ORIGINAL RESEARCH

Marine sponges of the rocky reefs of Punta Amapala, El Salvador, eastern Tropical Pacific

Alejandra Trejo[1, 2, *] and Johanna Segovia[1, 2]

[1]Centro de Investigación Marina y Limnológica (CIMARyL), Universidad Francisco Gavidia, 1101 - San Salvador, El Salvador.
[2]Instituto de Ciencia, Tecnología e Innovación (ICTI), Universidad Francisco Gavidia, 1101 - San Salvador, El Salvador.
ORCID *Alejandra Trejo* https://orcid.org/0000-0002-5565-076X, *Johanna Segovia* https://orcid.org/0000-0001-8548-3790

ABSTRACT. Sponges represent one of the groups with the greatest abundance and diversity among invertebrates. They tolerate a wide range of environmental factors allowing them to surpass the survival of other organisms. Punta Amapala is located between the eastern coastal plain and the Gulf of Fonseca, El Salvador, characterized by the presence of rocky reefs surrounded by sand. Sponge richness, frequency and distribution of rocky reefs at Punta Amapala was recorded following the transect and quadrat methodology. The study resulted in the recording of ten taxa: *Aplysina gerardogreeni*, *Haliclona* spp., *Axinella nayaritensis*, *Endectyon* (*Endectyon*) *hyle*, *Mycale* (*Carmia*) *cecilia*, *M.* (*Zygomycale*) *ramulosa*, *Tedania* (*Tedania*) *tropicalis*, *Cliona californiana*, *C. euryphylle* and a sponge of the subclass Calcinea (Calcarea). It is necessary to increase the studies directed to this group in order to know with greater accuracy their richness in the reefs of El Salvador and thus to understand the ecological role they play in ecosystem.

Key words: Shallow rocky reef, biodiversity, Calcarea, Demospongiae, spatial distribution.

*Correspondence:
e.atrejo@ufg.edu.sv

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Esponjas marinas de los arrecifes rocosos de Punta Amapala, El Salvador, Pacífico Tropical oriental

RESUMEN. Las esponjas representan uno de los grupos de mayor abundancia y diversidad entre los invertebrados, toleran una amplia gama de factores ambientales que les permiten superar la supervivencia de otros organismos. Punta Amapala se localiza entre la planicie costera oriental y el Golfo de Fonseca en El Salvador, caracterizada por la presencia de arrecifes rocosos rodeados de arena. La riqueza, frecuencia y distribución de esponjas en los arrecifes rocosos de Punta Amapala se registró siguiendo la metodología de transectos y cuadrantes. El estudio dio como resultado el registro de diez taxones: *Aplysina gerardogreeni*, *Haliclona* spp., *Axinella nayaritensis*, *Endectyon* (*Endectyon*) *hyle*, *Mycale* (*Carmia*) *cecilia*, *M.* (*Zygomycale*) *ramulosa*, *Tedania* (*Tedania*) *tropicalis*, *Cliona californiana*, *C. euryphylle* y una esponja de la subclase Calcinea (Calcarea). Es necesario incrementar los estudios dirigidos a este grupo para conocer con mayor exactitud su riqueza en los arrecifes de El Salvador y así entender el papel ecológico que juegan en el ecosistema.

Palabras clave: Arrecife rocoso somero, biodiversidad, Calcarea, Demospongiae, distribución espacial.

INTRODUCTION

El Salvador, despite its small coastline extension (321 km) has a great diversity of marine ecosystems along its coast. One of the most diverse and recently studied ecosystem is the rocky reef, which provide habitat for various marine organisms (Barros et al. 2001). Many studies in El Salvador have focused on the richness and distribution of benthic organisms, the structure of fish communities in intertidal pools, and the description of coral-associated marine communities (González-Murcia et al. 2016; Segovia et al. 2017; Ilosvay et al. 2021). Los Cóbanos, La Libertad, and the islands of the Gulf of Fonseca and Punta Amapala are the main reefs in the country. The latter two are located in the eastern part of the country, where there is little information about their marine biodiversity, with the exception of some studies on invertebrates such as cnidarians and opisthobranchs (López 2017; Segovia et al. 2021). Reefs of eastern El Salvador are located in the coastal strip associated with the Jucuarán mountain range and the Conchagua volcano. They receive high energy from waves beating the cliffs and are surrounded by sandbanks (Jiménez et al. 2004; Segovia 2012).

Sponge studies carried out in El Salvador consist of the recording of freshwater *Spongilla alba* and *Ephydatia fluviatilis* species in Lake Ilopango (Poirrier and Trabanino 1989). In marine ecosystems, Pacheco et al. (2018) carried out the first faunal and descriptive record of boring sponges in Los Cóbanos reef, registering six species belonging to the genera *Cliona*, *Cliothosa*, *Thoosa* and *Siphonodictyon*. Trejo et al. (2021) worked with the diversity and abundance of boring sponges in two intertidal beaches of this same reef. In the subtidal zone of this same site, Trejo (2020) studied the spatial distribution of sponges in rocky reefs up to 16 m deep, recording 17 sponges of genera *Callyspongia*, *Haliclona*, *Axinella*, *Raspailia*, *Higginsia*, *Cinachyra*, *Mycale*, *Tedania*, *Cliona*, *Ciocalypta*, *Coleocalypta*, *Terpios*, *Suberea* y *Aplysina*. Technical reports indicate the presence of genera *Aplysina* and *Axinella* from Maculís beach and the islands of Gulf of Fonseca in the eastern part of the country (Domínguez 2011; MARN 2014). Apart from this information, there are no studies directed towards the group. For this reason, the objective of this study was to record the richness, frequency and spatial distribution of sponges in three rocky reefs of Punta Amapala, El Salvador.

MATERIALS AND METHODS

Description of the study area

Punta Amapala is located in the eastern part of the country, in the department of La Unión. It corresponds to a section of the Salvadoran coastal plain. The study area is cliff type, although very low, where rock formations are interrupted by small sandy beaches. (Gierloff-Emden 1976; Domínguez 2011). Communities of algae, octocorals, oyster banks and abalone have been documented (Domínguez 2011; Segovia 2012; MARN 2021).

