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Marine cyanobacteria of Costa Rica: published records

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ABSTRACT

Introduction: Cyanobacteria, also known as blue-green algae, are photosynthetic bacteria that play a crucial role in the marine environment, including food and oxygen production, nitrogen fixation, yield antibiotics and other bioproducts which might be used by other members of the community. Cyanobacteria remain understudied, particularly in the marine environments of Central America. While research on cyanobacteria has been conducted in Costa Rica, most studies have focused on freshwater environments, leaving a significant gap in understanding their diversity in the region.

Objective: This study compiles the diversity of marine cyanobacteria in Costa Rica through a review of scientific publications and herbarium collections.

Methods: a review of the scientific literature and cyanobacterial specimens from the Pacific and Caribbean from 1936 to the present was conducted. In November 2023, the Dr Luis A. Fournier Origgi Herbarium at the University of Costa Rica was visited to examine the available specimens.

Results: We found 50 records of cyanobacteria in the references and herbarium collections, of which 10 belonged to Sections I and II, 26 to Section III, nine to Section IV and five to the unclassified category. Genomic data from two studies were found in public databases.

Conclusions: The diversity of marine cyanobacteria in Costa Rica represents a valuable resource for ecological and evolutionary studies. This work provides a baseline for future research and highlights the importance of continuing to explore and document the biodiversity of these bacteria.

Key words: marine biodiversity; herbarium; blue-green algae; microalgae; prokaryota.

RESUMEN

Cianobacterias marinas de Costa Rica: registros publicados

Introducción: Las cianobacterias, también conocidas como algas verdeazuladas, son bacterias fotosintéticas que desempeñan un papel crucial en el ambiente marino, incluyendo la producción de alimento y oxígeno, la fijación de nitrógeno, la producción de antibióticos y otros bioproductos los cuales pueden ser utilizados por otros miembros de la comunidad. Las cianobacterias siguen siendo poco estudiadas, sobre todo en los ambientes marinos de América Central. Aunque en Costa Rica se han realizado investigaciones sobre cianobacterias, la mayoría de

los estudios se han centrado en ambientes de agua dulce, lo que deja un vacío importante en la comprensión de su diversidad en la región.
Objetivo: Este estudio recopila la diversidad de cianobacterias marinas en Costa Rica a través de una revisión de publicaciones científicas y colecciones de herbario.
Métodos: Se realizó una revisión de la literatura científica y de especímenes de cianobacterias del Pacífico y el Caribe desde 1936 hasta la actualidad. En noviembre de 2023, se visitó el Herbario Dr. Luis A. Fournier Origgi de la Universidad de Costa Rica para examinar los especímenes disponibles.
Resultados: Se encontraron 50 registros de cianobacterias en las referencias y colecciones del herbario, de los cuales 10 pertenecían a las Secciones I y II, 26 a la Sección III, nueve a la Sección IV y cinco a la categoría no clasificada. Se encontraron datos genómicos de dos estudios en bases de datos públicas.
Conclusiones: La diversidad de cianobacterias marinas en Costa Rica representa un recurso valioso para estudios ecológicos y evolutivos. Este trabajo proporciona una línea base para futuras investigaciones y resalta la importancia de continuar explorando y documentando la biodiversidad de estas bacterias.

Palabras clave: biodiversidad marina; herbario; algas verdeazuladas; microalgas; procariota.

INTRODUCTION

Cyanobacteria, also known as blue-green algae, are a group of photosynthetic bacteria that play an important role in marine environments, as a source of food, oxygen production, nitrogen fixation, antibiotics production, and other bioproducts that are used by other community members (Hoffman, 1999). They are part of complex bacterial communities as biofilms (Zhong et al., 2024) and have been used as model organisms to study interactions with viruses in marine environments (Carlson et al., 2022). The picocyanobacteria *Synechococcus* and *Prochlorococcus* are the most abundant phototrophs in the global oceans, and account for a substantial fraction of marine primary production (Arias-Orozco et al., 2024; Flombaum et al., 2013).

