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Biology-Botany

Planktonic Dinoflagellates in a tropical anthropic estuary in Northeastern Brazil

Dinoflagelados planctônicos em um estuário antropizado tropical no Nordeste do Brasil

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ABSTRACT

Dinoflagellates are unicellular organisms, an important component of phytoplankton, with great representation in tropical aquatic ecosystems. The aim of this study was to identify planktonic dinoflagellates and their distribution in the estuary of the Paraguaçu River, state of Bahia, in a region influenced by the Pedra do Cavalo dam. Sampling was carried out bimonthly from March 2018 to March 2019 at twelve stations along the estuary. Plankton was sampled with a 20 µm mesh net and preserved with formaldehyde at a final concentration of 4%. We identified 21 species of dinoflagellates. The highest species richness was observed in the genera *Protoperidinium* (six spp.), *Prorocentrum* (four spp.), and *Tripos* (three spp.). Based on the literature, among the identified species, 11 are potentially harmful: *Dinophysis acuminata*, *D. caudata*, *Gonyaulax polygramma*, *G. spinifera*, *Prorocentrum gracile*, *P. mexicanum*, *P. micans*, *Protoperidinium brevipes*, *P. pellucidum*, *Scrippsiella* cf. *Acuminata,* and *Tripos hircus*. *Glochidinium penardiforme* was recorded for the first time in northeastern coastal waters.

Keywords: Dinophyta; Dinophyceae; Miozoa; Morphology; Scanning electron microscopy

RESUMO

Dinoflagelados são organismos unicelulares, importante componente do fitoplâncton, com grande representatividade em ecossistemas aquáticos tropicais. O objetivo deste estudo foi identificar os dinoflagelados planctônicos e sua distribuição no estuário do Rio Paraguaçu, estado da Bahia, em uma região influenciada pela barragem Pedra do Cavalo. As amostragens foram realizadas bimestralmente de março de 2018 a março de 2019 em doze estações ao longo do estuário. O plâncton foi amostrado com uma rede de malha de 20 µm, e preservado com formaldeído a concentração final de 4%. Foram identificadas 21 espécies de dinoflagelados. A maior riqueza de espécies foi observada nos gêneros

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Protoperidinium (seis spp.), *Prorocentrum* (quatro spp.) e *Tripos* (três spp.). Com base na literatura, dentre as espécies identificadas, 11 são potencialmente nocivas: *Dinophysis acuminata*, *D. caudata*, *Gonyaulax polygramma*, *G. spinifera*, *Prorocentrum gracile*, *P. mexicanum*, *P. micans*, *Protoperidinium brevipes*, *P. pellucidum*, *Scrippsiella* cf. *acuminata* e *Tripos hircus*. *Glochidinium penardiforme* foi registrado pela primeira vez nas águas costeiras do Nordeste.

Palavras-chave: Dinophyta; Dinophyceae; Miozoa; Morfologia; Microscopia eletrônica de varredura

1 INTRODUCTION

Dinoflagellates are unicellular organisms with around 3639 identified species, of which approximately 2500 are currently extant (Guiry & Guiry, 2024). They are an important component of phytoplankton in marine, brackish, and freshwater environments and are widely distributed in tropical waters (Gómez, 2012). After diatoms, they are the second most representative group within the phytoplankton community in tropical and subtropical coastal zones (Falkowski et al., 2004; Islabão & Odebrecht, 2011).

Pioneering studies on the phytoplankton community in Brazil, which includes dinoflagellates, presented a descriptive and taxonomic approach to the organisms. Later studies focused on ecological aspects, mainly related to impacted and pristine environments (Brandini et al., 1997). The Flora e Funga do Brasil database (Flora e Funga do Brasil, 2025) contains the diversity and distribution of several plant taxa and microalgae, comprising 435 dinoflagellate species recorded in Brazil.

Studies addressing the taxonomic aspects of dinoflagellates have been conducted along the Brazilian coast, mainly in the southern and southeastern regions (*eg* Kutner & Sassi, 1979; Sevrin-Reyssac, 1981; Kremer & Rosa, 1983; Cardoso et al., 1994; Haraguchi & Odebrecht, 2010; Islabão & Odebrecht, 2011). In addition to the studies aimed at identification using morphological and molecular tools, the ecology of potentially toxin-producing benthic dinoflagellates has also been studied (Nascimento et al., 2012; Nascimento et al., 2015; Nascimento et al., 2016). Several studies have been conducted in the Northeastern region (*i.e.* Passavante, 1979; Passavante et al., 1982; Lavôr-Fernandes,

1988; Koening & Lira, 2005; Tenenbaum, 2006; Gama et al., 2011; Cavalcante et al., 2018, Affe et al., 2019; Nunes et al., 2019; Nunes et al., 2022; Nunes et al., 2023; Noga et al., 2025).

In addition to studies that combined morphological and molecular tools for the identification of epibenthic dinoflagellates (Mendes et al., 2017; Mendes et al., 2019), further research has expanded our understanding of dinoflagellate biodiversity in the region. Most studies on dinoflagellates in the Northeast region focus on the states of Pernambuco and Bahia.

Most studies on dinoflagellates in the northeast region focus on in the states of Pernambuco and Bahia. However, despite the importance of dinoflagellates, knowledge about the species distribution and occurrence and their ecological aspects still need to be improved.

The Paraguaçu River, the main tributary of Todos os Santos Bay, is dammed by the installation of the Pedra do Cavalo Dam, changing the river's hydrological regime and affecting the economic activities of riverside populations directly or indirectly. In addition, it has potential environmental impacts that affect the planktonic community and may favor the development of harmful dinoflagellate species that are still unknown.

