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NOTES ON GEOGRAPHIC DISTRIBUTION

First record of *Trigonium zonatulatum* (Greville) A. Mann (Bacillariophyta, Trigoniumaceae) from the tropical Atlantic Ocean (Caribbean Sea)

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Abstract. *Trigonium zonatulatum* (Greville) A. Mann, originally described as *Triceratium zonatulatum* Greville, was previously known solely from the Indo-Pacific, Indian Ocean, and Bering Sea. Here, we report the first record of this diatom species from the Atlantic Ocean (Caribbean Sea), based on material collected at Boca Chica Beach, Dominican Republic. A single valve was examined under light microscopy and agrees with Greville's (1865) original and subsequent descriptions of *T. zonatulum*. This record substantially extends the known geographic distribution of this species and provides new evidence of its occurrence in the Caribbean Sea.

Keywords. Benthic diatoms, Boca Chica Beach, Dominican Republic, epiphyte, *Thalassia testudinum*

López-Fuerte FO, Perdomo-Sánchez OP, Siqueiros Beltrones DA, Altamirano-Cerecedo MC (2026) First record of *Trigonium zonatulatum* (Greville) A. Mann (Bacillariophyta, Trigoniumaceae) from the tropical Atlantic Ocean. Check List 22 (5): 925–932. https://doi.org/10.15560/22.5.925

Introduction

The marine diatom *Trigonium zonatulatum* (Greville) A. Mann was originally described by Greville (1865) as *Triceratium zonatulatum* from material collected off the coast of Singapore (tropical Indo-Pacific). It was later transferred to the genus *Trigonium* by Mann (1907) who altered the spelling of the epithet to *zonulatum*. Unlike *Triceratium* Ehrenberg, *Trigonium* Cleve is a relatively small genus, currently comprising 32 accepted species and a few infraspecific taxa, whereas *Triceratium* includes 242 accepted species and exhibits considerably greater nomenclatural complexity, including hundreds of synonymised, unresolved, and unassessed names (Guiry and Guiry 2026). These differences reflect the broader historical circumscription of *Triceratium*, while *Trigonium* remains a comparatively species-scarce genus whose diversity and distribution are still incompletely known.

Trigonium comprises primarily littoral species that inhabit mainly benthic environments. The geographic range of the genus is difficult to determine and may be considered nearly cosmopolitan in some respects, although its species are relatively uncommon in certain regions. Cells are generally solitary and, during the early stages of their life cycle, remain attached to the substrate by a mucilaginous stalk or cushion secreted from a specialised area located at the valve angles (Hendey 1964). Frequently, *Trigonium* species occur as epiphytes on macroalgae where they may reach high abundances, although they may also occur attached to other benthic substrates. Round et al. (1990) described the genus as having a tri- to multiangular cell that is rectangular in girdle view. This diatom forms zigzag chains attached to seaweeds. *Trigonium zonatulatum* cosmopolitan but mainly it is distributed in warm waters.

The most conspicuous feature of *T. zonatulatum* is its cruciform valve, with broadly rounded lobes and valve angles occupied by densely packed areolae, separated from a weakly ornamented central

OPEN ACCESS

Academic editor: Thaís Garcia da Silva
Received: 10 July 2026
Accepted: 4 October 2026
Published: 8 October 2026

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region by transverse hyaline bands (Greville 1865). All these are traits discernible under light microscopy. Since its original description this taxon has been reported only sporadically from several localities in the Indo-Pacific and Indian Ocean regions, and the Bering Sea in the North Pacific (Mann 1907) (Figure 1). Previous records of *T. zonatulatum* provide very limited ecological information. Greville (1865) found specimens in shell scrapings, suggesting an association with hard benthic substrates or epibiotic communities, although no detailed ecological data were provided. Approximately four decades later, Mann (1907) reported the species as exceedingly abundant in a single hydrographic sounding from station 4029H in the Bering Sea, recovered from a bottom of gray sand and clay at ca. 1,670 m deep, but without identifying either its living substrate or habitat.

