanctaecrucis* was unnoticed for several years on Oaxaca coast (Gómez *et al.* 1997), the Gulf of Tehuantepec (González-Ortíz *et al.* 1996; Gamboa-Contreras & Tapia-García 1998; Solís-Weiss *et al.* 2000), and in Huave Lagoon System (Chávez 1979; Ortiz-Gallarza *et al.* 1991; Serrano-Guzmán 2004). It is possible that the introduction of this species into the lagoons occurred between 1972, the date of the first recorded samples from the Pacific of Panamá, and 2000 when it was first collected in Oaxaca (Bastida-Zavala & Ten Hove 2002, 2003).

How far *H. sanctaecrucis* aggregations have dispersed at the bottom of the lagoons is unknown; however, the benthic fauna associated/alongside these small reefs includes other polychaete, mollusk, and crustacean species (Fig. 2C, E). In the future, it will be important to evaluate its ecological and economic impacts, since there are examples, such as *Ficopomatus enigmaticus* (Fauvel, 1923), an invasive serpulid species that have relevant ecologic or economic impacts in some localities, because it also build large aggregations in some Mediterranean lagoons (Ten Hove 1974; Ten Hove & Weerdenburg 1978; Fornós *et al.* 1997; Bianchi & Morri

2001). This species can build reefs of 750 m in length as in Lake Tunis (Ten Hove & Van den Hurk 1993); or circular reefs of 2-3 m in diameter, covering extensive areas in the Mar Chiquita Lagoon, Argentina, producing changes in the benthic communities and the human fishery activities (Schwindt *et al.* 2001, 2004); or small aggregations like those spreading along Long Beach, California (Pernet *et al.* 2016) and in Galveston Bay, Texas (Fernández-Rodríguez*et al*. 2023).

Another serpulid species, *Ficopomatus miamiensis*, was recorded, first as non-native (Salgado-Barragán *et al.* 2004) and then as an invasive species, in Sinaloa shrimp farms, where this species builds "true reef colonies", and on Urías estuary mangrove roots, where it was found in small aggregations (Tovar-Hernández *et al.* 2009). Posteriorly, Bastida-Zavala *et al.* (2016) recorded *Salmacina tribranchiata*, an allegedly native species, that builds small aggregations on the Gulf side of Baja California Sur. Thus, *H. sanctaecrucis* is the third serpulid and second invasive species, recorded in the Tropical Eastern Pacific that builds massive aggregations.

Hydroides sanctaecrucis compete for space with other encrusting species, such as native serpulids, barnacles, and mollusks. In the areas where it invades, it can reach high abundance, as occurred in Marina Chahué, Oaxaca, where more than 1700 specimens of *H. sanctaecrucis* were recorded on fouling plates over a year (Ramos-Morales *et al*. 2024).

Although reef construction by serpulids polychaetes would cause negative impacts on native communities and changes in the hydrodynamic conditions in the lagoons, as occurs with *Ficopomatus enigmaticus* in an Argentinian lagoon (*e.g.*, Schwindt *et al*. 2004), it can also have positive impacts due to increasing the three-dimensional relief of the bottom, providing refuge and feeding habitat for fish and invertebrate species, even it can also alter the interactions between native species (Schwindt *et al*. 2001; Palmer *et al*. 2021). It remains to be analyzed how these aggregations of *H. sanctaecrucis*, a new habitat to the Oaxaca lagoons, are distributed in the Huave Lagoon System, how to modify their hydrodynamics and its impacts on the interactions with other benthic species and fishes.

ACKNOWLEDGMENTS

We are grateful to Edgar Rosas-Alquicira, María de Jesús Trejo-Méndez, and Cotsikayala Pacheco-Ramírez (UMAR, Puerto Ángel) for their help with the sampling in Oaxaca lagoons. We thank CONAHCYT (Consejo Nacional de Humanidades, Ciencias y Tecnologías) for the SEMARNAT-CONACYT grant (A3-S-73811 "Poliquetos exóticos invasores en marinas y puertos de México: vulnerabilidad y resiliencia al cambio climático") for partial support of this research. Thank you to the three anonymous referees for their critical corrections and comments.

