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How hidden is the diversity of the genus *Cosmarium* (Desmidiaceae) in the Brazilian Caatinga?

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ABSTRACT

The Caatinga domain is the largest and most diverse tropical semiarid ecoregion of South America; however, little is known about the diversity of desmids it harbors, especially the genus *Cosmarium* (Desmidiaceae, Zygnematophyceae). Our study contributes to the knowledge of *Cosmarium* in the Caatinga through the report of 42 interesting taxa, including a new species (*Cosmarium imperiale*), 22 new records for South America, and 19 additions to the desmid flora from Brazil. The samples were gathered from periphytic material from the "Pantanal dos Marimbus" in the Chapada Diamantina region of Northeast Brazil. We provide taxonomic notes, ecological information, including habitat conditions with limnological data, and updated global distributions for all taxa of *Cosmarium*. A complementary quantitative study was performed during the last year of sampling (2018), which revealed that most taxa have their highest densities in the months with low precipitation and when the water's conductivity and transparency are greater. Our results also have implications for the conservation of the biota from Marimbus do Baiano and understand South America's desmids' biogeography since some rare taxa identified here were previously only known from other continents such as Europe and Africa.

Keywords: algae, desmids, periphyton, scanning electron microscopy, semiarid region, taxonomy

Introduction

South America is characterized by having a mosaic of phytogeographical domains, with diverse types of environments from dry deserts to very wet rainforests and semiarid areas (Moro *et al.* 2016). Among the most interesting semiarid regions from that continent, one of the most interesting is the Caatinga domain, which is considered the largest and most diverse tropical semiarid ecoregion from South America. This is the only biome found exclusively in Brazil (Leal *et al.* 2003; Silva & Souza 2018). Despite that, little is known on the diversity of freshwater algae in that domain, especially desmids, since just a few taxonomic studies have been performed there.

Desmids comprise a polyphyletic algal group, with great phenotypical plasticity, occurring in various types of freshwater habitats, although they are generally more common and diverse in oligotrophic environments (Brook 1981; 1984; Gerrath 1993; Coesel & Meesters 2007; Gontcharov & Melkonian 2011). In Brazil, desmids have been reported in taxonomic studies since the 19th century (Ehrenberg 1843; Nordstedt 1870; Borge 1899). Overall, the taxonomic studies on desmids of Brazil can be classified into two phases: (1) until the mid of 20th century, where the foreign researchers were the main contributors, especially

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Borge (1903; 1918; 1925), Grönblad (1945), Krieger (1950), Prescott (1957), Förster (1963; 1964), Scott *et al*. (1965), (2) from the 1960s until nowadays, the Brazilian researchers were the main contributors, usually studying desmids from the southeastern and southern regions.

Until the late 2000s, Northeastern Brazil was one of the regions with the least known desmid flora. However, in the last decade, the studies in that region have been considerably expanded, particularly in the eastern part of the Bahia State, with records of several new and rare species of desmids, including interesting taxa of the genus *Cosmarium* Corda ex Ralfs (Oliveira *et al*. 2010; 2011; Ramos *et al*. 2018; 2019; 2020).

Cosmarium is one of the oldest genera of Desmidiaceae, in addition to having the largest number of taxa described (over 1500 species and several intraspecific taxa) (Guiry & Guiry 2020). The genus is characterized by having solitary cells, with shallow to deep median constriction, semicells morphologically diverse, rounded, elliptical, oblong, pyramidate, quadrate to rectangular, margins rounded or undulated, cell wall smooth or ornamented by scattered pores, granules, verrucae, chloroplast axial, with one or two pyrenoids per semicell, and some species might have a mucilage sheath surrounding the cells (Bicudo & Menezes 2017; Guiry & Guiry 2020). In Brazil, there are about 650 taxa (including taxa not nominated), of which over 200 were described based on Brazilian material (Biolo & Bicudo 2018). In contrast, there are about 120 taxa reported in the Bahia State, generally from the eastern part (coastal plains of the northern region) and only 12 to the Chapada Diamantina region.