The study was carried out in three rocky reefs: Las Mueludas, Maculís and El Flor, with depths between 3 and 8 m (Figure 1). Las Mueludas is a shallow rocky area (3-4 m deep) with boulder-type rocks ranging from small to very large sizes. The water column had a large amount of silt-type sediment and very little coarse-grained sand. Maculís and El Flor are characterized by small and medium-sized basaltic rocks with some rocky patches with banks of coarse sand and ground shell around them.

Data collection

Three linear transects of 30 m length were traced perpendicular to the coast at each site. The transect was traversed by SCUBA with a quadrat of 1 m^2, making a total study area of 90 m^2. Sponges were

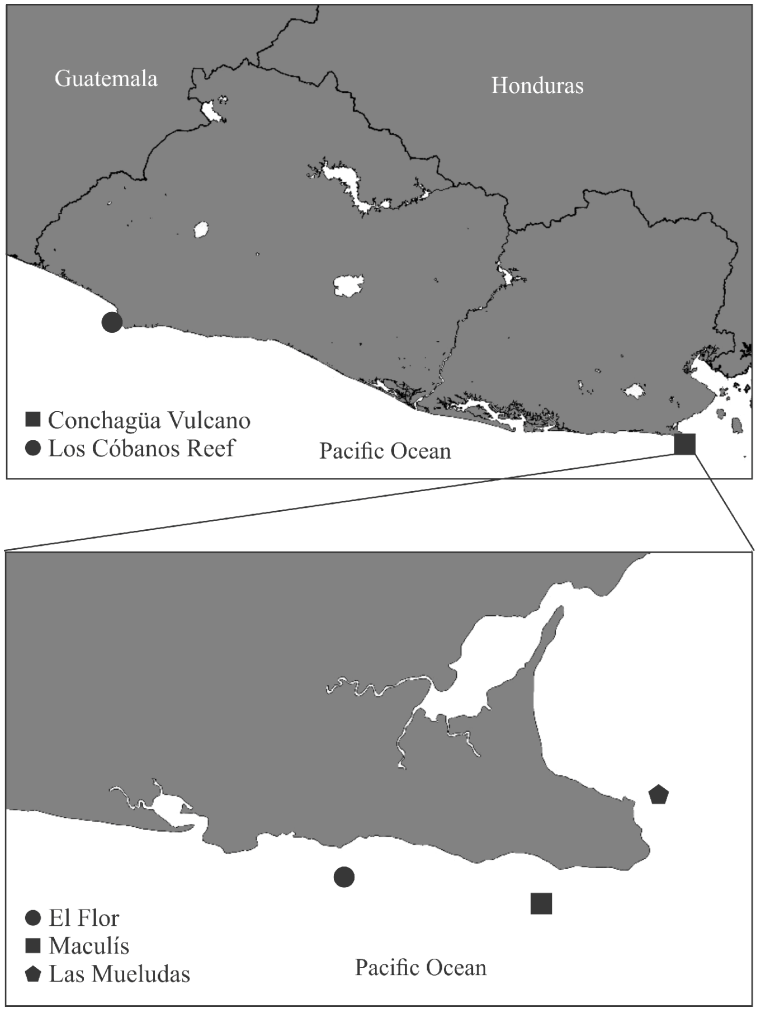

Figure 1. Location of the three rocky reefs of Punta Amapala, department of La Unión, El Salvador.

identified by observation when possible. Unidentified sponges were collected and stored in 96% ethanol, and subsequently analyzed at the laboratory using spicule preparations for light microscopy. For every sponge, each type of spicule was identified, and the maximum length and width were measured with the Motic Images Plus 2.0 program. Taxonomic guides consulted and available for the region were Boury-Esnault and Rützler (1997), Carballo and Cruz-Barraza (2000), Hooper and Soest (2002), Carballo et al. (2004), Cruz-Barraza and Carballo (2008), and Aguilar-Camacho et al. (2013). Frequency was recorded by registering the presence of each sponge within the quadrat.

Data analysis

Cluster analysis based on Bray-Curtis Index of species richness was used to study dissimilarities between sites. In addition, non-metric multidimensional scaling ordination (nMDS), based on Bray-Curtis Index, was used to create groupings by species according to physical characteristics of the reefs.

RESULTS

Systematics

Class Calcarea Bowerbank, 1862
Subclass Calcinea Bidder, 1898

Locality. Maculís, El Flor.

Description. Calcarea with anastomosed tubes, comprising triactines with blunt tips. Color in life and after preservation is translucid white (Figure 2).

Class Demospongiae Sollas, 1885
Subclass Heteroscleromorpha
Cárdenas, Pérez and Boury-Snault, 2012
Family Chalinidae Gray, 1867
Genus *Haliclona* Grant, 1841
Haliclona spp.

Locality. El Flor.

Description. Massive sponge with elevations taking the form of small volcanoes, its consistency is compressible but not elastic. Color in life is white, when preserved in alcohol it becomes beige. The ectosomal skeleton is tangential and unispicular formed by oxeas that are joined at each tip by spongin. The coanosome is reticulate and unispicular forming triangular and quadrangular meshes. The only present spicules are oxeas, which are robust and with sharp points measuring between 80-120 µm (Figure 3; Table 1).

Family Axinellidae Schmidt, 1862
Genus *Axinella* Carter, 1875
Axinella nayaritensis Carballo,
Bautista-Guerrero and Cruz-Barraza, 2018

Locality. Maculís, El Flor.

Description. Erect sponge with cylindrical ramifications, and corrugated surface very difficult to break. The size of the sponge varies between 15-20 cm high by 16-20 cm wide. The branches have a diameter of 0.4-1.2 cm. It has small, slightly raised oscula. Color in life is orange and turns brown when preserved in alcohol. The skeleton is distinguished by having a condensed axial center that expands towards the surface, many styles exceed the surface of the sponge forming groups of spicules that resemble brushes. The spicules present are oxeas (280-500 µm) and styles (250-430 µm) (Figure 4; Table 1).