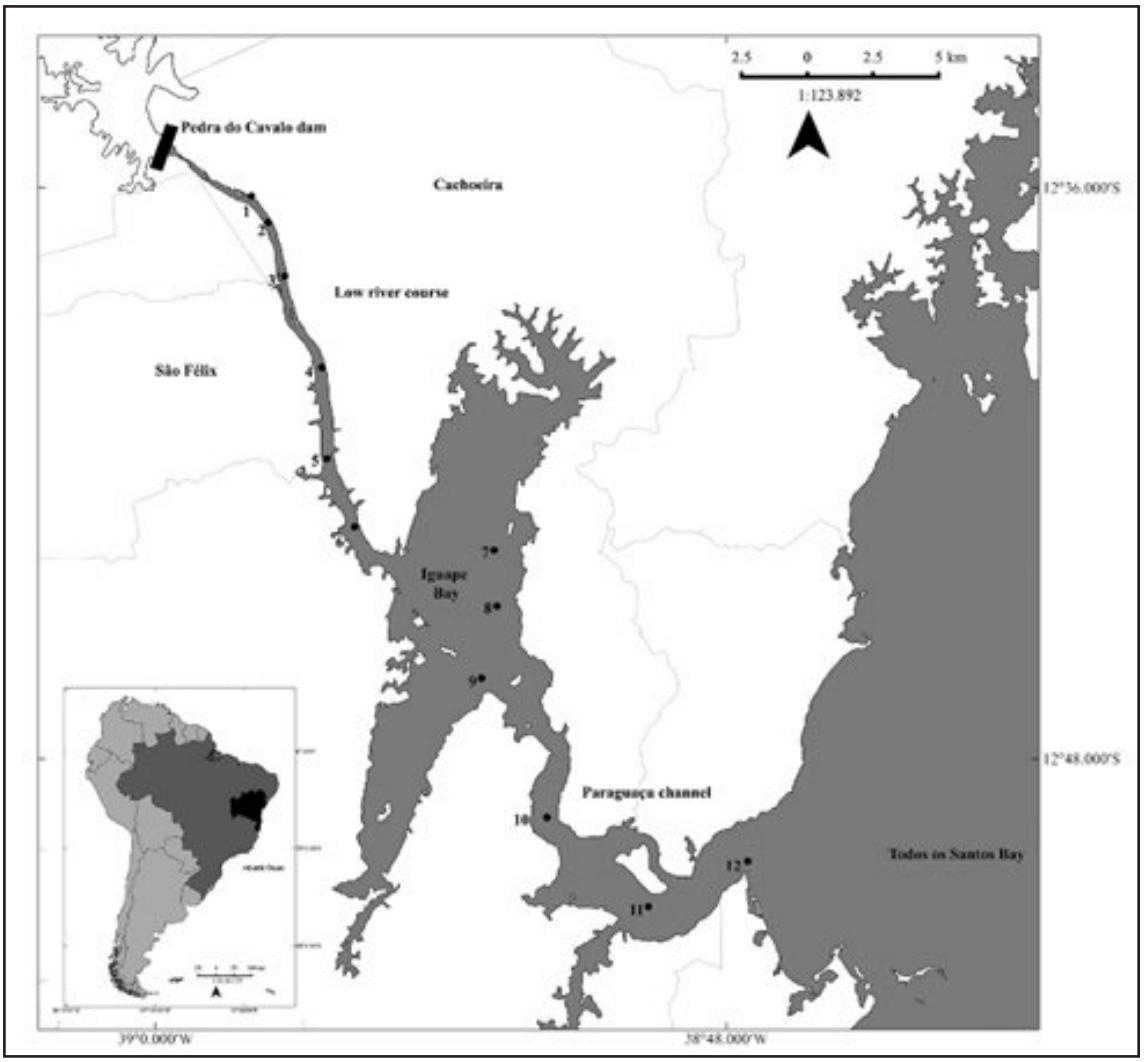
Considering the ecological importance of dinoflagellates in the Paraguaçu River, and given the lack of information regarding the composition of dinoflagellate assemblages along the estuarine gradiente,especially in terms of the potential effects of the Pedra do Cavalo dam, the aim of the present study was to identify dinoflagellates along the estuarine gradient of the Paraguaçu River and discuss aspects of their distribution.

2 MATERIAL AND METHODS

The estuarine system of the Paraguaçu River (12°00'S and 13°00'S and 38°30'W and 39°30'W), extends from the municipality of Cachoeira to the Baía de Todos os Santos (BTS), an area of about 80 km^2 and 127.9 km^2 (Genz et al., 2008). The climate in the region is hot and humid, with an average annual temperature of 24°C, with a range of 5°C, with a minimum monthly average temperature of 21°C and a maximum of 26°C (Cirano & Lessa, 2007).

The estuary of the Paraguaçu River is divided into three segments: (1) the lower course, with a length of 16 km, starts downstream from the Pedra do Cavalo dam until it flows into the Iguape Bay; (2) Iguape Bay, which occupies a total area of 76.1 km², also with a length of 16 km. with a depth between 5 to 10m and large areas of mangroves, where the Marine Extractive Reserve of Baía do Iguape is located, whose main economic activities are fishing and shellfishing, and, more recently, fish farming has been developed by extractivists Unidades de Conservação no Brasil (2021); and (3) Paraguaçu channel, with an extension of 18 km, which establishes the connection between Iguape Bay and BTS (Genz et al., 2008).

Figure 1 – Paraguaçu River estuary with the sampling stations in the Low river course (points 1–6), Iguape bay (points 7–9), and Paraguaçu channel (points 10–12)



Source: Nunes et al. (2022)

Bimonthly collections were conducted from March 2018 to March 2019 along the estuary of the Paraguaçu River at 12 points (figure 1): (1) points 1–6 in the low river course, (2) points 7–9 in Iguape Bay, and (3) points 10–12 in the Paraguaçu Channel, according to the division of the estuary proposed by Genz et al. (2008)

For species identification, water samples were collected in horizontal subsurface trawls using a plankton net (20 µm mesh size) for 5 min at each sampling station and stored in 250 mL bottles. All samples were stored in polyethylene flasks and fixed with formaldehyde at a final concentration of 4%.

Taxonomic identification was performed using light microscopy (LM) and scanning electron microscopy (SEM). For LM analysis, fast slides were mounted and observed under an optical microscope (Olympus Trinocular CX31RTS5). Microphotographs were captured using an image capture program (QCapture Pro) and a digital camera (QImaging GO-3) attached to the microscope.

For SEM analyses, dinoflagellate cells were isolated by capillarity, fixed on round coverslips containing poly-L-lysine, and then dehydrated in an ethanol series (30%, 50%, 70%, 90%, and 100%) for 10 min at each concentration, with three baths in ethanol at a concentration of 100%. The samples were then critical-point-dried using a Leica EM CPD030, and the slides were fixed on stubs. The material was ion-sputtered with gold using a Desk IV sputter coater (Denton Vacuum IV) and analyzed using a JEOL JSM 6390LV scanning electron microscope.

The total length (TL), total width (TW), cell length (CL), cell width (CW), epitheca length (EL), hypotheca length (HL), left antiapical horn (LAH), right antiapical horn (RAH), distance between ribs 1 and 2 (R1-R2), and distance between ribs 2 and 3 (R2-R3), as abbreviated by Nunes et al. (2019), were taken for morphometric analysis.

Identification was based on a specialized bibliography (*e.g.* Dodge, 1975; Balech, 1988; Steidinger & Tangen, 1997) and recent reviews of each species. The classification system adopted for families and genera followed that adopted in Guiry & Guiry (2025). Taxa were arranged in alphabetical order by family. The distribution of taxa in Brazilian

states was based on the Brazilian Flora database Flora e Funga do Brasil (2025), which was updated with references cited in the text. Samples were deposited in the Herbarium Alexandre Leal Costa (ALCB) at the Federal University of Bahia, Salvador, Brazil.