There is a wide morphological, genetic, and functional diversity of marine cyanobacteria that is still poorly explored. They can be classified based on their morphological characteristics, including cell length and cell width of axenic culture. However, morphology does not provide sufficient taxonomic resolution and cyanobacteria with similar or identical morphology may have significantly different physiology (Nübel et al., 1997). Culturing strains is limited to replicating environmental conditions in the laboratory. Genetics and high-throughput sequencing techniques have allowed for more detailed identification of their abundance and taxonomy in marine environments. Currently, there are 431 genera and 1 653 species valid under ICN and ICNP according to the CyanoDB database (http://www.cyanodb.cz/) (Hauer & Komárek, 2022).

Understanding the diversity of marine cyanobacteria is crucial for studying key ecological processes like upwelling and cyanotoxin production, which can have significant economic and health implications (Hallegraeff, 2010). Cyanobacteria have been successful in colonizing harsh environmental conditions such as salty environments and high radiation, using halophily and halotolerance as survival strategies. These characteristics, along with their role in oxygen production and the food chain, their functions in rhodolith beds or corals, and their symbiotic relationships with invertebrates such as sponges and ascidians, are interesting to study from both ecological and evolutionary perspectives (Cavalcanti et al., 2014; Donia et al., 2011; Mutalipassi et al., 2021).

In Central America, marine cyanobacteria have been poorly explored. Most studies of this group in Costa Rica focus on field observations, with few specimens in herbaria. Therefore, the objectives of this work were to compile cyanobacterial diversity in Costa Rican marine environments based on scientific publications and collections in herbaria as a baseline for future research.

MATERIALS AND METHODS

Scientific articles and books from 1936 (the first record) to the present were reviewed, and a list of the genera and in some cases species of cyanobacteria reported from the Costa Rican Pacific and Caribbean Sea was compiled by location. In November 2023, the Dr. Luis A. Fournier Origgi Herbarium (USJ) at Escuela de Biología of the Universidad de Costa Rica was visited to review the cyanobacteria specimens. There are no other herbarium collections of marine cyanobacteria in the country.

The list of cyanobacteria was arranged according to the subdivisions proposed by Rippka et al. (1979), which are based on differences in morphological structure and development, allowing the recognition of five major sections among cyanobacteria (I, II, III, IV, and V). The taxonomic classification at the genus level was based on the system proposed in AlgaeBase (Guiry & Guiry, 2024). For each report, the taxonomic classification at the order, family, and genus levels, the collection site, and the references are provided.

The search for DNA sequences of marine cyanobacteria from Costa Rica was conducted in 2023 and 2024 using the NCBI (The National Center for Biotechnology Information), and ENA (European Nucleotide Archive) databases (Burgin et al., 2023), as well as scientific articles. We focused on nucleotide sequences, genomes, MAGs (Metagenome Assembled Genomes), and bioprojects.

RESULTS

We found 50 records of cyanobacteria in the references and in the herbarium, 10 belong to Sections I and II, 26 in Section III, nine to Section IV and five under unclassified category. A total of 20 species are reported from the Pacific and 33 from the Caribbean with three species/genus in common, *Symploca hydnoides*, *Schizothrix calcicola* and *Spirulina* spp. *Trichodesmium erythraeum*, *Symploca* spp. and *Lyngbya* spp. have the highest number of records, with *Symploca* having the most herbarium accessions.

Unicellular cyanobacteria (Section I and Section II): We found ten species in these sections. Among the unicellular cyanobacteria reported in the literature are the genera *Merismopedia, Anacystis, Synechocystis, Synechococcus,* and *Prochlorococcus* (Table 1). Belonging to Section II, we find *Chamaecalyx* in the Orden Pleurocapsales. Chrococcales has the largest number of reported species, but the genera *Synechococcus* and *Prochlorocococcus* have been reported from a greater number of sites. The reports of these groups were based on culture-independent techniques, while others were based on optical microscopy.