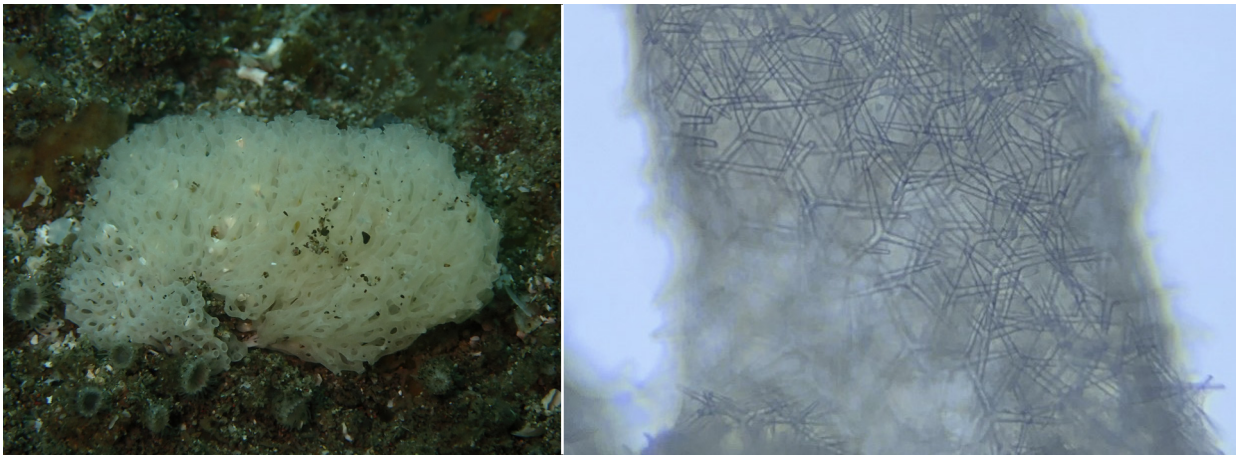

Figure 2. Calcinea sponge with blunt tips triactines.

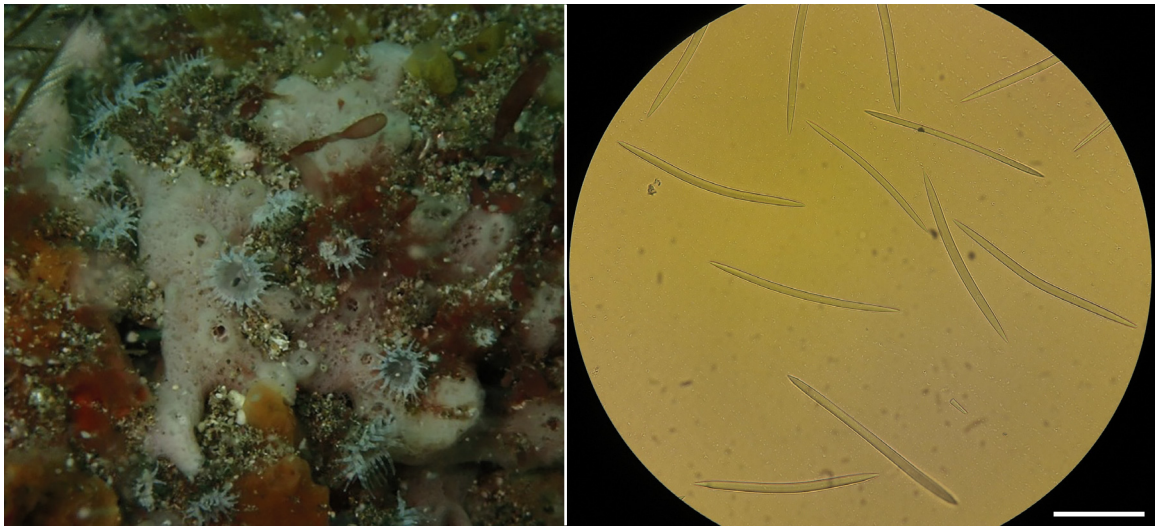

Figure 3. *Haliclona* spp. Oxeas spicules, scale bar = 50 µm.

Genus *Endectyon* Topsent, 1920
Endectyon* (*Endectyon*) *hyle
de Laubenfels, 1930

Locality. Maculís.

Description. Branched sponge 3 cm wide and 5 cm high. Each branch of the sponge has two rounded lobes of 0.5 cm in diameter. The surface is irregular, no oscula are observed. Hard consistency and difficult to break. Color in life is bright orange with sediments on it, when preserved in alcohol it turns beige. The ectosome consists of a layer of straight, long and thin styles (205-247 × 1-2 µm) (Figure 5; Table 1). There is an extra-axial subectosome made up of styles that project their tips toward the surface. The choanosome is a compressed axial skeleton formed by primary multispicular fibers interconnected by secondary fibers of two or more spicules, where styles and acanthostyles meet.

Family Mycalidae Lundbeck, 1905
Genus *Mycale* Gray, 1867
Mycale* (*Carmia*) *cecilia de Laubenfels, 1936

Locality. Las Mueludas, El Flor.

Description. Cushion or encrusting sponge 4-6 mm thick. Color in life is intense orange or reddish, when preserved it becomes light brown or beige. The spicules are mycalostyles, these are straight and with a very pronounced tip (260 × 5.2 µm), the head is slightly oval. As microscleres, there are anisochela in a single category (20 µm) and C shaped sigmas (35 µm) (Figure 6; Table 1). In the skeleton, free mycalostyles are observed, while in the choanosome there are multispicular bands that ascend to the surface, forming brushes.

Mycale* (*Zygomycale*) *ramulosa
Carballo and Cruz-Barraza, 2010

Locality. Las Mueludas, El Flor.

Description. Massive sponge with 7 cm long × 10 wide coverage, the surface is irregular and smooth, but when observed under the microscope there are notable groups of spicules that protrude from it. The sponge is of compressible and elastic consistency. The skeleton is formed by a tangential reticulate ectosome containing fibers of multiple mycalostyles. The choanosome contains traces formed by mycalostyles that arise from the base of the sponge

Table 1. Spicule measurement of sponge species registered in three rocky reefs of Punta Amapala, El Salvador. Values are presented as minimun (mean) maximum in μm.