Overall, taxonomic studies on desmids from the Caatinga are rather scarce. Little is known on the current known diversity and distribution of that algal group in that northeastern Brazil's semiarid biome. Based only on taxonomic and floristic studies (Förster 1964; Ramos *et al*. 2019; 2020), there are only 13 taxa of *Cosmarium* reported to that domain (12 from Bahia and only one in Piaui), including some endemic taxa such as *Cosmarium decedens* var. *bahiense*, *C. diamantinum*, *C. femmeasense*, and *C. subundulatum* var. *ellipticum*. To increase the knowledge on the biodiversity and distribution of desmids from the Caatinga, the present paper reports 42 interesting taxa of *Cosmarium*, including a new species and rare taxa reported or confirmed for the first time to the desmid flora of Brazil or South America.

Material and methods

One hundred periphytic samples were collected during the years 2011, 2012, 2017, and 2018 in the "Pantanal dos Marimbus", a floodplain located between the Andaraí and Lençóis municipalities, Chapada Diamantina region, Bahia State, northeastern Brazil (Fig. 1). Those wetlands have been considered important ecosystems in the Chapada Diamantina, Caatinga domain, harboring rich biodiversity and hence were partially incorporated into the Marimbus-Iraquara Environmentally Protected Area by Gubernatorial Decree in the 1990s. The samples were gathered through the squeezing of three species of aquatic macrophytes: *Utricularia foliosa* L., *Cabomba caroliniana* A. Gray, and *Nymphaea amazonum* Mart & Zucc. These plants have distinct morphologies and form large populations in the study area.

We measured limnological parameters in the natural habitats during the years of 2017 and 2018, such as the temperature (T), pH, electric conductivity (EC) and total dissolved solids (TDS) using a multiparameter portable probe (Hanna HI98130), dissolved oxygen (DO) using an Instrutherm device (MO-910), depth and water transparency (WT) using a Secchi disk. The precipitation values were consulted in the database of the Instituto Nacional de Meteorologia (INMET 2020). Although periods of rain and drought are generally well defined in the Pantanal dos Marimbus region, precipitation data in 2018 were considered atypical, with rains concentrated in June (historically dry month) and drought in April (generally a rainy month). Thus, here we consider for the year 2018 the dry period the following months, April, June, and October, whereas for the rainy period the months of February, June, and December. For most taxa, we provided the values of limnological parameters represented by the mean and standard deviation.

The samples collected in 2011, 2012, and 2017 were used only for qualitative analysis. On the other hand, the material from 2018 was periodically collected (bimestrial, February to December) by the scraped area in each studied macrophyte and used for both qualitative and quantitative analysis. Thus, only the data from 2018 were submitted to statistical analysis.

The Redundancy Analysis (RDA) was performed to verify the relationship between the limnological parameters and the *Cosmarium* taxa in "Marimbus do Baiano" during 2018. The multicollinearity of the environmental variables was evaluated based on the variance inflation factor (VIF). Considering the AIC criterium, we used the forward-selection method to reduce the data's dimensionality (Blanchet *et al*. 2008; Oksanen *et al*. 2011). The matrix with the taxa's density values was standardized according to the transformation of "Hellinger" (Legendre & Gallagher 2001). We performed a permutation test (999 permutations) to evaluate the model's significance and the RDA axes. The analysis was performed using R software (R Development Core Team 2020).

All the materials were examined under an Olympus BX45 Optical Microscope and photographed using a MicroPublisher - QImaging MP5.0-RTV-CLR-10-C digital camera. Some samples were dried, coated with gold based on protocols of Ramos *et al*. (2017), and observed through scanning electron microscopy (SEM). The samples were