Filamentous cyanobacteria without heterocysts (Section III): This is the group of cyanobacteria with the most reports, there are 22 species in the Caribbean and seven species in the Pacific (Table 2). This reflects the higher sampling effort along the Caribbean coast. Oscillatoriales is the most reported order, followed by Coleofasciculae. These groups are characterized by being filamentous and are often the main phototrophic component of the biofilms. Interestingly, the genus *Spirulina*, which is widely used in the food industry, was reported from both coasts.

Filamentous cyanobacteria with heterocysts and true branching (Section IV): The genera *Isactis, Calothrix, Rivularia, Anabaena, Bachytrichia,* and *Nodularia* were found within the Order Nostocales, each belonging to different families (Table 3). All these genera possess heterocysts, which makes them potential nitrogen fixers. Nitrogen-fixing cyanobacteria play an important role in transforming elemental nitrogen into bioavailable nitrogen, which is of great importance for food chains.

Unclassified cyanobacteria: Investigations carried out in the Pacific using light microscopy or independent culture techniques reported five samples as unclassified cyanobacteria (Table 4).

Table 1
Marine cyanobacteria that belong to the orders Chroococcales, Synechococcales and Pleurocapsales (Sections I and II) and its geographic distribution in Costa Rica.

Order	Family	Genus/species	Biogeographic distribution	References
Chroococcales	Chamaesiphonaceae	*Stichosiphon sansibaricus* (Hieronymus) F. E.Drouet & W.A.Daily, 1956	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
	Chroococcaceae	*Chroococcus* sp. Nägeli, 1849	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
	Cyanothrichaceae	*Johannesbaptistia pellucida* (Dickie) W.R.Taylor & Drouet, 1938	Caribbean: Isla Uvita	Muñoz-Simon (2012), Muñoz-Simon et al. (2020)
	Microcystaceae	*Anacystis* sp. Meneghini, 1837	Pacific: Golfo de Papagayo	Loza-Álvarez et al. (2018)
		Merismopedia glauca (Ehrenberg) Kützing, 1845	Pacific: Bahía Culebra	Cortés et al. (2012), Drouet, (1936)
		Merismopedia elegans A.Braun ex Kützing 1849	Pacific: Gulf of Nicoya	Calvo Vargas et al. (2014)
		Synechocystis sp. Sauvageau, 1892	Caribbean: Isla Uvita	Muñoz-Simon et al. (2020)
Pleurocapsales	Hyellaceae	*Chamaecalyx leibleiniae* (Reinsch) Komárek & Anagnostidis, 1986	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
Synechococcales	Synechococcaceae	*Synechococcus* sp. Nägeli, 1849	Pacific: Costa Rica Thermal Dome	Ahlgren et al. (2014), Cox et al. (2014), Gutiérrez-Rodríguez et al., (2014), Saito et al. (2005)
	Prochlorococcaceae	*Prochlorococcus* sp. Chisholm, Frankel, Goericke, Olson, Palenik, Waterbury, West-Johnsrud & Zettler ex Komárek et al., 2020	Pacific: Isla del Coco National Park; Open ocean, 30 miles from Isla del Coco; and Costa Rica Thermal Dome	Ahlgren et al. (2014), Cortés (2012), Cox et al. (2014), Gutiérrez-Rodríguez et al. (2014), Williamson et al. (2008)

The taxonomic classification is based on Algae Base.

Table 2
Marine cyanobacteria belonging to the orders Oscillatoriales, Leptolyngbyales, Pseudanabaenales, Coleofasciculales, Geitlerinematales, Spirulinales and Gomontiellales (Section III) and its geographic distribution in Costa Rica.