The aim of this study is to document the occurrence of *T. zonatulatum* in the Atlantic Ocean (Caribbean Sea). A single specimen was retrieved from epiphytic material scraped off *Thalassia testudinum* Banks & Sol. ex K.D. Koenig blades collected at Boca Chica Beach, from which the first systematic checklist of marine benthic diatoms was recently compiled (López-Fuerte unpubl.). Although the checklist comprises 360 taxa, it did not include *T. zonatulatum*. Morphological observations and ecological information based on a single collected specimen are here provided. We compared valve morphology with representative previous descriptions and discussed the biogeographic significance of our finding.

Study area

Boca Chica Beach is located on the southeastern coast of the Dominican Republic (18.4427, −069.6143; Figure 1). The beach is protected by a continuous coral reef with an average depth of 2 m and a width of approximately 400 m from the shoreline to the reef crest. Patches of *Thalassia testudinum* occur in shallow waters in front of the beach and around adjacent islets. Sea surface temperature ranges from 26.44 to 30.66 °C and is largely influenced by local currents (Vargas 2021).

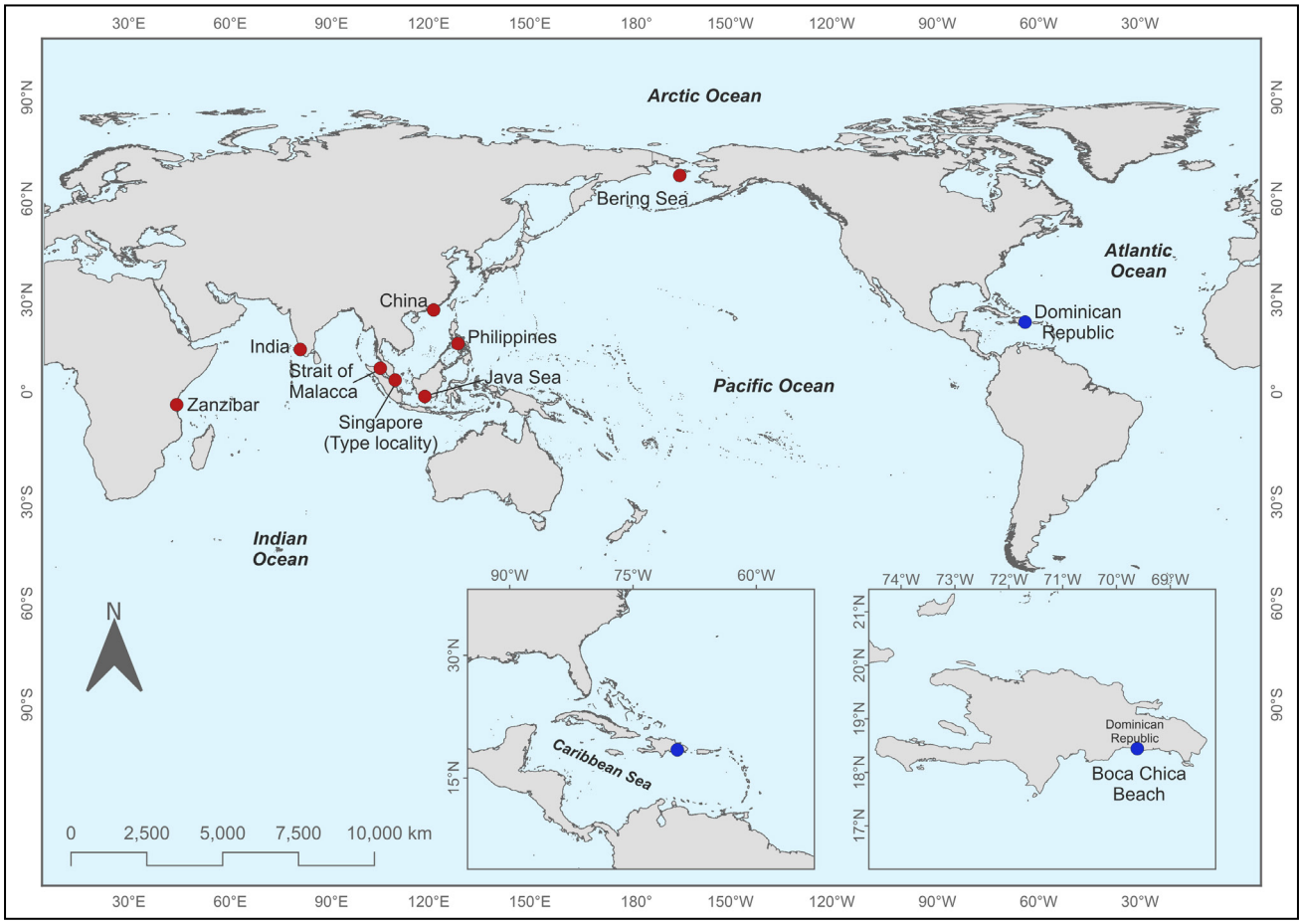

Figure 1. Geographic distribution of *Trigonium zonatulatum* showing the type locality, historical and recent records from the Indo-Pacific region (red circles), and the first record for the Atlantic Ocean (blue circles). Insets show the location of the new record in the Caribbean Sea, of Boca Chica Beach, Dominican Republic.

Methods

The specimen of *Trigonium zonatulatum* was collected off Boca Chica Beach (Figure 1) during a survey conducted on 3 December 2025. Epiphytic material was scraped from 15 leaves of *T. testudinum* collected from several shoots using a glass slide. The scraped material was transferred to a 250 mL flask and stored under refrigeration until further processing. To clean the diatom