REFERENCES

Abbott, I. A. 1985. *New species of Gracilaria Grev. (Gracilariaceae, Rhodophyta) from California and Hawaii*. En: *Taxonomy of economic seaweeds with reference to some Pacific and Caribbean species*. Eds. I. A. Abbott & J. N. Norris. California Sea Grant College Program, I: 115-121.

Bastida-Zavala, J. R. 2008. Serpulids (Annelida: Polychaeta) from the Eastern Pacific, including a brief mention of Hawaiian serpulids. *Zootaxa* 1722: 1-61. http://dx.doi.org/10.11646/zootaxa.1722.1.1

Bastida-Zavala, J. R. & H. A. Ten Hove. 2002. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Western Atlantic Region. *Beaufortia* 52: 103-178.

Bastida-Zavala, J. R. & H. A. Ten Hove. 2003. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Eastern Pacific Region and Hawaii. *Beaufortia* 53(4): 67-110.

Bastida-Zavala, J. R. & M. S. García-Madrigal. 2012. First record in the Tropical Eastern Pacific of the exotic species *Ficopomatus uschakovi* (Polychaeta, Serpulidae). *ZooKeys* 238: 45-55. http://dx.doi.org/10.3897/zookeys.238.3970

Bastida-Zavala, J. R. & M. S. García-Madrigal. 2022. *La biodiversidad de invertebrados marinos del Pacífico sur de México*. En: *Invertebrados marinos y costeros del Pacífico sur de México*. Eds. J. R. Bastida-Zavala & M. S. García-Madrigal. Universidad del Mar y Geomare, Puerto Ángel, Oaxaca, México: 1-20.

Bastida-Zavala, J. R., M. S. García-Madrigal, E. F. Rosas-Alquicira, R. A. López-Pérez, F. Benítez-Villalobos, J. F. Meraz-Hernando, A. M. Torres-Huerta, A. Montoya-Márquez & N. A. Barrientos-Luján. 2013. Marine and coastal biodiversity of Oaxaca, Mexico. *Check List* 9(2): 329-390. http://dx.doi.org/10.15560/9.2.329

Bastida-Zavala, J. R., A. S. Rodríguez-Buelna, J. A. de León-González, K. A. Camacho-Cruz & I. Carmona. 2016. New records of sabellids and serpulids (Polychaeta: Sabellidae, Serpullidae) from the Tropical Eastern Pacific. *Zootaxa* 4184(3): 401-457. http://dx.doi.org/10.11646/zootaxa.4184.3.1

Bastida-Zavala, J. R., L. D. McCann, E. Keppel & G. M. Ruiz. 2017. The fouling serpulids (Polychaeta: Serpulidae) from United States coastal waters: an overview. *Eur. J. Taxon.* 344: 1-76. http://dx.doi.org/10.5852/ejt.2017.344

Bianchi, C. N. 1981. *Policheti Serpuloidei. Guideper il riconoscimento delle specie animali delle acque lagunari e costiere italiane*. AQ/1/96, Consiglio Nazionale delle Ricerche, Genova 5: 187 pp.

Bianchi, C. N. & C. Morri. 2001. The battle is not to the strong: serpulid reefs in the lagoon of Orbetello (Tuscany, Italy). *Est. Coast. Shelf Sci.* 53: 215-220. http://dx.doi.org/10.1006/ecss.2001.0793

Blainville, H. M. D. de. 1818. Mémoire sur la classe des Sétipodes, partie des Vers à sang rouge de M. Cuvier, et des Annélides de M. de Lamarck. *Bull. Sci. Soc. Philom., París* 1818: 78-85.

Chávez, E. A. 1979. Análisis de la comunidad de una laguna costera en la costa sur occidental de México. *An. Cent. Cienc. Mar Limnol.* 6(2): 15-44.

Çinar, M. E. 2013 Alien polychaete species worldwide: current status and their impacts. *J. Mar. Biol. Assoc. U. K.* 93(5): 1257-1278. http://dx.doi.org/10.1017/S0025315412001646

Conabio. 2013. *La biodiversidad en Chiapas: Estudio de Estado*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad/Gobierno del Estado de Chiapas, México, Vol. 2, 431 pp.