3 RESULTS

In total, 21 species distributed across 9 families and 11 genera were identified: *Protoperidinium* (six species), *Tripos* (three species), *Prorocentrum* (four species), *Gonyaulax* (two species), *Dinophysis* (two species), *Glochidinium, Metadinophysis, Pyrophacus* and *Scrippsiella* with one species each.

Dinophyceae

Dinophysiales

Dinophysaceae

Dinophysis acuminata Claparède & Lachmann (Figure 2a).

Cells flattened laterally. Rounded epitheca, reduced, much smaller than the hypotheca. Short girdle, narrow, with well-developed fins. Anterior and posterior list fins anteriorly inclined, the anterior being larger than the posterior. Well developed sulcal list supported by three ribs. Ovoid hypotheca. TL: 40.6 µm; CL: 35.3 µm; TW: 28.2 µm; CW: 21.2 µm (n=1).

Recorded in samples: (ALCB137331, ALCB137333).

Distribution in Brazil: Northeast (Bahia), Southeast: (Espírito Santo, Rio de Janeiro, São Paulo), South: Paraná, Santa Catarina and Rio Grande do Sul (Flora e Funga do Brasil, 2025).

Dinophysis caudata W.S.Kent (Figure 2b).

Cells flattened laterally, with reduced epitheca, covered by the cingular list; large hypotheca, prolonged by a well-defined caudal appendage; sulcal list supported by well-developed ribs. CL: 78.6–90.6 µm (85.1 ± 4.7 µm), TL: 88.1–100.0 µm (94.4 ± 3.6 µm), CW: 42.4–50.4 µm (45.9 ± 3.5 µm), TW: 60.7–77.6 µm (70.1 ± 6.2 µm), R1–R2: 17.6–23.3 µm (19.2 ± 1.7 µm), R2–R3: 17.6–23.3 µm (19.2 ± 1.7 µm) (n = 10).

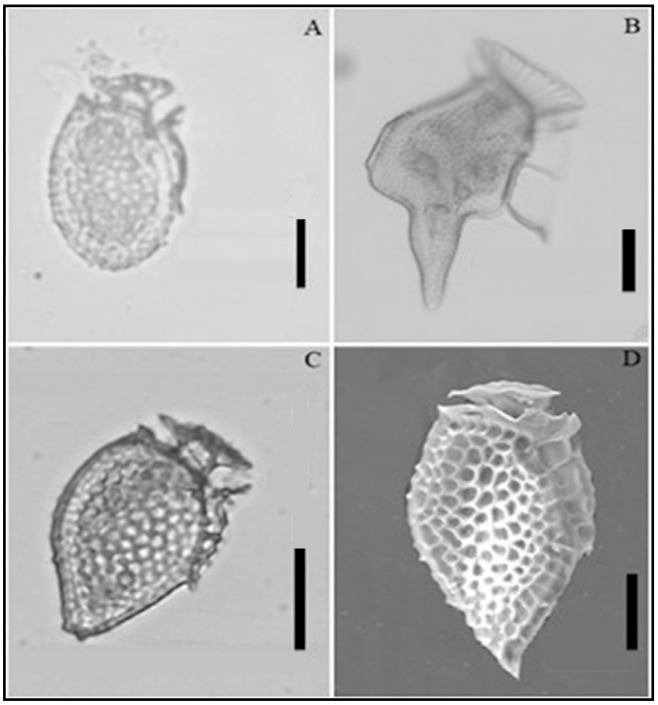
Recorded in samples: (ALCB137338, ALCB137343, ALCB137345, ALCB137346, ALCB137356, ALCB137379, ALCB137450).

Distribution in Brazil: Northeast: (Rio Grande do Norte, Pernambuco, Alagoas, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro, São Paulo), South: (Paraná, Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Metadinophysis sinensis Nie & Wang (Figure 2c-d)

Cells flattened laterally, reduced epitheca, hypotheca prolonged by an acute extension in the antapex. This species is characterized by a slight slant of the epitheca and girdle and by a flexion of the sagittal plane containing the dorso-ventral axis. CL: 33.5–42.9 µm (39.3 ± 2.8 µm), TL: 38.8–50.0 µm (45.9 ± 3.5 µm), CW: 14.3–27.8 µm (22.4 ± 3.7 µm), TW: 22.9–30.6 µm (26.6 ± 2.1 µm), R1–R2: 3.0–7.1 µm (4.8 ± 1.7 µm), R2–R3: 3.0–7.1 µm (4.8 ± 1.7 µm) (n = 10).

Figure 2 – Species of *Dinophysis* and *Metadinophysis* (All in lateral view). A. *Dinophysis acuminata* B. *Dinophysis caudata*. C. *Metadinophysis sinensis* (Optical Microscopy). D. *Metadinophysis sinensis* (Scanning Electron Microscopy). Scale bars A = 30 µm; B = 50 µm; C = 20 µm, D = 10 µm



Source: Authors' private collection (2022)

Recorded in samples: (ALCB137328, ALCB137329, ALCB137330, ALCB137331, ALCB137332, ALCB137333, ALCB137334, ALCB137340, ALCB137341, ALCB137342, ALCB137343, ALCB137344, ALCB137345, ALCB137346, ALCB137351, ALCB137352, ALCB137353, ALCB137355, ALCB137361, ALCB137450, ALCB137458, ALCB137477, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137382, ALCB137383, ALCB137384, ALCB137386, ALCB137388, ALCB137389, ALCB137391, ALCB137392, ALCB137393, ALCB137394, ALCB137395, ALCB137396, ALCB137397, ALCB137398).

Distribution in Brazil: Northeast: Bahia Affe et al. (2019), Nunes et al. (2019), Noga & Gomes (2020).

Gonyaulacales

Ceratiaceae

Tripos falcatus (Kofoid) F. Gómez. (Figure 3a).

Narrow and long cells with almost straight sides, much longer than wide. Excavated girdle. Longer and narrower hypotheca than epitheca, with differently sized horns, the left being much larger than the right. Two parallel antapical horns of variable length, the left antapical horn with pronounced curvature. Right antapical undeveloped. TL: 478.6 µm; EL: 250 µm; CW: 35.6µm; AP: 214.3 µm; RAH: 21.4 µm; LAH: 178.6 µm (n=1).

Recorded in samples: (ALCB137341, ALCB137346, ALCB137450, ALCB137389).

Distribution in Brazil: North: (Pará, Northeast: (Maranhão, Ceará, Rio Grande do Norte, Pernambuco, Bahia), Southeast: (Espírito Santo, Rio de Janeiro, São Paulo), South: (Paraná, Santa Catarina and Rio Grande do Sul) (Flora e Funga do Brasil, 2025).

Tripos hircus (Schröder) F.Gómez (Figure 3b-c).