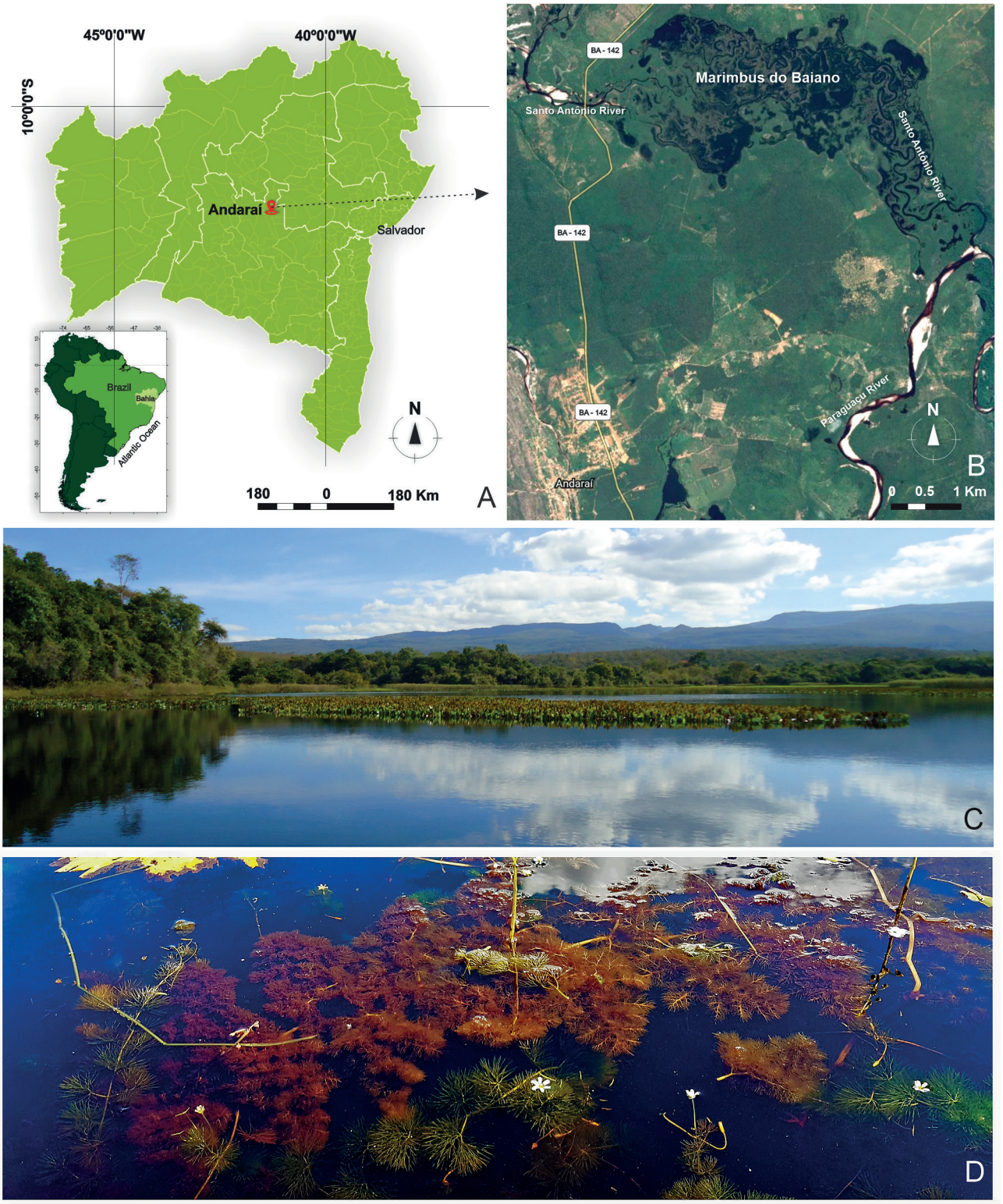

Figure 1. Study area. **A.** Location of Andaraí municipality in the Bahia State, Brazil; **B.** Satellite image showing the Santo Antonio River and Pantanal dos Marimbus (Baiano), Chapada Diamantina (Google Earth); **C.** General view of Pantanal dos Marimbus (Baiano). **D.** Some aquatic macrophytes of the Pantanal dos Marimbus: *Utricularia foliosa* (brownish specimens) and *Cabomba caroliniana* (greenish specimens).

preserved in Transeau's solution (Bicudo & Menezes 2017) and subsequently incorporated into the liquid collection in the herbarium of the Universidade Estadual de Feira de Santana (HUEFS). The samples for counting were fixed in Lugol solution (0.5 %), and the quantification was performed in an Inverted Microscope (Olympus IX51). We used the random field method (Uehlinger 1964), establishing as a counting limit the observation of 10 random fields without the occurrence of new taxa.