Conabio. 2017. *Análisis de riesgo rápido de Hydroides sanctaecrucis*. Sistema de información sobre especies invasoras en México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México. 8 pp.

Dueñas, P. D. 1981. Inventario preliminar de los poliquetos (Annelida) de aguas someras de la bahía de Cartagena y áreas adyacentes. *Bol. Mus. Mar* (10): 82-123.

FAUVEL, P. 1923. Un nouveau serpulien d'eau saumatre *Merceriella* n.g., *enigmatica* n.sp. *Bull. Soc. Zool. France* 47: 424-430.

FERNÁNDEZ-RODRÍGUEZ, V., JURGENS, L. & SCHULZE, A. 2023. Is *Ficopomatus enigmaticus* (Annelida: Serpulidae) becoming a nuisance in Galveston Bay, Texas? *Diversity* 15(7): 1-6. https://doi.org/10.3390/d15070852

FERRARIO, J. & D. MINCHIN. 2017. Spread of the non-indigenous serpulid *Hydroides sanctaecrucis* Krøyer in Mörch, 1863 in the Pacific Ocean: a new record from Taiwan. *BioInv. Rec.* 6(1): 33-38. https://doi.org/10.3391/bir.2017.6.1.06

FORNÓS, J. J., V. FORTEZA & A. MARTÍNEZ-TABERNER. 1997. Modern polychaete reefs in Western Mediterranean lagoons: *Ficopomatus enigmaticus* (Fauvel) in the Albufera of Menorca, Balearic Islands. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 128: 175-186. https://doi.org/10.1016/S0031-0182(96)00045-4

GAMBOA-CONTRERAS, J. A. & M. TAPIA-GARCÍA. 1998. *Invertebrados bentónicos de la plataforma continental interna*. En: *El Golfo de Tehuantepec: el ecosistema y sus recursos*. Ed. M. TAPIA-GARCÍA. Universidad Autónoma Metropolitana, Unidad Iztapalapa, México: 103-128.

GARCÍA-MENDOZA, A. J., M. J. ORDÓÑEZ & M. BRIONES-SALAS. 2004. *Biodiversidad de Oaxaca*. Instituto de Biología, UNAM, Fondo Oaxaqueño para la Conservación de la Naturaleza, WWF, México. 605 pp.

GÓMEZ, P., J. A. MERCADO, L. M. MITCHELL & S. I. SALAZAR-VALLEJO. 1997. Poliquetos de fondos duros (Polychaeta) de bahías de Huatulco y Puerto Ángel, Oaxaca, México. *Rev. Biol. Trop.* 45(3): 1067-1074.

GONZÁLEZ-ORTÍZ, L., P. HERNÁNDEZ-ALCÁNTARA & V. SOLÍS-WEISS. 1996. New records of polychaetes (Annelida: Polychaeta) from the Gulf of Tehuantepec. *Bull. Mar. Sci.* 59(1): 235-240.

GUNNERUS, J. 1768. Om nogle norske coraller. *Skrifter Kong. norske Vidensk. Trond.* 4: 38-73.

HAINES, J. L. & D. MAURER. 1980. Benthic invertebrates associated with a serpulid polychaete assemblage in a temperate estuary. *Int. Revue Ges. Hydrobiol.* 65(5): 643-656. https://doi.org/10.1002/iroh.19800650504

HASWELL, W.A. 1883. On some new Australian tubicolous Annelids. *Proc. Linn. Soc. New So. Wales* 7: 633-638.

HOEKSEMA, B. W. & H. A. TEN HOVE. 2011. Aggregation of the reef-building tube worm *Filogranella elatensis* at Semporna, eastern Sabah, Malaysia. *Coral Reefs* 2011: 1. https://doi.org/10.1007/s00338-011-0785-8

KEPPEL, E., I. KEITH, G. M. RUIZ & J. T. CARLTON. 2019. New records of native and non-indigenous polychaetes (Annelida: Polychaeta) in the Galapagos Islands. *Aquat. Inv.* 14(1): 59-84. https://doi.org/10.3391/ai.2019.14.1.03

KUPRIYANOVA, E., Y. SUN, E. WONG & H. A. TEN HOVE. 2023. Hydroides *of the World*. CRC Press, Australia. 238 pp.