Order	Family	Genus/species	Biogeographic distribution	References
Coleofasciculales	Coleofasciculaceae	*Coleofasciculus chthonoplastes* (Gomont) M.Siegesmund, J.R.Johansen & T.Friedl 2008	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
		Symploca sp. Kützing ex Gomont, 1892	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
		Symploca hydnoides Kützing ex Gomont, 1892	Caribbean: Vicinity of Puerto Limón, Portete, Parque Nacional Cahuita Pacific: Isla Bolaños, Bahía Salinas, Playa Sámara, Cangrejal, Península de Nicoya, Isla del Caño	Dawson (1962); USJ-73046, USJ-73108, USJ-73152, USJ-73305, USJ-73341, USJ-73498, USJ-73528, USJ-73537, USJ-73570, USJ-73686

Order	Family	Genus/species	Biogeographic distribution	References
		Symploca hydnoides var. fasciculata Gomont, 1892	Caribbean: Portete	Dawson (1962)
		Symploca thermalis Gomont, 1892	Pacific: Isla del Caño	USJ-73837
Geitlerinematales	Geitlerinemataceae	*Geitlerinema cf. exile* (Skuja) Anagnostidis, 1989	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
Gomontiellales	Gomontiellaceae	*Borzia* sp. Cohn ex Gomont, 1892	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
Leptolyngbyales	Leptolyngbyaceae	*Leptolyngbya* sp. Anagnostidis & Komárek, 1988, nom. et typ. cons.	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
	Trichocoleusaceae	*Schizothrix* sp. Kützing ex Gomont, 1892	Caribbean: Cahuita National Park	USJ-73851
		Schizothrix calcicola var. symplociformis Hansgirg ex Elenkin, 1949	Caribbean: Vicinity of Puerto Limón Pacific: Playa Manuel Antonio (reported as Playa Manuel Garcia)	Dawson (1962)
Oscillatoriales	Microcoleaceae	*Blennothrix cantharidosma* (Gomont) Anagnostidis & Komárek, 1988 as *Hydrocoleum cantharidosmum*	Pacific: Bahía Culebra	Cortés et al., 2012; Drouet, 1936
		Leibleinia gracilis (Rabenhorst ex Gomont) Anagnostidis & Komárek, 1988	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
		Lyngbya sp. C.Agardh ex Gomont, 1892, nom. et typ. cons.	Caribbean: Isla Uvita	Muñoz-Simon (2012)
		Lyngbya majuscula Harvey ex Gomont, 1892	Caribbean: Vicinity of Puerto Limón	Dawson (1962)
		Lyngbya sordida f. bostrychicola Gomont, 1892	Caribbean: Portete, Vicinity of Puerto Limón	Dawson (1962)
		Lyngbya subconfervoides O.Borge, 1918	Caribbean: Cahuita National Park	Bernecker & Wehrtmann, (2009)
		Microcoleus chthonoplastes Thuret ex Gomont, 1892	Caribbean: Puerto Vargas	Dawson (1962)
		Trichodesmium erythraeum Ehrenberg ex Gomont, 1892	Pacific: Bahía Culebra, Gulf of Nicoya, Caldera	Calvo Vargas et al. (2014), Calvo Vargas et al. (2016), Vargas-Montero (2004), Vargas-Montero & Freer (2004)
	Oscillatoriaceae	*Oscillatoria* sp. Vaucher ex Gomont, 1892	Caribbean: Isla Uvita	Muñoz-Simon (2012), Muñoz-Simon et al. (2020)
		Oscillatoria corallinae Gomont, 1890	Caribbean: Vicinity of Puerto Limón	Dawson (1962)

Order	Family	Genus/species	Biogeographic distribution	References
		Phormidium sp. Kützing ex Gomont, 1892	Caribbean: Isla Uvita	Muñoz-Simon (2012), Muñoz-Simon et al. (2020)
		Phormidium crosbyanum Tilden, 1909	Caribbean: Undefined site	Dawson (1962)
		Phormidium monile Setchell & Gardner, 1930 as *Lyngbya gracilis*	Pacific: Bahía Culebra	Taylor (1945)
Pseudanabaenales	Pseudanabaenaceae	*Pseudanabaena* sp. Lauterborn, 1915	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
Spirulinales	Spirulinaceae	*Spirulina* sp. Turpin ex Gomont, 1892	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo Pacific: Mangrove sediments, Golfo Dulce	Medeanic et al. (2008); Muñoz-Simon (2012)
		Spirulina subsalsa Oersted ex Gomont, 1892	Caribbean: Parque Nacional Cahuita	Hargraves & Víquez (1981)

The taxonomic classification is based on Algae Base. Codes correspond to USJ-Herbaria Collection number, Universidad de Costa Rica.