Examined material	Oxeas (length x width)	Styles (length × width)	Tylostyles (length × width; head width)	Acanthostyles (length × width)	Sigma (length)	Anisochela (length)	Toxa (length)	Isochela (length)	Raphid (length)	Tylotes (length × width)	Onychaetes (length × width)	Spiraster (length)	Locality
Haliclona spp.	80 (104) 120 × 2.3 (5.5) 6.9												El Flor
Axinella nayaritensis	280 (347.8) 495 × 5 (12.7) 17.9	260 (324.2) 428 × 10 (14.1) 19											Maculís
Axinella nayaritensis	300 (341.6) 500 × 8 (13.4) 19	250 (328.5) 430 × 11 (13.9) 20.1											El Flor
Endectyon (*Endectyon*) *hyle*		Ectosome 205 (248.7) 247 × 1 (1.5) 2 Choanosome 230.1 (310.5) 370 × 5 (7.7) 13.1		160 (187.5) 230.4 × 9 (11.3) 12.9									Maculís
Mycale (*Carmia*) *cecilia*			Mycalostyles 232 (260) 260.5 × 2.3 (5.2) 7.2; 4.1 (5.4) 7.2		30.1 (35) 42.7	17 (20) 21.3							Maculís
Mycale (*Zygomycale*) *ramulosa*			Mycalostyles 240 (267) 310 × 4.1 (5.9) 8; 3.5 (5) 6.4		56.7 (66.8) 76.3	I: 40 (45.4) 50.1 II: 15.5 (21.2) 25.1	29.8 (49.5) 67.3	10 (10.4) 11.6	25 (28.6) 33.3				Las Mueludas
Tedania (*Tedania*) *tropicalis*		222 (235.4) 240 × 4.9 (5.1) 7.3								185 (189.5) 205 × 2 (2.2) 2.5	147 (166.4) 178 × 2.5		Maculís
Cliona californiana			133 (233.1) 301.8 × 3.5 (4.3) 6.8; 4.1 (5.4) 6.1										Las Mueludas
Cliona euryphylle			150 (255) 355 × 3.5 (6.6) 8.5; 5.2 (5.6) 6.1									10 (16.8) 24.7	El Flor

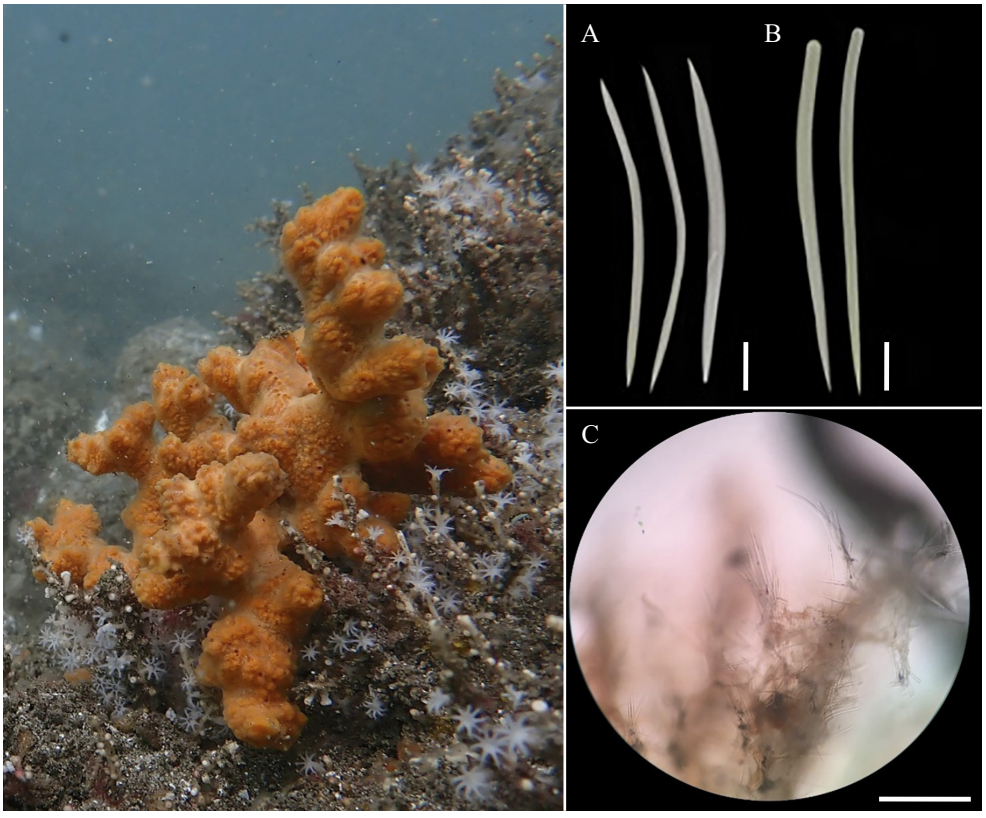

Figure 4. *Axinella nayaritensis* Carballo, Bautista-Guerrero and Cruz-Barraza, 2018. A) Oxeas. B) Styles. C) Extra-axial skeleton with spicules projecting towards the surface. Scale bars: A and B = 50 µm; C = 500 µm.