LAKSHMANA-RAO, M. V. 1969. Fouling serpulids from some Indian harbours. *J. Timber Develop. Assoc. India* 15(2): 1-20.

Lamouroux, J. V. F. 1813. Essai sur les genres de la famille des *Thalassiophytes* non articulées. *Ann. Mus. Hist. Natur., Paris* 20: 21-47, 115-139, 267-293.

Lewis, J. A., C. Watson, H. A. TenHove. 2006. Establishment of the Caribbean serpulid tubeworm *Hydroides sanctaecrucis* Krøyer [in] Mörch, 1863, in northern Australia. *Biol. Inv.* 8: 665-671. http://dx.doi.org/10.1007/s10530-005-2062-7

Long, E. R. 1974. Marine fouling studies off Oahu, Hawaii. *The Veliger* 17(1): 23-36. http://dx.doi.org/10.1111/j.1096-3642.1933.tb01640.x

Montefalcone, M., A. Oprandi, A. Azzola, C. Morri & C. N. Bianchi. 2022. Serpulid reefs and their role in aquatic ecosystems: A global review. *Adv. Mar. Biol.* 92: 1-54. http://dx.doi.org/10.1016/bs.amb.2022.06.001

Moore, J. P. 1923. The polychaetous annelids dredged by the U.S.S. "Albatross" off the coast of southern California in 1904. IV. Spionidae to Sabellariidae. *Proc. Acad. Natur. Sci. Phil.* 75: 179-259.

Mörch, O. A. L. 1863. Revisio critica Serpulidarum. Et bidrag til røromenes naturhistorie. *Naturhistor Tidsskrift Henrik Krøyer, København*, series 3(1): 347-470.

Ortiz-Gallarza, S. M., G. de la Lanza Espino & M. R. García-Hernández. 1991. Análisis hidrológico y bentónico de la laguna Superior, Oaxaca, México. *Univ. Ciencia* 8(16): 5-24.

Palmer, T. A., N. Breaux, B. Lebreton, G. Guillou & J. B. Pollack. 2021. Importance of serpulid reef to the functioning of a hypersaline estuary. *Est. Coasts* 45: 603-618. https://doi.org/10.1007/s12237-021-00989-0

Pernet, B., M. Barton, K. Fitzhugh, L. H. Harris, D. Lizárraga, R. Ohl & C. R. Whitcraft. 2016. Establishment of the reef-forming tubeworm *Ficopomatus enigmaticus* (Fauvel, 1923) (Annelida: Serpulidae) in southern California. *BioInv. Rec.* 5(1): 13-19. https://doi.org/10.3391/bir.2016.5.1.03

Philippi, A. 1844. Einige Bemerkungen über die Gattung *Serpula*, nebst Aufzählung der von mir im Mittelmeer mit dem Thier beobachteten Arten. *Arch. Natur., Berlin* 10(1): 186-198.

Pillai, T. G. 1960. Some marine and brackish-water serpulid Polychaeta from Ceylon, including new genera and species. *Ceylon J. Sci. (Biol. Sci.)* 3(1): 1-40.

Pillai, T. G. 2009. Description of new serpulid polychaetes from the Kimberleys of Australia and discussion of Australian and Indo-West Pacific species of *Spirobranchus* and superficially similar taxa. *Rec. Austr. Mus.* 61(2): 93-199. http://dx.doi.org/10.3853/j.0067-1975.61.2009.1489

Pixell, H. L. M. 1913. Polychaeta of the Indian Ocean, together with some species from the Cape Verde Islands. The Serpulidae, with a classification of the genera *Hydroides* and *Eupomatus*. *Trans. Linn. Soc. London* (ser 2) 16: 69-92.

Rafinesque, S.C. 1815. *L'analyse de la nature*. Palermo, 224 pp.