The identification of the taxa was based on morphological features. It was performed using specialized literature, such as West & West (1896; 1898; 1908), Krieger & Gerloff (1962; 1965; 1969), Scott & Grönblad (1957), Prescott *et al.* (1981), Thérézien (1985), Coesel & Meesters (2007), among others.

Additional approaches, including taxonomic notes for each taxon, habitat conditions, updated worldwide distribution, and richness of *Cosmarium* in the macrophytes, are provided. Moreover, a quantitative study was conducted based on samples collected in 2018 to evaluate the relation between the limnological parameters and the *Cosmarium* taxa density.

Results and discussion

Our research revealed 42 interesting taxa of *Cosmarium* occurring in a floodplain from the Caatinga domain, including a new species and 41 additions to Brazil or South America's desmid flora.

Taxonomic treatment

1. *Cosmarium amoenum* var. *compactum* West & G.S.West, Trans. Linn. Soc. Lond., ser. 2, Botany 5: 251. 1896.
(Fig. 2A-D).

Cell dimensions – length 32.5–42.5 µm, breadth 27–31.5 µm, breadth of isthmus 11.5–13 µm.

Habitat – This variety was generally associated with periphyton of *Nymphaea amazonum* and *Utricularia foliosa*. Conductivity 0.04 (± 0.03 mS.cm^{-1}); dissolved oxygen 6.8 (± 1.4 mg.L^{-1}); pH 6.8 (± 0.4); total dissolved solids 0.02 (± 0.018); water temperature 30.3 (± 1.8 °C); water transparency 0.64 (± 0.19 m).

Distribution – North America (Canada); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n (HUEFS 253740, HUEFS 253743, HUEFS 253749).

Note – *Cosmarium amoenum* var. *compactum* differs from the nominate variety by having semicircular cells with vertical series of granules. This variety is rarely reported in the literature and is probably endemic to the American continent. Morphologically, it resembles *Cosmarium conspersum* var. *attenuatum* Nordst., but this latter variety differs by having larger cells (66–77 µm x 51–58 µm), with more granules, which are arranged in concentric ellipses in the apical view.

2. *Cosmarium anceps* P.Lundell, Nova Acta R. Soc. Sc. Upsal., ser. 3, 8 (2): 48. 1871.
(Fig. 2E-F).

Cell dimensions – length 21 µm, breadth 14.5 µm, breadth of isthmus 7.5 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 mS.cm^{-1}; dissolved oxygen 5.9 mg.L^{-1}; pH 6.9; total dissolved solids 0.03; water temperature 29.9 °C; water transparency 0.76 m.

Distribution – Cosmopolitan; South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n (HUEFS 253742).

Note – *Cosmarium anceps* is characterized by having trapezoid semicells with concave sides, broadly elliptic in apical view. This species has a wide distribution; however, there are no taxonomic records in Brazil. Even in other regions from South America, the records are unclear. According to West & West (1908), *C. anceps* is a very characteristic alpine and subalpine species, occurring among mosses on the dripping rocks of mountain glens and boggy springs high up on the mountains. In the Marimbus, a few specimens were observed associated with *Utricularia foliosa*.

3. *Cosmarium anisochondrum* var. *isthmolatum* Thérézien, Biblioth. Phycol.72: 93. 1985.
(Fig. 2G-J).

Cell dimensions – length 23.5–24 µm, breadth 13 µm, breadth of isthmus 3.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa*, *Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.8 (± 1.6 mg.L^{-1}); pH 6.8 (± 0.4); total dissolved solids 0.03 (± 0.015); water temperature 28.7 (± 2.2 °C); water transparency 0.8 (± 0.15 m).

Distribution – South America: French Guiana, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n (HUEFS 253741, HUEFS 253750); 09/IV/2018, M.A.Santos *et al.* s/n (HUEFS 253753).