frustules, the sample was oxidised by adding 5 mL of nitric acid and 3 mL of commercial ethanol (70%) to 3 mL of sample (Siqueiros Beltrones and Voltolina 2000), followed by heating the mixture to boiling, using a burner. The reaction was maintained until gas evolution ceased, indicating the completion of oxidation (ca. 5 min). The oxidised sample was rinsed repeatedly with deionised water until a circumneutral pH was reached. Clean aliquots were mounted on five permanent slides using Zyrax (RI = 1.7). The permanent slides were examined under a Zeiss® Axio Lab A1 (Zeiss, Germany) compound microscope equipped with phase-contrast optics and a Canon EOS 5D Mark II camera (Canon, Japan). Identification was based on the original description (Greville 1865), subsequent taxonomic treatments of the genus (Hendey 1964) and species (Mann 1907; Desikachary 1988). Slides were housed in the diatom collection of the Universidad Autónoma de Baja California Sur, Mexico (DIATOMARIO-UABCS).

In the field, sea-surface temperature and salinity were measured in situ using a field multi-sensor (BLE-C600 multiparameter device). The map of the study area was prepared using QGIS v. 4.2.3 (QGIS Development Team 2026).

Results

Bacillariophyta
Thalassiosirophyceae
Trigoniumales
Trigoniumaceae

***Trigonium zonatulatum* (Greville) A. Mann**
Figure 2

≡ *Triceratium zonatulatum* Greville 1865, Transactions of the Microscopical Society, New Series, London 13: 102; pl. IX [9]: fig. 17 [*non Triceratium zonatum* Greville 1864: 84, pl. 10: fig. 3].

≡ *Amphitetras zonatulata* (Greville) De Toni 1894, Sylloge algarum omnium hucusque cognitarum 2 (3): 900.

New record. DOMINICAN REPUBLIC — Santo Domingo • Boca Chica Beach, Boca Chica municipality, 18.4427, −069.6143; 0 m alt.; 03.XII.2025; Francisco Omar López Fuerte leg.; 1 spec.; epiphytic material scraped from 15 leaves of *Thalassia testudinum* of several shoots using a glass slide; DIATOMARIO-UABCS RDTT-I.