Ramos-Morales, A., J. D. Gómez-Vásquez, M. S. García-Madrigal & J. R. Bastida-Zavala. 2024. Fouling invertebrates from PVC plates at Chahué Marina, Oaxaca, Southern Pacific coast of Mexico. *Check List* 20(3): 728-760. http://dx.doi.org/10.15560/20.3.728

Récluz, C. 1849. Description de quelques nouvelles espèces de coquilles. *Rev. Magasin. Zool. Pure Appl*. 2(1): 64-71.

Rioja, E. 1941. Estudios Anelidológicos, III. Datos para el conocimiento de la fauna de poliquetos de las costas mexicanas del Pacífico. *An. Inst. Biol., México* 12: 669-746.

Rioja, E. 1958. Estudios Anelidológicos XXII: Datos para el conocimiento de la fauna anélidos poliquetos de las costas orientales de México. *An. Inst. Biol., México* 29: 219-301.

Ruiz, G. M., P. W. Fofonoff, B. Steves, S. F. Foss & S. N. Shiba. 2011. Marine invasion history and vector analysis of California: a hotspot for western North America. *Divers. Distrib.* 17: 362-373. https://doi.org/10.1111/j.1472-4642.2011.00742.x

Salgado-Barragán, J., N. Méndez & A. Toledano-Granados. 2004. *Ficopomatus miamiensis* (Polychaeta: Serpulidae) and *Styela canopus* (Ascidiacea: Styelidae), non-native species in Urías estuary, SE Gulf of California, Mexico. *Cah. Biol. Mar.* 45: 167-173.

Sandonnini, J., Y. Del Pilar Ruso, E. Cortés Melendreras & F. Giménez Casalduero. 2021. Massive aggregations of Serpulidae associated with eutrophication of the Mar Menor, Southeast Iberian Peninsula. *Front. Mar. Sci.* 7: 531726. https://doi.org/10.3389/fmars.2020.531726

Schwindt, E., A. Bortolus & O. O. Iribarne. 2001. Invasion of a reef-builder polychaete: direct and indirect impacts on the native benthic community structure. *Biol. Inv.* 3: 137-149. https://doi.org/10.1023/A:1014571916818

Schwindt, E., O. O. Iribarne & F. I. Isla. 2004. Physical effects of an invading reef-building polychaete on an Argentinean estuarine environment. *Est. Coast. Shelf Sci.* 59: 109-120. https://doi.org/10.1016/j.ecss.2003.06.004

Serrano-Guzmán, S. J. 2004. *Estudio de ordenamiento ecológico para la zona costera del Istmo de Tehuantepec que favorezca y contribuya al desarrollo ordenado y racional de la pesca y la acuacultura*. Universidad del Mar, Oaxaca, México. 159 pp.

Sodhi, N. S., B. W. Brook & C. J. A. Bradshaw. 2009. *Causes and consequences of species extinctions*. En: *The Princeton guide to Ecology*. Ed. S. A. Levin. Princeton University Press, Nueva Jersey: 514-520.

Solís-Weiss, V., J. A. de León-González & L. González-Ortiz. 2000. Un análisis biogeográfico de los poliquetos (Annelida: Polychaeta) del golfo de Tehuantepec, México. *Rev. Peruana Biol.* 7(1): 5-15. https://doi.org/10.15381/rpb.v7i1.6724

Spalding, M. D., H. E. Fox, G. R. Allen, N. Davidson, Z. A. Ferdaña, M. Finlayson, B. S. Halpern, M. A. Jorge, A. Lombana, S. A. Lourie, K. D. Martin, E. McManus, J. Molnar, C. A. Recchia & J. Robertson. 2007. Marine ecoregions of the World: A bioregionalization of coastal and shelf areas. *BioScience* 57(7): 573-583. https://doi.org/10.1641/B570707

Sun, Y., H. A. Ten Hove & J. W. Qiu. 2012. Serpulid polychaetes from Hong Kong. *Zootaxa* 3424: 1-42. http://dx.doi.org/10.11646/zootaxa.3424.1.1