Narrow and long cells with almost straight sides, much longer than wide, epitheca fused with apical horn, forming a well-defined structure; circular girdle, hollowed out; excavated groove, well-defined. Hypotheca characterized by very long antapical horns of practically the same size, which can be slightly curved outwards. TL: 200-214µm (206.2 ± 4.4µm); EL: 124-133µm (129 ± 3.6 µm); CW: 36-

48µm (43.6 ±3.3µm); AP: 95-106µm (99.7 ± 3.6µm); RAH: 40-48µm (44.2 ± 2.5µm); LAH: 40-55µm (44.6 ± 4.6µm) (n=10).

This differs from *Tripos furca* in that it presents antapical horns of practically equal sizes, whereas they are of very different sizes in the former.

Recorded in samples: (ALCB137328, ALCB137331, ALCB137339, ALCB137340, ALCB137341, ALCB137342, ALCB137343, ALCB137344, ALCB137345, ALCB137346, ALCB137348, ALCB137349, ALCB137350, ALCB137351, ALCB137352, ALCB137353, ALCB137354, ALCB137355, ALCB137356, ALCB137357, ALCB137362, ALCB137363, ALCB137364, ALCB137365, ALCB137366, ALCB137449, ALCB137450, ALCB137453, ALCB137454, ALCB137456, ALCB137457, ALCB137458, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137383, ALCB137384, ALCB137385, ALCB137386, ALCB137387, ALCB137388, ALCB137389, ALCB137391, ALCB137392, ALCB137393, ALCB137394, ALCB137395, ALCB137396, ALCB137397, ALCB137398).

Distribution in Brazil: North: (Amapá, Pará), Northeast: (Pernambuco, Bahia), Southeast: (Espírito Santo, Rio de Janeiro, São Paulo), South: (Paraná, Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Tripos trichoceros (Ehrenberg) Gómez (Figure 3d).

Narrow and long cells with almost straight sides, much longer than wide, asymmetrical epitheca, fused with long, thin apical horn; circular girdle, hollowed out; excavated groove. Hypotheca with two well-developed antapical horns directed anteriorly, diverging from the apical horn. TL: 200-214µm (206.2 ± 4.4µm); EL: 124-133µm (129 ± 3.6 µm); CW: 36-48µm (43.6 ±3.3µm); AP: 95-106µm (99.7 ± 3.6µm); RAH: 40-48µm (44.2 ± 2.5µm); LAH: 40-55µm (44.6 ± 4.6µm) (n=10).

Recorded in samples: (ALCB137328, ALCB137330, ALCB137331, ALCB137334, ALCB137344, ALCB137345, ALCB137346, ALCB137356, ALCB137365, ALCB137366, ALCB137449, ALCB137450, ALCB137380, ALCB137388, ALCB137389).

Distribution in Brazil: North: (Amapá, Pará), Northeast: (Ceará, Pernambuco, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro, São Paulo), South: (Paraná, Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Gonyaulacaceae

Gonyaulax polygramma F.Stein (Figures 3e-f)

Pentagonal cells, with epitheca larger than the hypotheca, conical, with a short apical horn. Post-median girdle, excavated and descending. Narrow groove in the epitheca stretching towards the antapical region. Straight-sided hypotheca with a variable number of spines. TL: 33.5–45.8 µm (39.2 ± 3.6 µm), CW: 26.5–35.4 µm (30.9 ± 2.7 µm) (n = 10).

Recorded in samples: (ALCB137330, ALCB137340, ALCB137342, ALCB137343, ALCB137344, ALCB137345, ALCB137356, ALCB137449, ALCB137456, ALCB137457, ALCB137458, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137382, ALCB137383, ALCB137384, ALCB137385, ALCB137386, ALCB137387, ALCB137388, ALCB137389, ALCB137393, ALCB137395, ALCB137396, ALCB137397, ALCB137398).

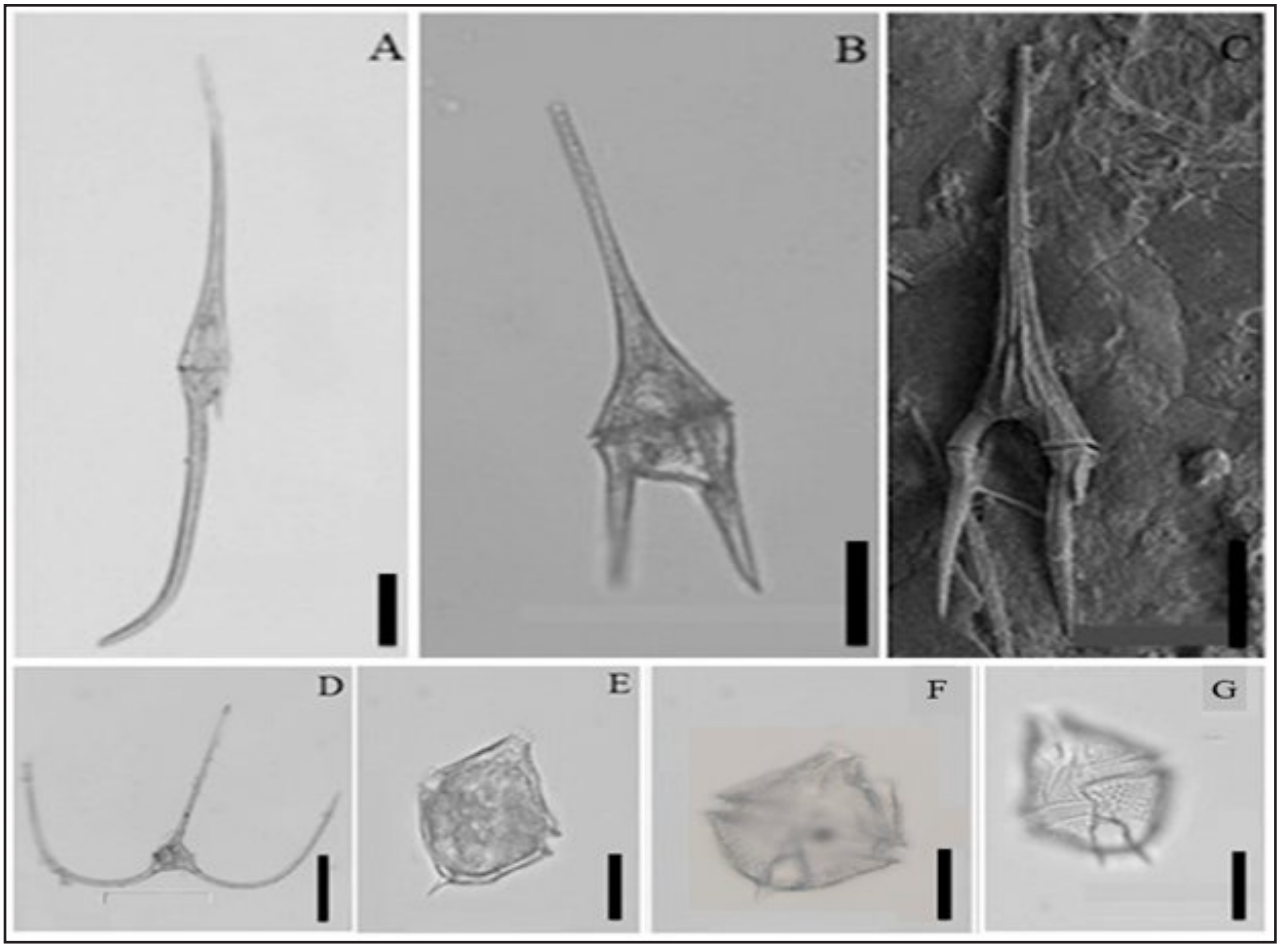
Distribution in Brazil: North: Pará, Northeast: (Maranhão, Rio Grande do Norte, Bahia- This study), Southeast: (Espírito Santo), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Gonyaulax spinifera (Claparède & Lachmann) Diesing (Figure 3g).