Identification. The valves are cruciform, with broadly rounded lobes bearing densely arranged areolae in longitudinal to slightly subradial rows; areola density gradually decreases toward the central region (Figure 2). Length between apices: 38 µm (n = 1), areolae in 10 µm: 11. The central valve surface bears a faint, circular area surrounded by fine, scattered puncta (Figure 2C, long arrow; Figure 2D, short arrows), whereas the angular areolae are separated from the central puncta by a weakly ornamented transverse hyaline band (Figure 2C, asterisks).

Remark. Sea-surface temperature at the sampling sites ranged from 27 to 28.5°C. Salinity was 40.

Discussion

Diatom taxonomy has experienced extreme changes concerning the classification of many taxa. This is understandable given the morphological criteria used to discriminate them, that has evolved based on scanning electron microscopy (SEM). It has helped to interpret and understand many structures of the diatom frustule. The pace for this evolution has allowed the reassignment of multiple taxa into new genera and higher categories injecting precision into the formal classification of the Bacillariophyta. Nonetheless, confusion persist when morphological alike taxa occur which are very distant taxonomically as in the case of *Trigonium* and *Triceratium* which are classified in different classes (Round et al. 1990). Although experienced formal taxonomist may be aware of these difficulties, they may still encounter considerable challenges in distinguishing morphologically similar taxa.