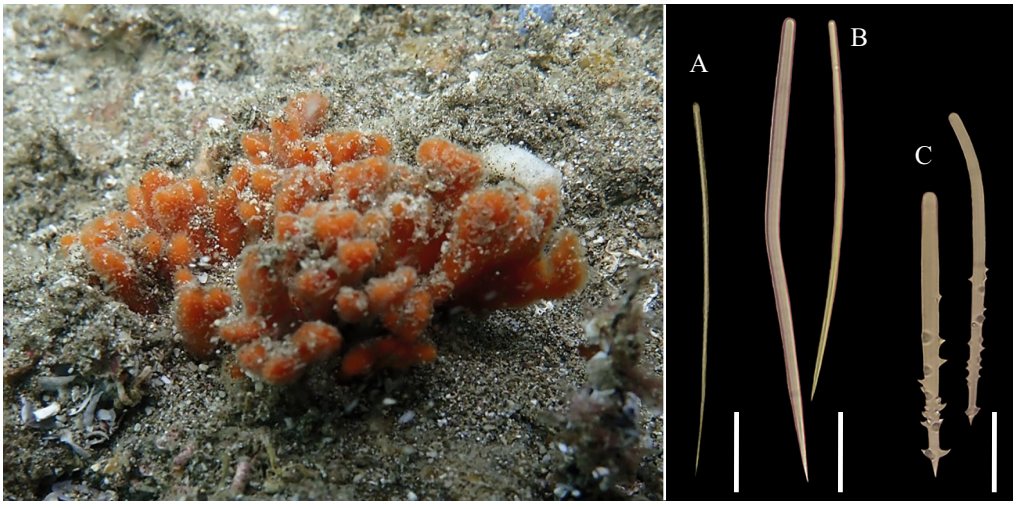

Figure 5. *Endectyon* (*Endectyon*) *hyle* de Laubenfels, 1930. A) Ectosome styles. B) Choanosome styles. C) Acanthostyles. Scale bars: A-C = 50 µm.

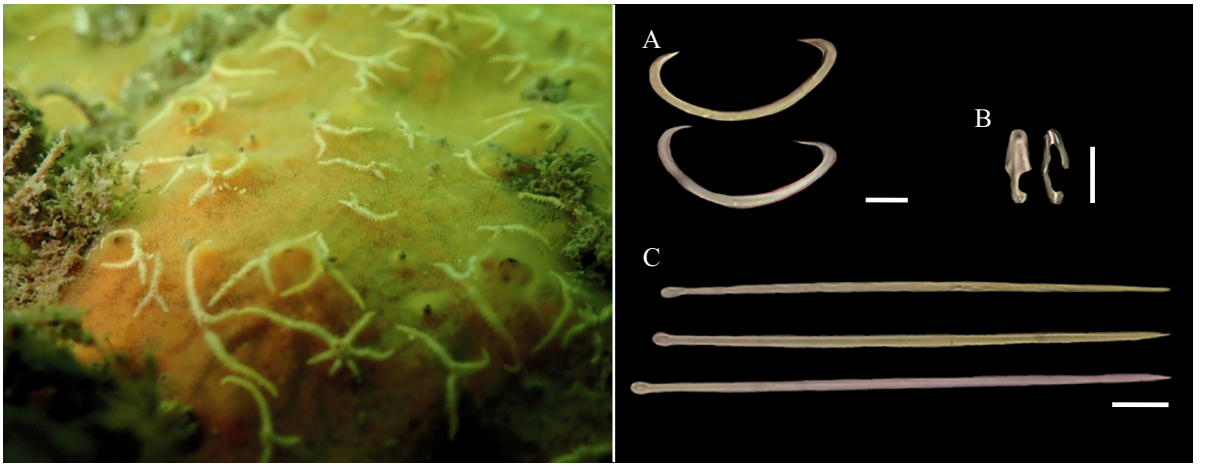

Figure 6. *Mycale* (*Carmia*) *cecilia* de Laubenfels, 1936. A) C shaped sigmas. B) Anisochela. C) Mycalostyles. Scale bars: A = 12 µm; B = 20 µm; C = 25 µm.

and come to exceed the surface assimilating small brushes. The spicules are mycalostyles, isochelae, sigma and anisochelae in two size categories, toxa and raphides (Figure 7; Table 1).

Family Tedaniidae Ridley and Dendy, 1886
Genus *Tedania* Gray, 1867
Tedania* (*Tedania*) *tropicalis Aguilar-Camacho, Carballo and Cruz-Barraza, 2018

Locality. Maculís.

Description. Massive sponge 5 cm long and 4-5 cm thick. The surface is irregular and smooth, with a flexible and elastic consistency. Color in life is orange and becomes pale when preserved in alcohol. The ectosome consists of tylotes with microspined heads (185-205 µm × 2.5-5 µm). Styles (222-240 µm) are found in the choanosome, forming multispicular lines and scattered onychaetes (147-178 µm) (Figure 8, Table 1).

Family Clionaidae D'Orbigny, 1851
Genus *Cliona* Grant, 1826
Cliona californiana de Laubenfels, 1932

Locality. Las Mueludas.

Description. Boring sponge for calcareous substrate, with a surface area of 15 × 18 cm. Color in life is bright yellow, it turns pale when preserved in alcohol. It has several circular papillae of 1-2.5 mm in diameter protruding from the surface. The skeleton consists only of tylostyles with a subterminal head, the spicule is slightly curved and with a pointed termination, measuring between 133-301.8 µm (Figure 9; Table 1).

Cliona euryphylle Topsent, 1888

Locality. El Flor.

Description. Boring sponge for calcareous substrate, with a surface area of 6 × 4 cm. The color in life is bright yellow, it turns pale when preserved in alcohol. It has oval oscular papillae of 2.5-3.5 mm in diameter slightly protruding from the surface. The skeleton is made up of tylostyles and spirasters. The tylostyles have a well-formed head, are straight and with a pointed termination, measuring between 150-355 µm. The spiraster are short, stout and with many thick spines. (Figure 10; Table 1).