Rhomboid cells, conical epitheca with a short apical horn. Wide girdle, hollowed out, descending and displaced 2x the height of the girdle. Hypotheca with a variable number of antapical spines. TL: 36.8–44.3 µm (40.0 ± 2.9 µm), CW: 26.5–34.5 µm (29.4 ± 2.5 µm) (n = 10).

Recorded in samples: (ALCB137328, ALCB137330, ALCB137331, ALCB137334, ALCB137340, ALCB137341, ALCB137342, ALCB137343, ALCB137344, ALCB137345, ALCB137346, ALCB137450, ALCB137457, ALCB137458, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137384, ALCB137386, ALCB137387, ALCB137388, ALCB137389, ALCB137395, ALCB137396, ALCB137397, ALCB137398).Distribution in Brazil: North: Pará, Northeast: Rio Grande do Norte, Bahia- Affe et al. (2018), Nunes et al. (2019), Southeast: (Rio de Janeiro), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Figure 3 – Species of *Tripos* and *Gonyaulax*. A. *Tripos falcatus* (dorsal view) B. *Tripos hircus* (Optical Microscopy) (ventral view) C. *Tripos hircus* (Scanning Electron Microscopy) (ventral view). D. *Tripos trichoceros* (dorsal view). E. *Gonyaulax polygramma* (dorsal view). F. *Gonyaulax polygramma (ventral view). G. Gonyaulax spinifera* (ventral view). Scale bars A = 50 µm; B = 50 µm; C = 50 µm, D = 100 µm, E= 20µm, F= 20µm, G=20µm



Source: Authors' private collection (2022)

Peridiniales

Peridiniaceae

Glochidinium penardiforme (Er.Lemmermann) Boltovskoy 2000 (Figure 4a).

Oval or pentagonal cells in the ventral view flattened dorsoventrally. Variable size epitheca, equal to or smaller than the hypotheca. Circular girdle, hollowed out; narrow groove, extending to the final portion of the cell. Bilobed hypotheca. TL: 30.6 µm; TW: 28.2 µm (n=1).

Recorded in samples: (ALCB137347, ALCB137382, ALCB137383, ALCB137384).

Distribution in Brazil: North: Amazonas, Northeast: (Bahia- This study), Southeast: (Rio de Janeiro), South: (Paraná and Rio Grande do Sul) Flora e Funga do Brasil (2025), Cavalcante et al. (2017).

Protoperidiniaceae

Protoperidinium brevipes (Paulsen) Balech (Figure 4b).

Rhomboid cells with convex sides. Epitheca slightly larger than hypotheca, with a reduced apical horn. Girdle with raised edges, sloping to the right, ascending. Excavated groove. Hypotheca subcircular, with two tiny anti-apical spines, the right slightly diverging. TL: 29.2–37.1 (31.0 ± 3.0 µm), TW: 30.0 –33.5 µm (31.0 ± 1.3 µm), EL: 13.3–15.9 µm (14.2 ± 0.9 µm), HL: 11.7–15.9 µm (13.6 ± 1.5 µm) (n = 6).

Recorded in samples: (ALCB137340, ALCB137344, ALCB137352, ALCB137353, ALCB137356, ALCB137449, ALCB137458, ALCB137377, ALCB137378, ALCB137381, ALCB137386, ALCB137388, ALCB137389, ALCB137393, ALCB137395, ALCB137396).

Distribution in Brazil: North: (Amapá, Pará), Northeast: (Bahia- This study), South: (Santa Catarina) Flora e Funga do Brasil (2025).

Protoperidinium conicum (Gran) Balech (Figure 4c).

Cells pentagonal, dorsiventrally flattened; epitheca conical, without apical horn; girdle excavated, circular, without displacement; tabulation ortho-hexa, plate 1' diamond-shaped, as long as wide and plate 2a trapezoidal; hypotheca with short anti-apical horns ended by short spines. TL: 54.3 µm, TW: 49.8 µm, EL: 19.2 µm, HL: 28.8 µm (n = 1).

Recorded in samples: (ALCB137326, ALCB137346, ALCB137456, ALCB137383, ALCB137385, ALCB137386, ALCB137387, ALCB137388, ALCB137389, ALCB137393, ALCB137394, ALCB137395, ALCB137396, ALCB137397, ALCB137398).

Distribution in Brazil: coastal regions along the eastern, southeastern and southern coasts Flora do Brasil (2025).

Protoperidinium curvipes (Ostenfeld) Balech (Figure 4d-e).

Globular cells, slightly piriform, with short apical horn. Planozone, ascending girdle, with an offset of the girdle width. TL: 33.8- 36.2 (34.9 ± 1.2 µm), TW: 25.4- 27.7 µm (26.6 ± 1.2 µm), EL: 12.7- 16.7 µm (14.9 ± 2.0 µm), HL: 8.5- 11.5 µm (10.0 ± 1.5 µm) (n = 3).

Recorded in samples: (ALCB137355, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137383, ALCB137384, ALCB137386, ALCB137387, ALCB137388, ALCB137389, ALCB137393, ALCB137396, ALCB137397).

Distribution in Brazil: Northeast: Bahia Conceição et al. (2021)

Protoperidinium pellucidum Bergh ex Loebl. Jr. & A.R.Loeb. (Figure 4f).

Pyriform or quadrangular cells with short apex. Planozone girdle, ascending, with displacement of 0.5–0.9 in the width of the girdle. Hypotheca with two slightly divergent antapical spines. TL: 27.3 µm, CW: 23.2 µm (n=1)

Recorded in samples: (ALCB137344, ALCB137345, ALCB137380).

Distribution in Brazil: Northeast: (Rio Grande do Norte, Bahia), Southeast: (Espírito Santo, Rio de Janeiro and São Paulo) Flora e Funga do Brasil (2025).

Protoperidinium pentagonum (Gran) Balech (Figure 4g).