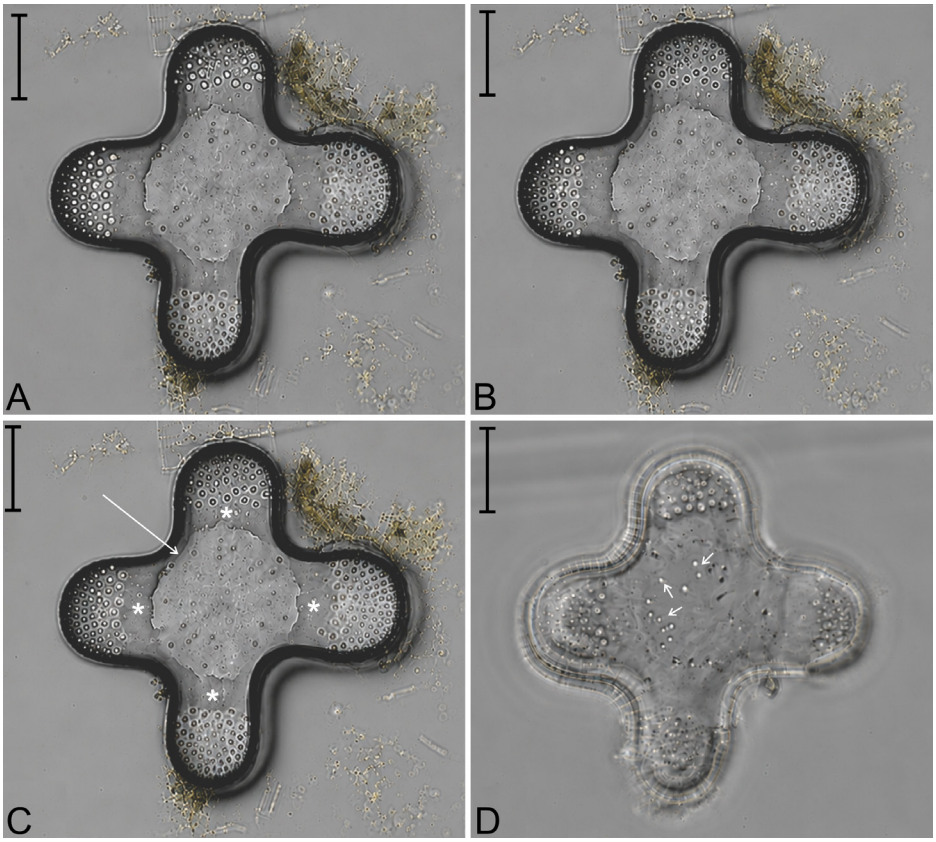

Figure 2. *Trigonium zonatulatum* (Greville) A. Mann: Light microscope images of the same specimen at different focal planes showing the external structure of the valve. **C.** Asterisks show a transverse hyaline band. **C, D.** Long and short arrows show a circular area surrounded by fine, scattered puncta. Scale bars: 10 µm.

Morphologically, the distinction between *Triceratium* Ehrenberg and *Trigonium* Cleve is based primarily on differences in valve architecture rather than merely on the presence of angular outlines. *Triceratium* was characterised by predominantly triangular valves, with three principal angles and, in many species, prominent angular processes or horns. In contrast, *Trigonium* is characterised by a multiangular or cruciform valve outline, commonly with rounded lobes or angles. Greville (1865) described the basionym *Triceratium zonatulatum* as having a triangular to angular outline, rounded angles, and radiating areolae, whereas Mann (1907), after transferring the species to *Trigonium*, emphasised its cruciform, polygonal outline and rounded lobes, noting the complete absence of the characteristic *Biddulphia* (or "*Amphitetras*") processes at the angles. Gao (2003) likewise illustrated the species as cruciform and polygonal, with radially arranged areolae and a distinctive hyaline central region (Table 1). Thus, although the general angular appearance of some *Triceratium* and *Trigonium* species may overlap under light microscopy, the combination of a cruciform, 4-lobed valve, broadly rounded lobes, absence of horns or spines, radiating to subradial areolation, and transverse hyaline bands delimiting the central region supports the placement of the present specimen in *Trigonium*.

Table 1. Comparison of the morphological characteristics of *Trigonium zonatulatum* reported in previous taxonomic treatments and those observed in the present study. ND = not determined.

Character	**Greville (1865: 102), as *Triceratium zonatulatum***	**Mann (1907: 296), as *Trigonium zonulatum***	**Guo (2003: 428), as *Triceratium zonulatium***	**Present study, *Trigonium zonatulatum***
Valve outline	Cruciform to triangular	Cruciform, polygonal	Cruciform	Cruciform
Valve symmetry	Triangular radial symmetry	Radially symmetrical	Radially symmetrical	Radially symmetrical
Valve angles	Rounded	Rounded	Rounded	Rounded
Valve dimensions (µm)	30.5 µm (maximum distance between opposite angles)	≈20 µm	28.5 µm	38 µm (*n* =1)
Valve ornamentation: spines or horns	Not reported	Absent	Absent	Absent
Central area	Hyaline transverse bands delimiting a weakly ornamented central region	Distinctive hyaline bands	Hyaline central region	Transverse hyaline bands clearly delimiting the central area
Areolae	Regularly arranged	Radially arranged	Radially arranged	Areolae densely arranged in longitudinal to slightly subradial rows on the four lobes, becoming progressively less dense toward the central region

At present, no published SEM images of *Trigonium zonatulatum* have been located in the taxonomic literature reviewed. Within the genus *Trigonium*, *T. arcticum* represents one of the species for which comparatively extensive ultrastructural information is available. However, even when numerous SEM images are available, a direct ultrastructural comparison does not necessarily guarantee an unequivocal species identification. For example, An et al. (2026) provided SEM observations of a *Trigonium* taxon that was provisionally assigned to *Trigonium* cf. *curvatus*. This taxon was originally described from Prydz Bay, Antarctica (Nair et al. 2015), and the specimens examined by An et al. (2026) closely corresponded to the original description in valve outline, the structure of the loculate areolae, and the presence of a central cluster of rimoportulae. Nevertheless, its identification remained provisional because of the morphological variability and taxonomic complexity within the group. More broadly, taxonomic delimitation within biddulphioid diatoms, including *Trigonium*, has historically been challenging because closely related taxa may exhibit overlapping morphological features and may consequently be confused or misidentified (Gibson and Mahoney 1984).