Table 3
Marine cyanobacteria belonging to the Order Nostocales (Section IV) and its geographic distribution in Costa Rica.

Order	Family	Genus/species	Biogeographic distribution	References
Nostocales	Aphanizomenonaceae	*Anabaena* sp. Bory ex Bornet & Flahault, 1886, nom. cons.	Pacific: Mangrove sediments, Golfo Dulce	Medeanic et al. (2008)
	Nodulariaceae	*Nodularia harveyana* Thuret ex Bornet & Flahault, 1886	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
	Nostocaceae	*Nostoc commune* (Vaucher ex Bornet et Flahault 1888)	Caribbean: Punta Manzanillo	USJ-28295
	Rivulariaceae	*Calothrix* C.Agardh ex Bornet & Flahault, 1886	Caribbean: Piuta, Isla Uvita, Puerto Vargas, Puerto Viejo, Manzanillo	Muñoz-Simon (2012)
		Calothrix crustacea f. simulans F.S.Collins, 1907	Caribbean: Vicinity of Puerto Limón	Dawson (1962)
		Calothrix pilosa Harvey ex Bornet & Flahault, 1886	Caribbean: Vicinity of Puerto Limón	Dawson (1962)
		Isactis plana (Harvey) Thuret ex Bornet & Flahault, 1886	Pacific: Bahía Culebra	Taylor (1945)
		Rivularia sp. C.Agardh ex Bornet & Flahault, 1886, nom. cons.	Pacific: Mangrove sediments, Golfo Dulce	Medeanic et al. (2008)
	Scytonemataceae	*Brachytrichia quoyi* Bornet & Flahault, 1886	Caribbean: Puerto Vargas	Dawson (1962)

The taxonomic classification is based on Algae Base. Codes correspond to USJ-Herbaria Collection number, Universidad de Costa Rica.

Table 4
Unclassified marine cyanobacteria of Costa Rica and its geographic distribution.

Order	Family	Genus/specie	Biogeographic distribution	References
unc. Cyanobacteria	unc. Cyanobacteria	unc. Cyanobacteria	Pacific: Isla del Coco National Park	Fernández (2008)
		unc. Cyanobacteria	Pacific: Área de Conservación Guanacaste	Cortés & Joyce (2020)
		unc. Cyanobacteria	Pacific: Coral reefs and submerged pinnacles around Isla del Caño Biological Reserve; coastal rocky reefs and islets along the Osa Peninsula, including Corcovado National Park	Friedlander et al. (2022)
		unc. Cyanobacteria	Pacific: Golfo Dulce	Steinsdóttir et al. (2022)
		unc. Cyanobacteria	Pacific: In front of Punta Copal, Isla Bolaños, Bahía Salinas, Guanacaste	USJ-73735

The taxonomic classification is based on Algae Base. Codes correspond to USJ-Herbaria Collection number, Universidad de Costa Rica.

Table 5
DNA sequences of cyanobacteria in the NCBI and ENA databases.

Site/Bioproject	Accesion ID	Taxonomic classification	Reference
Costa Rica Dome Upwelling Zone (8 m depth)	EF102542	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102614	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102613	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102612	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102611	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102590	unclassified Cyanobacteria	Zehr et al. (2007)
	EF102573	unclassified Cyanobacteria	Zehr et al. (2007)
Stomach content of the crab *Paralomis* sp.	HE974904	Uncultured Cyanobacterium sp.	Niemann et al. (2013)

We found two studies that focused on cyanobacterial genome analysis (Table 5). Zehr et al. (2007) investigated the genomic diversity of tropical oceanic nitrogen-fixing cyanobacteria in the Dome Upwellling Zone in Pacific Costa Rica, obtaining cultures and amplifying the region encoding the cytochrome C gene using Sanger sequencing. The second study by Niemann et al. (2013) examined the bacterial communities associated with the decapod *Paralomis*.