Pentagonal cells asymmetric, flattened dorsoventrally. Conical epitheca with short cylindrical apical horn. Middle girdle hollow and descending. Trapezoidal hyphoteca with straight margins, more or less developed into antapical horns. TL: 55.4 µm, TW: 49.8 µm, EL: 18.6 µm, HL: 27.4 µm (n = 1).

Recorded in samples: (ALCB137355, ALCB137356, ALCB137377, ALCB137378, ALCB137380, ALCB137386, ALCB137387, ALCB137394, ALCB137457).

Distribution in Brazil: Northeast: (Rio Grande do Norte, Pernambuco, Bahia- This study), Southeast: (Rio de Janeiro and São Paulo), South: (Paraná, Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

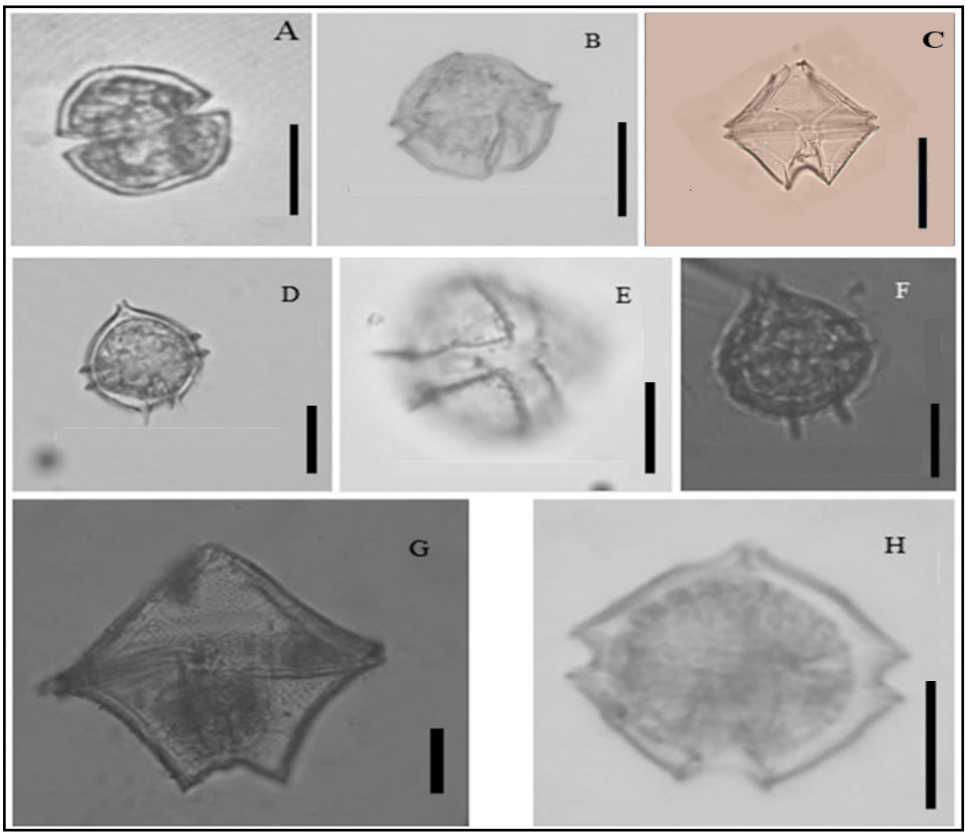
Protoperidinium cf. *subinerme* (Paulsen) A.R.Loeblich III (Figure 4h).

Pentagonal cells, bilaterally symmetric. Conical epitheca with slightly convex margins, very short apical horn. Cleft girdle, ascending, slightly sloping to the right. Hypotheca with almost straight margins and flat anti-apex. TL: 43.1 µm, CW: 39.1µm (n = 1).

Recorded in samples: (ALCB137326, ALCB137356, ALCB137391, ALCB137392).

Distribution in Brazil: North: Amapá, Northeast: Rio Grande do Norte, Bahia-Nunes et al. (2019), South: (Santa Catarina) Flora e Funga do Brasil (2025).

Figure 4 – Species of *Glochidinium* and *Protoperidinium*. A. *Glochidinium penardiformes* (dorsal view) B. *Protoperidinium brevipes* (ventral view) C. *Protoperidinium conicum* (ventral view) D. *Protoperidinium curvipes* (dorsal view). E: *Protoperidinium curvipes* (sulcus details) (ventral view). F. *Protoperidinium pellucidum* (dorsal view). G: *Protoperidinium pentagonum* (ventral view). H: *Protoperidinium* cf. *subinerme* (ventral view). Scale bars A= 20 µm; B = 15 µm; C = 40 µm, D = 15 µm; E = 15 µm; F = 15 µm; G = 30 µm, H = 15 µm



Source: Authors' private collection (2022)

Prorocentrales

Prorocentraceae

Prorocentrum gracile F.Schütt (Figure 5a).

Cells elongated, piriform, with asymmetrical sides; one margin convex and other slightly sigmoid; antapex pointed; one long, winged anterior spine. CL: 40–72.5 µm (64.8 ± 9.5 µm), TL: 55–90 µm (82.7 ± 10.4 µm), CW: 20–25 µm (18.6 ± 2.7 µm) (n = 10).

Recorded in samples: (ALCB137334, ALCB137338, ALCB137340, ALCB137342, ALCB137343, ALCB137345, ALCB137356, ALCB137379, ALCB137389, ALCB137395)

Distribution in Brazil: North: (Amazonas, Amapá, Pará), Northeast: (Maranhão, Ceará, Rio Grande do Norte, Paraíba, Piauí, Pernambuco, Alagoas, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro and São Paulo), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Prorocentrum mexicanum Osório-Tafall (Figure 5b).

Oval cells with asymmetrical sides, larger diameter in the central portion of the valve. CL: 30µm, CW: 21.4µm (n = 1).

Recorded in samples: (ALCB137342, ALCB137343, ALCB137344, ALCB137345, ALCB137346, ALCB137353, ALCB137356, ALCB137360, ALCB137378, ALCB137455).

Distribution in Brazil: North: (Amazonas, Amapá, Pará, Rondônia, Roraima, Tocantins), Northeast: (Maranhão, Ceará, Rio Grande do Norte, Paraíba, Piauí, Pernambuco, Alagoas, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro and São Paulo), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Prorocentrum micans Ehrenberg (Figure 5c-d).

Oval cells with asymmetrical sides, larger diameter in the central portion of the valve; antapex attenuated; one anterior, winged, straight spine. CL: 40–50 µm (45.4 ± 3.2 µm), TL: 50–60 µm (55.3 ± 3.4 µm), CW: 25–30 µm (27.6 ± 1.8 µm) (n = 10).