This example illustrates that SEM provides valuable information on ultrastructural characters, but the availability of SEM images alone does not necessarily resolve species-level identification in *Trigonium*. Rather, species delimitation requires the evaluation of multiple, relatively stable morphological characters in combination with comparative material from different populations. In the case of *T. zonatulatum*, the absence of published SEM observations should therefore be considered a limitation of the available ultrastructural information rather than, by itself, evidence against its identification. The distinctive cruciform valve outline, four broadly rounded lobes, densely arranged areolae at the valve angles, and transverse hyaline bands delimiting the central region provide a consistent set of characters supporting the identification of the present material under light microscopy. However, SEM observations of additional specimens would be valuable for assessing the ultrastructure of the areolae, girdle bands, and other diagnostic features.

When working floristics pursuing ecological or biogeographical purposes it becomes surprising that apparently very similar specimens are members of separate taxa. Dealing with several hundreds of species we rely mostly or exclusively on light microscopy and are compelled to consult the great late taxonomers successfully identifying the specimens. However, this type of difficulty arises which is part of the same taxonomy dynamics requiring evidence that we are dealing with the referred taxon. In this case, the occurrence of *Trigonium zonatulatum* on *Thalassia testudinum* is consistent with Hendey's (1964) interpretation of *Trigonium* as a predominantly littoral and benthic genus whose species frequently occur attached to macroalgae and other submerged substrates. However, our single specimen may well be an incidental occurrence, trapped among the epiphytic material on *T. testudinum* blades. These taxa occur occasionally in plankton samples as tychoplankton because of resuspension processes driven by wave action, currents, or storms (Round et al. 1990). As with many other marine benthic diatoms, this taxon may also be dispersed through multiple natural pathways, for example, ocean currents, rafting on floating substrates, and also anthropogenic pathways, such as ship-hull fouling or ballast water (Cermeño and Falkowski 2009).

Although only a single individual was observed, its distinctive morphology and well-preserved condition provide evidence supporting the occurrence of *T. zonatulatum* in the study area. The observed combination of morphological characters is consistent with the historical treatments of the species and supports its identification under light microscopy.

Nomenclatural note. The basionym, *Triceratium zonatulatum* Greville, was originally published in 1865. De Toni (1894) retained the original spelling of the epithet in *Amphitetras zonatulata* (Greville) De Toni. When transferring the species to *Trigonium*, Mann (1907) cited Greville's name as the basionym but altered the spelling of the epithet to *zonulatum*. Because a new combination takes its final epithet from the basionym (Art. 6.10), and the original spelling of an epithet is to be retained except where correction is required under the ICN (Art. 60.1), the epithet *zonulatum* is treated as an orthographical variant of *zonatulatum* (Arts. 61.2, 61.4) (Turland et al. 2025). Therefore, the correct citation is *Trigonium zonatulatum* (Greville) A. Mann.

Distribution. The record of *Trigonium zonatulatum* in the Dominican Republic considerably expands the known geographic distribution of the species. Since its original description from Singapore by Greville (1865). *Trigonium zonatulatum* has been reported sporadically from the Indo-Pacific and Indian Ocean regions, including the Java Sea, Strait of Malacca, Bay of Bengal, India, Zanzibar, China, and the Philippines, as well as from the Bering Sea in the North Pacific (Greville 1865; Mann 1907; Liu 2008; Martinez-Goss 2021). Sampling zones in Desikachary (1988) indicate a conspicuous presence of this taxon in Indian Ocean region. The present finding extends the known range of the species to