Note – The var. *isthmolatum* differs from the nominate variety by having two larger subapical granules. In the median region of the semicell, there are double granules surrounded by two vertical rows of 2-3 granules and a horizontal row composed of 3 supraisthmal granules. This variety is very rare, known only so far in French Guiana (type locality, Thérézien 1985). Coesel (1992), based on samples from Colombia, identified *C. dichondrum*, but after analyzing the figures

provided by the author (Coesel 1992: Pl. 3, Figs. 9,10), and mainly the cell wall pattern, we consider the taxon closer to *C. anisochondrum* var. *isthmolatum* than *C. dichondrum*. Thus, it is possible this variety also might occur in Colombia. The few records, all of them from South America, suggest the endemism of this variety for that region.

4. *Cosmarium baccatum* Scott & Grönblad, Acta Soc. Sci. Fenn. Nov. Ser. B. 2(8): 15. 1957.

(Fig. 2K-O).

Cell dimensions – length 70–72.5 µm, breadth 59–61.5 µm, breadth of isthmus 15–17 µm.

Habitat – This species was found generally associated with periphyton of *Cabomba caroliniana*. Conductivity 0.02 $mS.cm^{-1}$; dissolved oxygen 12 $mg.L^{-1}$; pH 7.5; total dissolved solids 0.01; water temperature 22 °C; water transparency 2.1 m.

Distribution – North America (USA); Asia (Korea); South America, Brazil (first record).

Material examined – BRAZIL. Bahia: Lençóis, Pantanal dos Marimbus (Remanso), 20/VIII/2011, G.J.P.Ramos