Recorded in samples: (ALCB137328, ALCB137329, ALCB137330, ALCB137331, ALCB137332, ALCB137333, ALCB137334, ALCB137335, ALCB137336, ALCB137337, ALCB137342, ALCB137343, ALCB137345, ALCB137346, ALCB137354, ALCB137355, ALCB137356, ALCB137365, ALCB137366, ALCB137449, ALCB137450, ALCB137457, ALCB137458, ALCB137377, ALCB137378, ALCB137379, ALCB137380, ALCB137382, ALCB137383, ALCB137384, ALCB137385, ALCB137386, ALCB137387, ALCB137388,

ALCB137389, ALCB137390, ALCB137392, ALCB137393, ALCB137395, ALCB137396, ALCB137397, ALCB137398).

Distribution in Brazil: North: (Amazonas, Amapá, Pará), Northeast: (Maranhão, Ceará, Rio Grande do Norte, Paraíba, Piauí, Pernambuco, Alagoas, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro and São Paulo), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Prorocentrum scutellum Schröder (Figure 5e).

Cells subcircular, wider in central portion of cells, antapex rounded; an anterior winged spine curved towards the dorsal portion. CL: 31.3 µm, CW: 27.3µm, SL: 2.81 µm (n = 1).

Recorded in samples: (ALCB137327, ALCB137328, ALCB137331, ALCB137332, ALCB137333, ALCB137334, ALCB137346, ALCB137449, ALCB137378, ALCB137379, ALCB137380, ALCB137384, ALCB137392).

Distribution in Brazil: North: (Amapá, Pará), Northeast: (Rio Grande do Norte, Bahia), Southeast: (Espírito Santo, Rio de Janeiro), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Pyrophacaceae

Pyrophacus horologium Stein (Figure 5f).

Flattened, lentil-shaped cells with a prominent apical pore; epitheca showing five apical and nine precingular plates; hypotheca with nine post-cingular, three antapical and one posterior intercalary plates. CW: 61.8 µm; TL: 65.3 µm (n = 1).

Recorded in samples: (ALCB137329, ALCB137333, ALCB137334, ALCB137337, ALCB137345, ALCB137384, ALCB137389).

Distribution in Brazil: North: (Pará), Northeast: (Ceará, Rio Grande do Norte, Pernambuco, Alagoas, Sergipe, Bahia), Southeast: (Espírito Santo, Rio de Janeiro and São Paulo), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

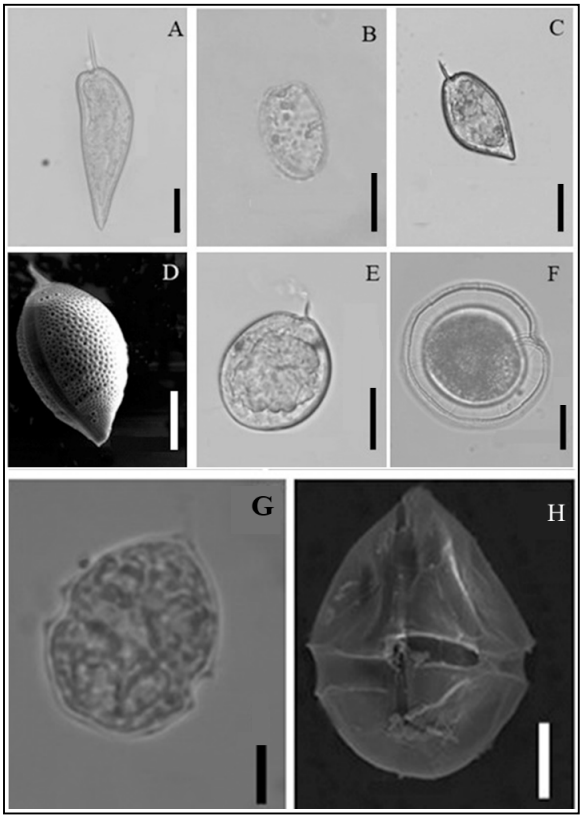
Thoracosphaerales

Thoracosphaeraceae

Scrippsiella acuminata (Ehrenberg) Kretschmann, Elbrächter, Zinssmeister, S.Soehner, Kirsch, Kusber & Gottschling (Figure 5 G-H).

The cells had an oval cell shape, epitheca conical, with convex margins, and a short apical spine. Tabulation ortho-hexa, with plate 1' being narrow and slightly asymmetric and three intercalary plates (a) with almost the same size. Plate 2a was hexagonal, while plates 1a and 3a were pentagonal and unequal precingular plates. Circular girdle, excavated, descending, displaced by approximately half the cingular width. The hypotheca was less than the epitheca, rounded with an excavated sulcus stretching from the girdle until close to bottom of the hypotheca. TL: 15–28.1 µm (22.8 ± 4.7 µm) and TW: 11.3–25.0 µm (17.5 ± 4.0 µm) (n=16).

Figure 5 – Species of *Prorocentrum*, *Pyrophacus* and *Scrippsiella*. A. *Prorocentrum gracile* (valvar view) B. *Prorocentrum mexicanum* (valvar view). C. *Prorocentrum micans* (Optical Microscopy) (valvar view). D. *Prorocentrum micans* (Scanning Electron Microscopy) (valvar view). E. *Prorocentrum scutellum* (valvar view). F. *Pyrophacus horologium* (Optical Microscopy) (antiapical view). G. *Scrippsiella acuminata* (Optical Microscopy) (ventral view). H. *Scrippsiella acuminata* (Scanning Electron Microscopy) (ventral view). Scale bars A = 20 µm; B = 20 µm; C = 20 µm, D = 10 µm. E = 20 µm; F = 20 µm; G = 20 µm, H = 5 µm



Source: Authors' private collection (2022)

Recorded in samples: (ALCB137326, ALCB137327, ALCB137334, ALCB137335, ALCB137338, ALCB137340, ALCB137343, ALCB137345, ALCB137358, ALCB137359, ALCB137360, ALCB137451, ALCB137452, ALCB137453, ALCB137454, ALCB137378, ALCB137383, ALCB137384, ALCB137386, ALCB137387, ALCB137388, ALCB137390).

Distribution in Brazil: North: (Pará), Northeast: (Rio Grande do Norte, Pernambuco, Alagoas, Bahia), Southeast: (Espírito Santo and Rio de Janeiro), South: (Santa Catarina and Rio Grande do Sul) Flora e Funga do Brasil (2025).

Among the identified species, 11 were potentially harmful: *Dinophysis acuminata, D. caudata, Gonyaulax polygramma, G. spinifera, Prorocentrum gracile, P. mexicanum, P. micans, Protoperidinium brevipes*, *P. pellucidum*, *Scrippsiella acuminata, Tripos hircus* (Steidinger & Williams, 1970; Balech, 1988; Jeong et al., 2004; Jeong et al., 2005; Jeong et al., 2010; Castro & Moser, 2012, Moestrup et al., 2025).