DISCUSSION

Published reports of cyanobacteria from the Pacific and the Caribbean of Costa Rica do not have photographs, and most of these reports lack data on temperature, salinity, pH, substrate type, or other metadata, which limits our understanding of the ecology of these group. Additionally, these cyanobacteria are not associated with herbarium specimens. There are only 14 cyanobacterial samples in the herbaria collection. The improvement of herbarium records and sample conservation would support the training of future scientists. High-quality collections serve as invaluable resources for teaching taxonomy, systematics, ecology, and fostering the development of new expertise in these fields. Plus, it increases the knowledge of the marine biodiversity of the country.

Due to traditional sampling techniques, where larger micro-organisms are more likely to be studied, unicellular cyanobacteria or pycocyanobacteria are probably among the least studied. The classification of cyanobacteria

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is undergoing rapid change due to advances in 16S rRNA gene and genome sequencing, independent and dependent culture techniques can now be used to characterize them, as well as other groups of cyanobacteria (Chen et al., 2021; Doré et al., 2023). Taxonomic studies must be polyphasic, incorporating morphological data such as cell size and shape, presence or absence of a mucilaginous sheath, and shape of apical cells, among others (Hauer & Komarék, 2022). The integration of genomic data is essential for conclusively defining the taxonomic clades of many cyanobacterial genera. The morphological similarity between some groups, such as the *Leptolyngbya* clade in Section III (Brenes-Guillén et al., 2021; Komarek, 2007), could be studied in marine environments to understand the coexistence of phylogenetic closely and ecologically similar cyanobacterial species.

There are several studies that summarize the cyanobacteria found in the region. Vargas et al. (2023) carried out a review of the diversity in the Caribbean region and reported 76 genera and 119 species of cyanobacteria associated with different environments such as coral reefs, ascidians, mangroves and others. In that study, *Lyngbya confervoides* is the only cyanobacteria mentioned for Costa Rica (based on the report by Bernecker & Wehrtmann, 2009), unlike our research where we report 33 species for the Caribbean. Studies in Honduras and Belize indicate that new genera similar to the genera *Lyngbya* and *Symploca* may be found in marine environments (Engene et al., 2015). In Panama, studies on marine cyanobacteria have focused on the extraction of metabolites to identify novel treatments for neglected parasitic diseases such as malaria. The Panama International Cooperative Biodiversity Group (ICBG) programme has investigated secondary metabolites mainly from *Leptolyngbya, Symploca, Lyngbya* and *Oscillatoria* (Linington et al., 2007; McPhail et al., 2007; Medina et al., 2008; Simmons et al., 2006; Vining et al., 2015). Additionally, Diaz et al. (2007) found *Oscillatoria spongeliae* associated with marine sponges in the Caribbean Sea of Panama.

Some groups of marine cyanobacteria are symbionts of protozoa, macroalgae, seagrasses, sponges, ascidians, and other invertebrates, altering the host's metabolism (Carpenter & Foster, 2003; Konstantinou et al., 2018; Mutalipassi et al., 2021). In addition, they possess cellular and molecular strategies that enable them to withstand nutrient limitation, temperature fluctuations, increased UV radiation, and high salinity (Li et al., 2019; Rastogi et al., 2014; Reignier et al., 2023). These characteristics suggest that these bacteria may have promising biotechnological applications. Current evidence shows the presence of marine cyanobacteria on both coasts of Costa Rica, highlighting their importance, but the morphological and genetic diversity of cyanobacteria in Costa Rican and Central Americans marine environments remains largely unknown. In order to improve our understanding of the taxonomic and functional diversity of cyanobacteria, it is essential to conduct studies focusing on morphological and genetic analysis, either using molecular markers such as 16S gene amplicons or whole genome sequencing. This will provide information on the microscopic characterization of cyanobacteria, their biogeographic distribution, temporal variations in abundance and the genetic reservoir. This publication will serve as a basis and motivation for future research.

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