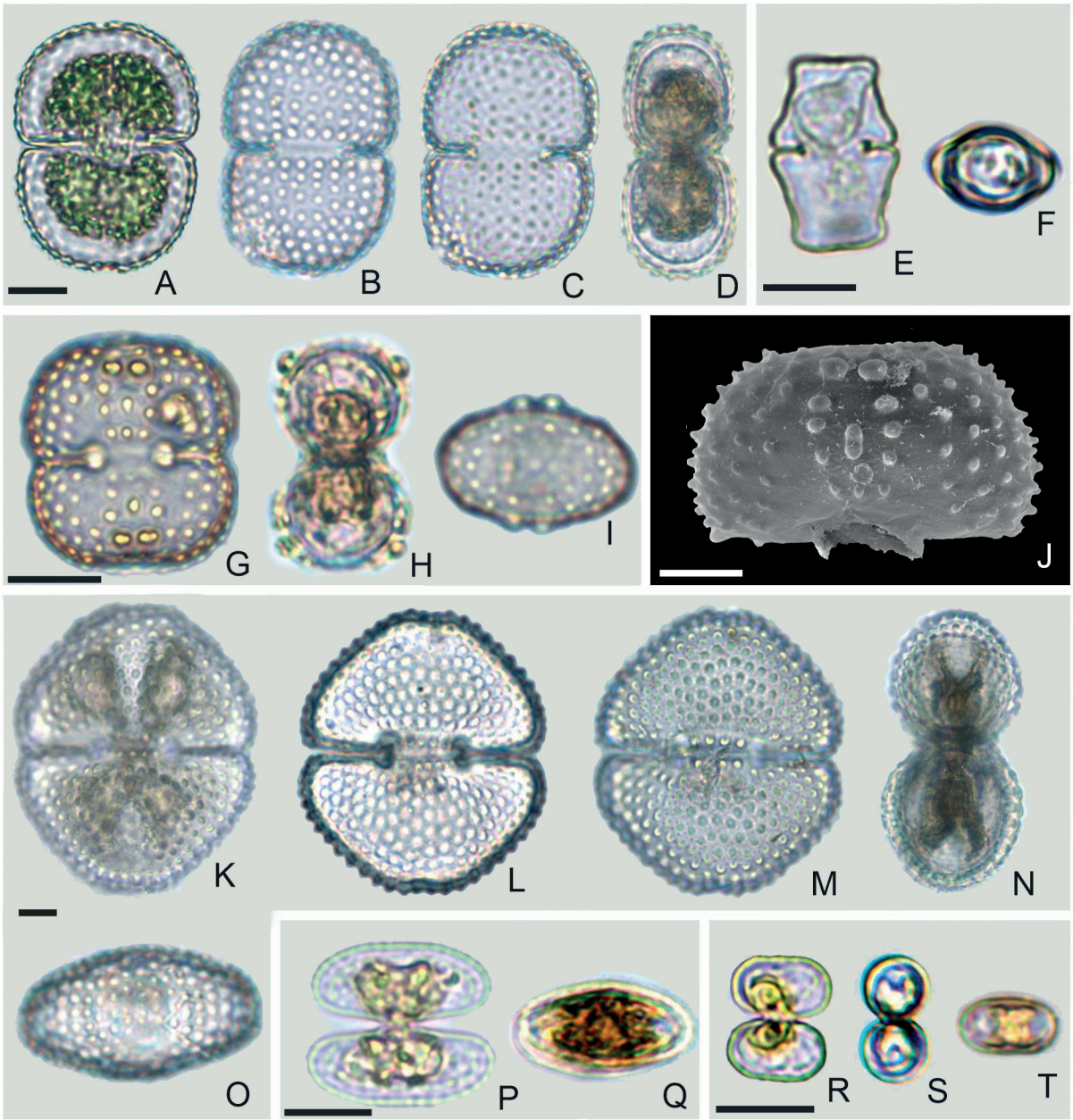

Figure 2. *Cosmarium* from the Pantanal dos Marimbus. **A–D.** *Cosmarium amoenum* var. *compactum*: frontal view (**A–C**), lateral view (**D**); **E–F.** *Cosmarium anceps*: frontal view (**E**), apical view (**F**); **G–J.** *Cosmarium anisochondrum* var. *isthmolatum*: frontal view (**G**), lateral view (**H**), apical view (**I**), detail of ornamentation of the semicell in SEM (**J**); **K–O.** *Cosmarium baccatum*: frontal view (**K–M**), lateral view (**N**), apical view (**O**); **P–Q.** *Cosmarium bioculatum* var. *boreale:* frontal view (**P**), apical view (**Q**); **R–T.** *Cosmarium bioculatum* var. *hians:* frontal view (**R**), lateral view (**S**), apical view (**T**). Scale bar 10 µm (LM), 5 µm (SEM).

& C.W.N. Moura s/n (HUEFS 185359); 11/II/2012, G.J.P.Ramos & C.A.Ribeiro s/n (HUEFS 185418).

Note – *Cosmarium baccatum* is a rare species described by Scott & Grönblad (1957) based on material from Florida, USA. This species is primarily characterized by having subpyramidate semicells, rotundate basal angles, truncate apices, and ornamented with granules surrounded by pores. A row with 3-4 granules is also noteworthy in the isthmus region.

The occurrence out of North America has been somewhat uncertain: Jung *et al.* (2017) reported its occurrence to Korea; however, the specimens illustrated (Fig. 2A-D) resemble more *Cosmarium decoratum* West & G.S.West than *C. baccatum*. On the other hand, the morphological features of Brazilian specimens agree with those described by Scott & Grönblad (1957); therefore, the geographic distribution of species has been expanded to South America.

5. *Cosmarium bioculatum* var. *boreale* (Børgesen) Willi Krieger & Gerloff, Die Gattung Cosmarium, Lieferung 1: 62. 1962.

≡ *Cosmarium boreale* Børgesen, Vid. Medd. Naturh. For. Kjøbenhavn 51: 328 (1899).

(Fig. 2P-Q).

Cell dimensions – length 18–19 µm, breadth 21–22.5 µm, breadth of isthmus 4–5.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.01 mS.cm^{-1}); dissolved oxygen 7.1 (± 1.7 mg.L^{-1}); pH 7 (± 0.5); total dissolved solids 0.03 (± 0.01); water temperature 32 (± 2.6 °C); water transparency 0.77 (± 0.13 m).

Distribution – Europe; South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242423, HUEFS 242434); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 242484).