4 DISCUSSION

The most frequent species in this study were *Tripos hircus*, *Dinophysis caudata*, and *Prorocentrum micans*, which were recorded throughout the study period and in all regions of the Paraguaçu River Estuary (Table 1). These species have typically marine habitats and are widely distributed along coastal ecosystems in Brazil (Flora e Funga do Brasil, 2025), but at the same time they are tolerant to variations in both salinity and nutrient concentration (Saldarriaga & Taylor, 2017). The occurrence of these species in the innermost areas of the estuary of the Paraguaçu River suggested a strong influence of sea currents on this environment. Additionally, this indicated that greater saline intrusion is possible due to reduced freshwater inflow into the system as a result of the Pedra do Cavalo Dam.

All dinoflagellate species observed in the Paraguaçu River Estuary, except for *G. penardiforme*, are from tropical, temperate, coastal, oceanic, or estuarine waters. This study only presented species of teak dinoflagellates, whose external structures are well preserved when collected using nets and preserved in formalin. Therefore, the fraction of athecate dinoflagellates (naked), which experience deterioration and cell death, affecting

crucial diagnostic structures such as the apical line, ventral pore, and the ultrastructure elements of the amphiesma (Hoppenrath et al., 2009; 2016), was likely underestimated.

Table 1 – Distribution of dinoflagellates in the estuary of Paraguaçu River, from March 2018 to March 2019 (LRC: Lower River Course; IB: Iguape Bay; PC: Paraguaçu Chanel)

Taxa	Mar/18	May/18	Jul/18	Sep/18	Nov/18	Jan/19	Mar/19
Dinophysis acuminata	IB, PC	-	-	-	-	-	-
D. caudata	-	LRC, IB, PC	PC	PC	PC	-	-
Metadinophysis sinensis	LRC, IB, PC	LRC, IB, PC	IB, PC	LRC, IB, PC	IB, PC	LRC, IB, PC	LRC, IB, PC
Tripos falcatus	-	IB, PC	-	PC	-	PC	-
Tripos hircus	IB, PC	LRC, IB, PC	LRC, IB, PC	LRC, IB, PC	LRC, IB, PC	LRC, IB, PC	LRC, IB, PC
Tripos trichoceros	LRC, IB, PC	PC	PC	IB, PC	PC	PC	-
Gonyaulax polygramma	IB	LRC, IB, PC	PC	PC	LRC, IB, PC	LRC, IB, PC	IB, PC
G. spinifera	LRC, IB, PC	LRC, IB, PC	-	PC	IB, PC	IB, PC	IB, PC
Glochidinium penadiforme	-	-	LRC	-	-	LRC	-
Protoperidinium brevipes	-	LRC, PC	IB, PC	PC	LRC, IB, PC	LRC, IB, PC	IB, PC
P. conicum	LRC, IB, PC	PC	-	-	LRC	LRC, IB, PC	IB, PC
P. curvipes	-	-	PC	-	IB, PC	LRC, IB, PC	IB, PC
P. pellucidum	-	PC	-	-	PC	-	-
P. pentagonum	-	-	PC	-	IB, PC	IB, PC	IB
P. cf. subinerme	LRC	-	PC	-	-	LRC, IB, PC	LRC
Prorocentrum gracile	PC	LRC, IB, PC	PC	-	PC	PC	IB
P. mexicanum	-	LRC, IB, PC	IB, PC	LRC	LRC, PC	-	-
P. micans	LRC, IB, PC	LRC, IB, PC	PC	IB, PC	IB, PC	LRC, IB, PC	LRC, IB, PC
P. scutellum	LRC, IB, PC	PC	-	PC	PC	IB	LTC
Pyrophacus horologium	IB, PC	LRC, PC	-	-	-	IB, PC	-
Scrippsiella acuminata	LRC, PC	LRC, IB, PC	-	LRC	LRC, PC	LRC, IB, PC	LRC

Source: Prepared by the authors based on species presence and absence matrix

The genera *Protoperidinium*, *Tripos*, and *Prorocentrum* were the most representative species. Several studies conducted along the Brazilian coast have pointed to the high species diversity of these genera (*i.e.* Villac et al., 2008; Santana et al., 2010; Villac & Tenenbaum, 2010; Nunes et al., 2019). *Tripos hircus* and *Prorocentrum micans*, which showed the highest occurrence, are commonly recorded along the Brazilian coast (Silva-Cunha et al., 2019; Flora e Funga do Brasil, 2025; Nunes et al., 2023). To date, *Metadinophysis sinensis* has been recorded only in the state of Bahia (Affe et al., 2019; Nunes et al., 2019; Noga & Gomes, 2020; Conceição et al., 2021; Nunes et al., 2023).

Gonyaulax polygramma has been reported in other Brazilian states (Alagoas, Maranhão, Pernambuco, Rio Grande do Norte, and Sergipe) (Flora e Funga do Brasil, 2025).

The species richness observed in this study was similar to that observed in other anthropic environments. For example, 25 species of dinoflagellates were recorded in the Maraú River estuary (Nunes et al., 2019), and the occurrence of 20 species in an anthropized region of Baía de Todos os Santos (Affe et al., 2021) was reported.

Among the species listed as potentially harmful, seven produce toxins (*Dinophysis acuminata*, *D. caudata*, *Gonyaulax spinifera*, *Prorocentrum mexicanum*, *P. micans*, *Protoperidinium brevipes*, and *P. pellucidum*), three cause mechanical injuries (*G. polygramma*, *Prorocentrum gracile, Tripos hircus*), and one species cause oxygen depletion and shading of the water column (*Scrippsiella acuminata*) (Castro & Moser, 2012). Blooms of *Scrippsiella acuminata* have previously been recorded in the Todos os Santos Bay region (Affe et al., 2021; Conceição et al., 2021; Nunes et al., 2022) without harmful effects registered. *Tripos hircus* is an abundant species in the South Atlantic, and can form localized blooms that cause mechanical injuries due to the apical and antiapical horns (Steidinger & Williams, 1970; Balech, 1988). *Dinophysis acuminata* and *Dinophysis caudata* are producers of okadaic acid-type diarrhetic shellfish toxins (DSP), which has already caused problems in cultivation areas in Santa Catarina (Proença et al., 1999a; Taylor et al., 2004; Tavares et al., 2009). *Prorocentrum micans* was cited as

toxic by Proença et al. (1999b) in mollusc farming areas in Santa Catarina, and by Affe and Santana (2016) in Camamu Bay, as potentially toxic, since no toxicity was recorded.

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5 CONCLUSIONS

Glochidinium penardiforme is a new occurrence in the northeast, and *Gonyaulax polygramma* is a new occurrence in Bahia. In addition, the identity of *Protoperidinium* cf. *subinerme*, which has not previously been reported in Bahia, had to be confirmed. This demonstrated that dinoflagellate diversity and distribution in estuaries and along the coastal regions of Bahia have been underestimated.

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