the western Atlantic and constitutes the first record of the species for the Atlantic Ocean, the Caribbean Sea, and the Dominican Republic (Figure 1). The disjunct distribution of *T. zonatulatum* between the Indo-Pacific and the western Atlantic may reflect a combination of long-distance dispersal and historical undersampling. Marine diatoms are known to possess considerable dispersal potential, although their documented distributions are also influenced by ecological filters, evolutionary history, and sampling effort (Finlay 2002; Vanormelingen et al. 2008; Cermeño and Falkowski 2009; Mann and Vanormelingen 2013). The present finding appears to be more related to lack of sampling in the region than to a recent expansion of the species' distribution into the Caribbean Sea. Regardless of the mechanisms responsible for its occurrence in the Caribbean Sea, the present record substantially expands the known distribution of this uncommon marine diatom and highlights the importance of regional floristic studies for improving our understanding of benthic diatom diversity and biogeography.

To fill knowledge gaps regarding diatom diversity in the region, more intensive sampling is required, including both explored and unexplored sites, various substrate types colonised by benthic diatoms, and potential temporal variations in species composition resulting from seasonality. Additional surveys of tropical and subtropical Atlantic coastal habitats, particularly epiphytic communities associated with seagrass and other benthic substrates are needed to clarify the distribution of the species within this ocean basin (Hein et al. 2008; López-Fuerte et al. 2013, 2019, 2022; López-Mejía et al. 2021; Siqueiros Beltrones et al. 2024, 2025).

Because our results were based on a single specimen and a single sampling event at a single locality, the ecological association reported here should be considered preliminary. Additional surveys across multiple localities and seasons are needed to assess the frequency of occurrence, habitat preferences, and geographic distribution of *T. zonatulatum* in the region. However, the present study provides the first documented record of *T. zonatulatum* for the Atlantic Ocean, Caribbean Sea, and Dominican Republic, substantially extending its known distribution, and its occurrence as an epiphyte on *T. testudinum*, representing one of the few published records documenting its habitat and the first published evidence of its association with seagrass leaves.

Future studies incorporating SEM observations and molecular data would be valuable for completing the morphological and taxonomic characterization of *T. zonatulatum*, particularly by documenting ultrastructural characters and evaluating its taxonomic placement and intraspecific morphological variation. These approaches are not required to support the present identification, which is based on distinctive valvar features observed under light microscopy and their agreement with the original description and previous taxonomic treatments, but would provide complementary evidence for a more comprehensive characterization of the taxon and its biogeographical distribution.

Acknowledgements

We thank the Ministry of the Environment and Natural Resources of the Dominican Republic for issuing permit VAPB-14274 for sample collection, and the Escuela de Biología of the Facultad de Ciencias of the Universidad Autónoma de Santo Domingo for providing access to their laboratory. Observations to the former manuscript by two anonymous reviewers are greatly acknowledged. FOLF. appreciates the support of the SNII-SECIHTI programs. DASB is COFAA and EDI fellow at Instituto Politécnico Nacional.

Additional information

Conflict of interest

The authors declare that no competing interests exist.

Ethical statement

No ethical statement is reported.

Use of artificial intelligence (AI)

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI. Regarding the use of AI in the preparation of this manuscript, the authors declare the following: Figure 2 edited with AI.

Funding

This study was financially supported by Asociación Cibao de Ahorros y Préstamos.

Author contributions

Conceptualisation: FOLF, OPPS. Data curation: FOLF, MCAC. Formal analysis: FOLF, OPPS, DASB. Fund-

ing acquisition: OPPS. Investigation: FOLF, OPPS, MCAC. Methodology: FOLF, OPPS, MCAC. Resources: OPPS. Supervision: DASB. Visualisation: FOLF. Project administration: OPPS. Software: FOLF. Validation: DASB. Writing – original draft: FOLF, OPPS, DASB. Writing – review and editing: FOLF, OPPS, DASB, MCAC.

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Data availability
All data supporting the findings of this study are available within the manuscript.

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