Note – *Cosmarium bioculatum* var. *boreale* differs from the nominate variety by having numerous pores on the cell wall, which resemble small granules due to mucilage remains. This variety can be confused with *C. perfissum* G.S.West, which differs in having oblong-elliptical semicells, usually with slightly convex apices. However, during the description of *C. perfissum*, West (1909) provided a morphological variation (Fig.2A) with rounded apices, identical to *C. bioculatum* var. *boreale*. When the cells of *C. perfissum* are observed in apical view, it is possible to see mild median inflation, which is absent in the var. *boreale*. Thus, we consider the apical view another important feature to separate both taxa.

6. *Cosmarium bioculatum* var. *hians* West & G.S.West, J. Roy. Micr. Soc. 17(6): 486. 1897.

(Fig. 2R-T).

Cell dimensions – length 12.5–14 µm, breadth 9–10.5 µm, breadth of isthmus 3–4.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.07 (± 0.025 mS.cm^{-1}); dissolved oxygen 6.5 (± 1.8 mg.L^{-1}); pH 7.6 (± 0.6); total dissolved solids 0.03 (± 0.01); water temperature 28.7 (± 1.2 °C); water transparency 0.80 (± 0.22 m).

Distribution – Cosmopolitan; South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 12/VI/2018, M.A.Santos *et al.* s/n (HUEFS 253765, HUEFS 253769); 22/VIII/2018, M.A.Santos *et al.* s/n (HUEFS 253777, HUEFS 253778, HUEFS 253780, HUEFS 253783).

Note – This variety is widely known in diverse regions globally; however, its occurrence is unknown in Brazil and other areas from South America. Recently, Rosen *et al.* (2019) reported the var. *hians* at the Arthur R. Marshall Loxahatchee National Wildlife Refuge, another Tropical wetland located in the Everglades, Florida.

In the Marimbus, this variety was very rare; just a few specimens were observed. Krieger & Gerloff (1969) synonymized *Cosmarium bioculatum* var. *hians* to *C. asphaerosporum* var. *strigosum* Nordst. Although these taxa to be morphologically identical, we still consider them distinct (*Cosmarium bioculatum* var. *hians* differs by having cells more robust and punctuated cell wall), therefore agreeing with recent studies such as Petlovany & Tsarenko (2015) and Kanetsuna & Yamagishi (2018). However, further studies with other approaches such as SEM and molecular data are recommended to verify the relation of those taxa.

7. *Cosmarium bireme* var. *barbadense* G.S.West, J. Bot 42: 286. 1904.

(Fig. 3A-D).

Cell dimensions – length 15 µm, breadth 13 µm, breadth of isthmus 4 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.03 (± 0.017 mS.cm^{-1}); dissolved oxygen 6.5 (± 1.5 mg.L^{-1}); pH 6.7 (± 0.9); total dissolved solids 0.005 (± 0.01); water temperature 30.8 (± 0.8 °C); water transparency 0.60 (± 0.15 m).

Distribution – North America (USA), Europe (Italy), Africa (Burundi), Asia (Bangladesh); South America: Brazil (Mato Grosso - ?; Bahia - first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 09/XII/2011, G.J.P.Ramos & C.A.Ribeiro. s/n (HUEFS 185390); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253745, HUEFS 253750); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253766); 04/XII/2018, M.A.Santos *et al.* s/n. (HUEFS 253804).