Subclass Verongimorpha
Erpenbeck, Sutcliffe, De Cook, Dietzel,

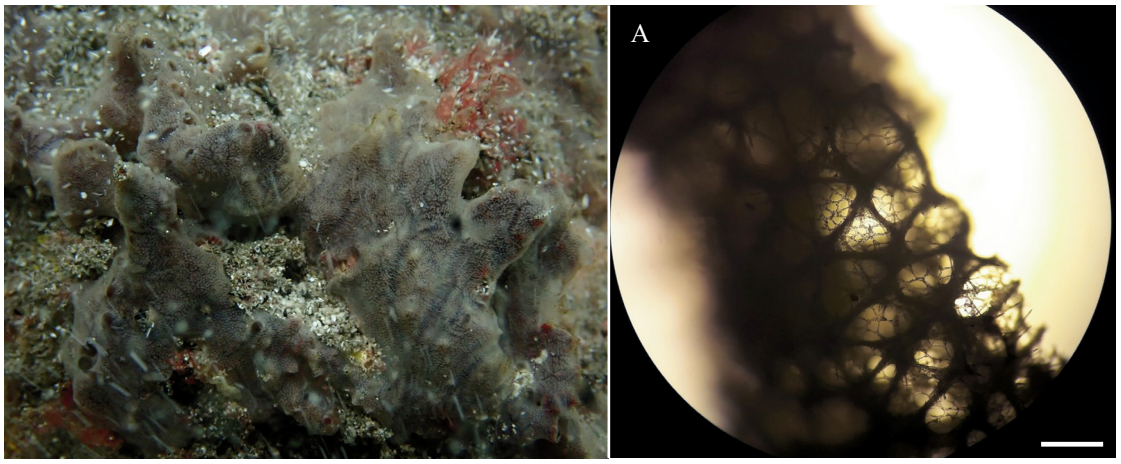

Figure 7. *Mycale* (*Zygomycale*) *ramulosa* Carballo and Cruz-Barraza, 2010. A) Tangential reticulate ectosome, scale bar = 300 µm.

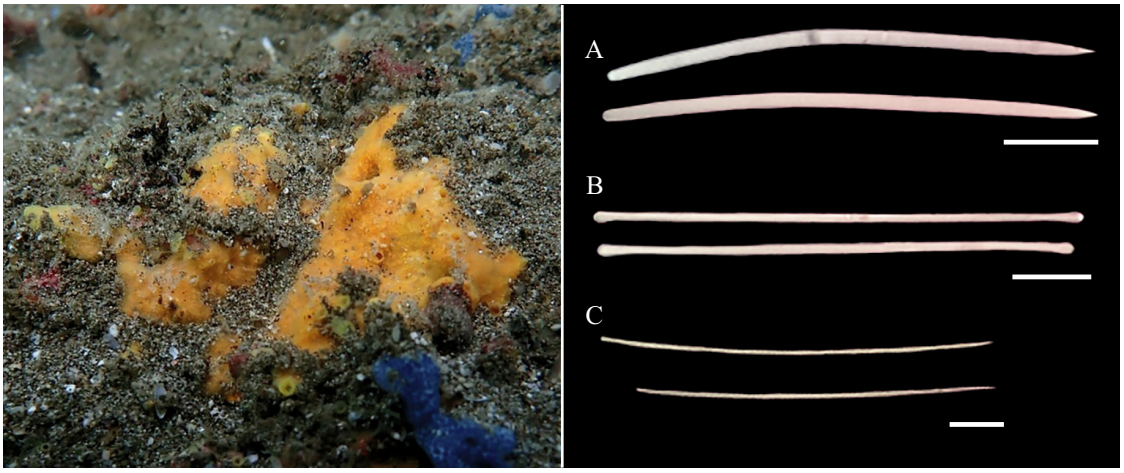

Figure 8. *Tedania* (*Tedania*) *tropicalis* Aguilar-Camacho, Carballo and Cruz-Barraza, 2018. A) Styles. B) Tylotes. C) Onychaeta. Scale bars: A = 50 µm; B = 30 µm; C = 25 µm.

Maldonado, van Soest, Hooper and Wörheide, 2012
Family Aplysinidae Carter, 1875
Genus *Aplysina* Nardo, 1834
Aplysina gerardogreeni Gómez and Bakus, 1992

Locality. Maculís, El Flor.

Description. Massive lobulated sponge with multiple tubular lobules, it can be easily distinguished on each lobule an apical oscular aperture. The surface is smooth to touch but it is also firm. Color in life is bright yellow with some pink or red regions, color changes to dark purple or brown when it gets in contact with the air (Figure 11).

Spatial distribution

A total of ten sponge taxa were recorded, distributed in seven genera, seven families, five orders, three subclasses and two classes. El Flor was the one that presented greatest richness, with seven

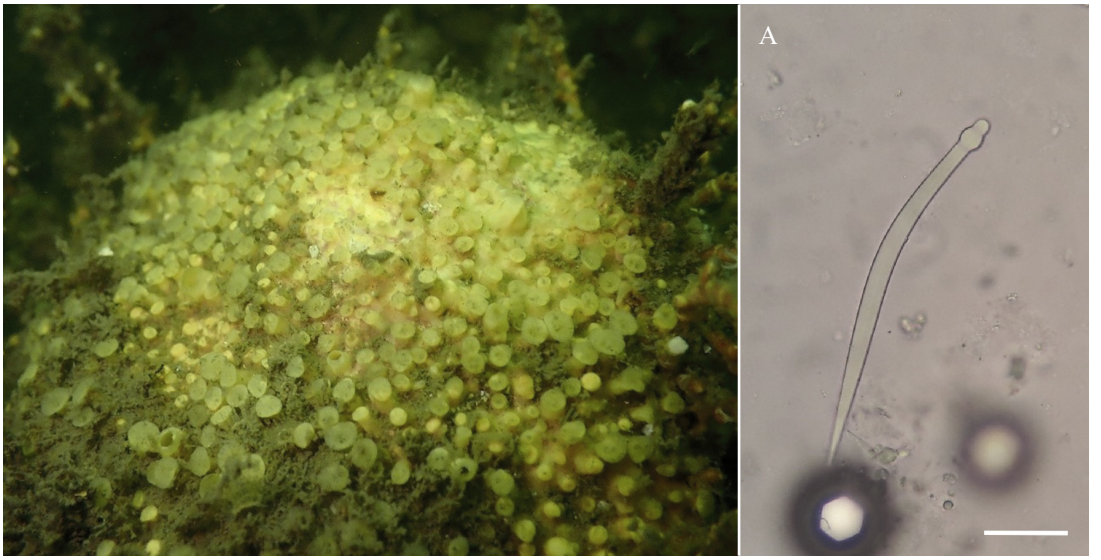

Figure 9. *Cliona californiana* de Laubenfels, 1932. A) Subterminal head tylostyle, scale bar = 50 µm.