Sun, Y., E. Wong, H. A. Ten Hove, P. A. Hutchings, J. E. Williamson & E. K. Kupriyanova. 2015. Revision of the genus *Hydroides* (Annelida: Serpulidae) from Australia. *Zootaxa* 4009(1): 1-99. http://dx.doi.org/10.3853/j.0067-1975.25.1959.654

Tapia-García, M. & D. B. Gutiérrez. 1998. *Recursos pesqueros de los estados de Oaxaca y Chiapas*. En: *El Golfo de Tehuantepec: el ecosistema y sus recursos*. Ed. M. Tapia-García. Universidad Autónoma Metropolitana, Unidad Iztapalapa, México: 149-162.

Ten Hove, H. A. 1974. Notes on *Hydroides elegans* (Haswell, 1883) and *Mercierella enigmatica* Fauvel, 1923, alien serpulid polychaetes introduced into the Netherlands. *Bull. Zoöl. Mus., Univ. Amsterdam* 4(5): 45-51.

Ten Hove, H. A. 1979. *Different causes of mass occurrence in serpulids*. En: *Biology and systematics of colonial organisms*. Eds. G. Larwood & B. R. Rosen. Systematic Association Special Volume (11): 281-298.

Ten Hove, H. A. & J. C. A. Weerdenburg. 1978. A generic revision of the brackish-water serpulid *Ficopomatus* Southern 1921 (Polychaeta: Serpulinae), including *Mercierella* Fauvel 1923, *Sphaeropomatus* Treadwell 1934, *Mercierellopsis* Rioja 1945 and *Neopomatus* Pillai 1960. *Biol. Bull.* 154: 96-120. https://doi.org/10.2307/1540777

Ten Hove, H. A. & P. Van den Hurk. 1993. A review of Recent and fossil serpulid “reefs”; actuopaleontology and the 'Upper Malm' serpulid limestones in NW Germany. *Geol. Mijnbouw* 72(1): 23-67.

Tovar-Hernández, M. A., N. Méndez & T. F. Villalobos-Guerrero. 2009. Fouling polychaete worms from the Southern Gulf of California: Sabellidae and Serpulidae. *Syst. Biodiv.* 7(3): 319-336. http://dx.doi.org/10.1017/s1477200009990041

Tovar-Hernández, M. A., T. F. Villalobos-Guerrero, B. Yáñez-Rivera, J. M. Aguilar-Camacho & I. D. Ramírez-Santana. 2012. *Guía de invertebrados acuáticos exóticos en Sinaloa*. Geomare, A.C., U.S. Fish and Wildlife Service, Instituto Nacional de Ecología-SEMARNAT, Mazatlán, Sinaloa. 41 pp.

Tovar-Hernández, M. A., B. Yáñez-Rivera, T. F. Villalobos-Guerrero, J. M. Aguilar-Camacho & I. D. Ramírez-Santana. 2014. *Invertebrados marinos exóticos en el Golfo de California*. En: *Especies invasoras acuáticas: Casos de estudio en ecosistemas de México*. Eds. A. M. Low Pfeng, P. A. Quijón & E. M. Peters Recagno. Secretaría de Medio Ambiente y Recursos Naturales, Instituto Nacional de Ecología y Cambio Climático, University of Prince Edwards Island, México: 15-32.

Treadwell, A. L. 1934. *Sphaeropomatus miamiensis*, a new genus and species of serpulid polychaete. *J. Wash. Acad. Sci.* 24(8): 338-341. https://biostor.org/reference/105893

Verrill, A. E. 1873. *Report upon the invertebrate animals of Vineyard Sound and the adjacent waters, with an account of the physical characters of the region*. In: *Report of the United States Commission for Fisheries*, 1871–72. Pp: 295-778. http://dx.doi.org/10.5962/bhl.title.57652

Zibrowius, H. 1971. Les espèces Méditerranée du genre *Hydroides* (Polychaeta Serpulidae). Remarques sur le prétendu polymorphisme de *Hydroides uncinata*. *Tethys* 2: 691-746.

Recibido octubre 2024
Aceptado: diciembre 2024