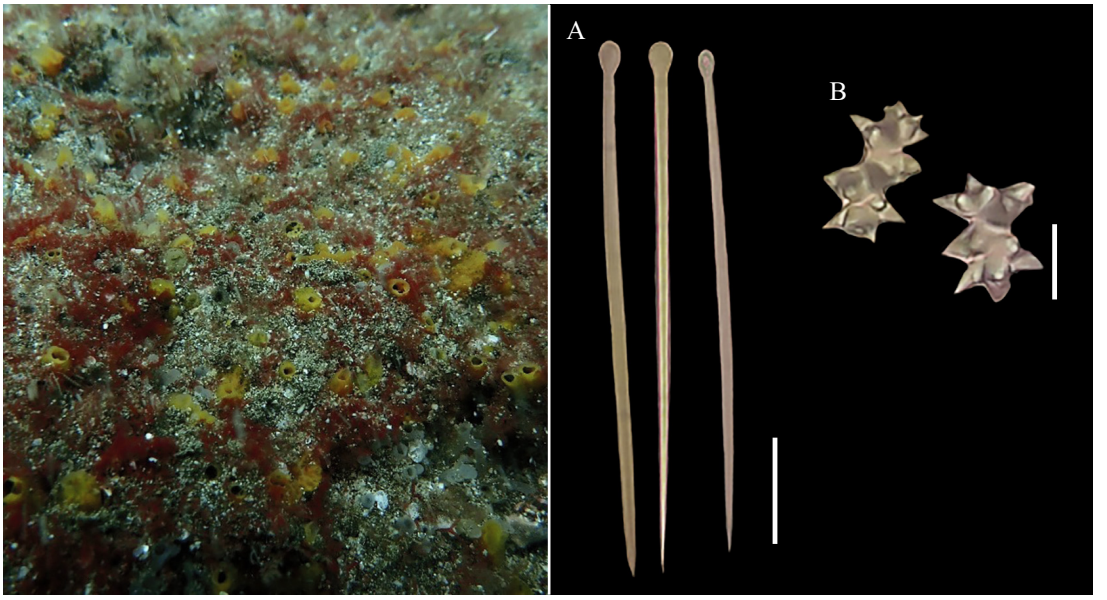

Figure 10. *Cliona euryphylle* Topsent, 1888. A) Tylostyles. B) Spirasters. Scale bars: A = 30 µm; B = 5 µm.

identified species and a frequency of 75 sponges. Maculís presented less richness with five species but similar frequency with 74 sponges. In the case of Las Mueludas, three species were recorded with a frequency of 53 sponges (Figure 12). Two hundred and two records belonging to the Phylum Porifera were obtained, of which those with the highest frequency were *A. nayaritensis*, *M.* (*Carmia*) *cecilia*, *M.* (*Zygomycale*) *ramulosa*, Calcinea and *A. gerardogreeni* (Figure 12).

According to the Multidimensional Scaling (nMDS) analysis, three groups were formed among the ten identified taxa. Group A was made up of five species: *A. nayaritensis*, *A. gerardogreeni*, Calcinea, *E.* (*Endectyon*) *hyle* and *T. tropicalis*. The first three species were all distributed in Maculís and El Flor, whereas the last two were only found in Maculís (Figure 13). Group B was made up of *M.* (*Carmia*) *cecilia*, *M.* (*Zygomycale*) *ramulosa* and *C. californiana*. The first two species were distributed in El Flor and Las Mueludas, being Las Mueludas the place where the highest frequency of these species of the three sampling sites was recorded. This site was the only one where *C. californiana* was present (Figure 13). Group C had the less frequent species (*C. euriphylle* and *Haliclona* spp.) only recorded in Maculís (Figure 13).

Figure 11. *Aplysina gerardogreeni* Gómez and Bakus, 1992.

According to the Cluster Analysis, the sites most similar to each other were El Flor and Maculís. They coincided on the record of five species and on the highest frequency of sponges. Las Mueludas formed a different cluster because it had the lowest richness with three species and the lowest frequency of sponges in the study (Figure 14).

DISCUSSION

The richness of ten species of Punta Amapala reefs was well represented, being similar to that reported in other reef locations in the country, such as Playa El Faro and Las Veraneras in Los Cóbanos.

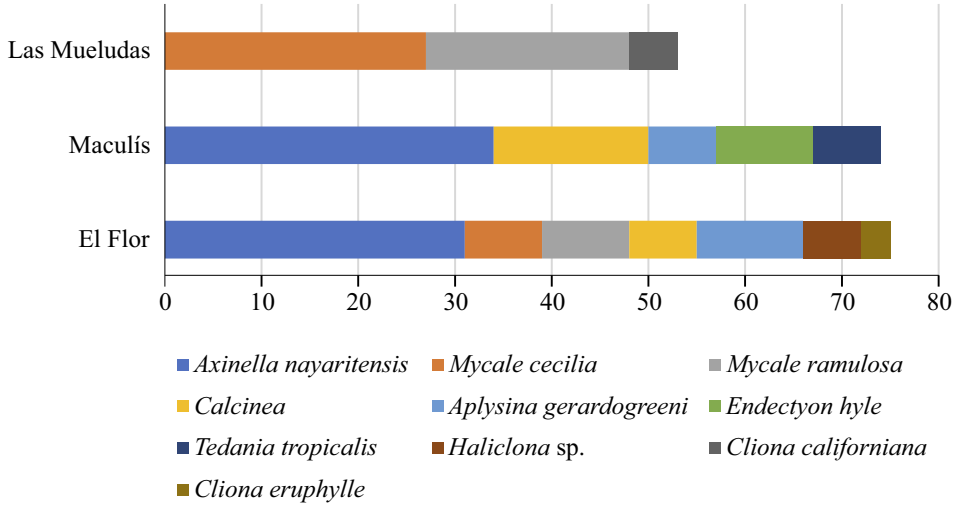

Figure 12. Richness and frequency of sponge species in three rocky reefs (El Flor, Maculís and Las Mueludas) of Punta Amapala, El Salvador.

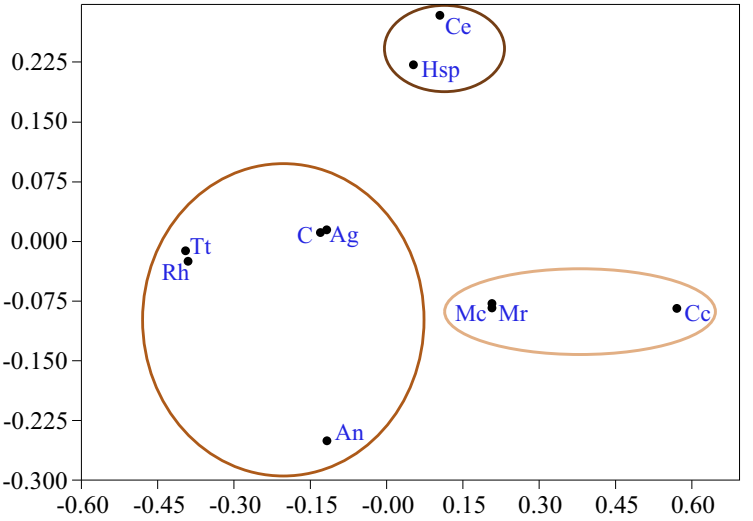

Figure 13. Bray-Curtis dissimilarity analysis of sponges in the three rocky reefs (El Flor, Maculís and Las Mueludas) of Punta Amapala, El Salvador (stress = 0.19). An: *Axinella nayaritensis*, Ag: *Aplysina gerardogreeni*, C: Calcácera, Cc: *Cliona californiana*, Ce: *Cliona euryphylle*, Hsp: *Haliclona* spp., Mc: *Mycale* (*Carmia*) *cecilia*, Mr: *Mycale* (*Zygomycale*) *ramulosa*, Rh: *Endectyon* (*Endectyon*) *hyle*, Tt: *Tedania tropicalis*.

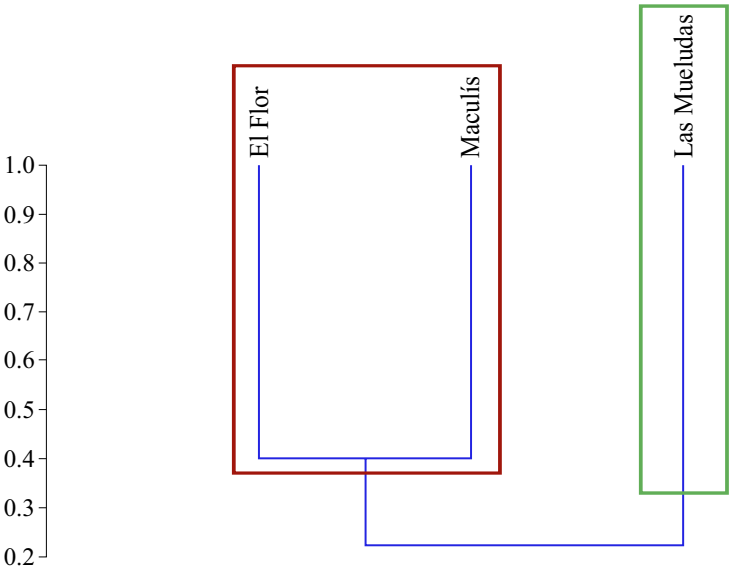

Figure 14. Bray-Curtis dissimilarity analysis between reefs based on the abundance of sponges in three reefs (El Flor, Maculís and Las Mueludas) of Punta Amapala, El Salvador, exposed in a cluster with a correlation coefficient of 0.90.

In this area, Pacheco et al. (2018) recorded eight species of boring sponges in the intertidal zone, while Trejo (2020) recorded 17 taxa belonging to 12 stations from the intertidal zone to reefs 16 m deep. So far, these are the comparable studies and locations in terms of sponge diversity in the country. For the region, Lizarazo et al. (2020) identified 24 morphotypes in the Colombian North Pacific.

Their study was carried out in 14 stations between 11-19 m depth, while Carballo et al. (2019) studied 20 reefs from the Mexican Pacific coast, recording a total of 87 species. Species richness was variable among reefs, with Playa Blanca having the highest richness (28 species) and Roca Partida the lowest (4 species). Both reefs belong to the Revillagigedo archipelago. It is probable that a greater sampling effort in Punta Amapala will generate an increase in the species richness.

Most frequent species were *Axinella nayaritensis*, *Mycale* (*Carmia*) *cecilia* and *M.* (*Zygomycale*) *ramulosa*. They coincided in El Flor, the site with the highest richness recorded in this study. As mentioned by Sara and Vacelet (1973), it is likely that the presence of rocky patches with banks of coarse sand and ground shell increase the complexity of the substrate, providing a greater amount of habitat for sponges and facilitating their settlement. Unlike Las Mueludas, where only boulder-type rocks and a lot of silt-type sedimentation in the water column were observed, these sites provided less stability to the substrate, limiting settlement success to a few species (Wulff 2012).

The nMDS and cluster analysis yield similar results, forming two clusters where El Flor and Maculís coincide in species richness and frequency, while Las Mueludas is characterized by having only three species and lower frequency. Further physicochemical studies will be needed to determine the distribution of sponges, since in this work analyzes were carried out based on the richness and frequency of species as the first characterization of the reefs.

The presence of borer sponges *Cliona californica* and *C. euryphylle* is of great importance since they are considered bioeroding species. It is necessary to pay special attention to this group since the calcareous material available in the reefs studied is provided by calcareous algae given the absence of reef-forming corals. It would be interesting to know the dynamics that borer sponges maintain in non-coral reefs, and how these ecosystems are modified by them. It is necessary to increase studies of diversity and distribution of sponges in the eastern part of the country, considering continental islands within Gulf of Fonseca to cover the majority of possible habitats and have greater certainty of the true richness of the group in the country.

Regarding other groups of invertebrate, Segovia and Trejo (2023) indicated that sponges are the second most important component of the benthos, surpassed only by octocorals, since they manage to cover between 4 and 20% of benthos in Los Cóbanos reefs. According to observations of reefs under study, it seems that this condition is also repeated, so it is necessary to validate this information by conducting community coverage studies on these same reefs.

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Author contributions

Alejandra Trejo: writing-original draft and conceptualization. Johanna Segovia: writing-review and editing, conceptualization.

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