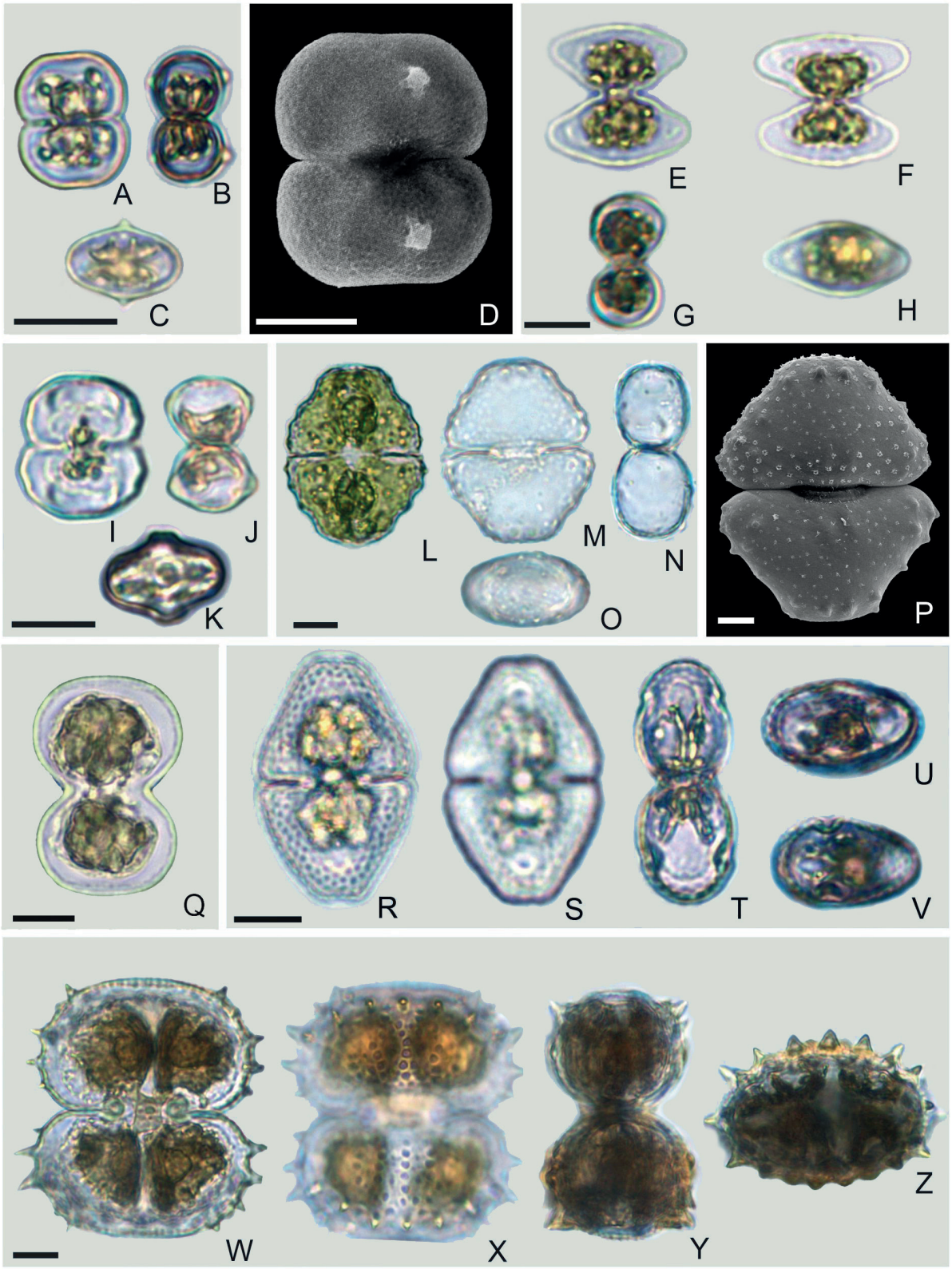

Figure 3. *Cosmarium* from the Pantanal dos Marimbus **A–D.** *Cosmarium bireme* var. *barbadense:* frontal view (**A, D**), lateral view (**B**), apical view (**C**), Detail of the cell wall in SEM (**D**); **E–H.** *Cosmarium capitulum:* frontal view (**E, H**), lateral view (**G**), apical view (**H**); **I–K.** *Cosmarium clepsydra* var. *alaskanum*: frontal view (**I**), lateral view (**J**), apical view (**K**); **L–P.** *Cosmarium columbianum*: frontal view (**L**, **M**, **P**), lateral view (**N**), apical view (**O**), Detail of the cell wall in SEM (**P**); **Q.** *Cosmarium connatum* var. *truncatum:* frontal view (**Q**); **R–V.** *Cosmarium granatum* var. *ocellatum*: frontal view (**R–S**), lateral view (**T**), apical view (**U–V**); **W–Z.** *Cosmarium guatemalense*: frontal view (**W–X**), lateral view (**Y**), apical view (**Z**). Scale bar 10 µm (LM), 5 µm (SEM).

Note – This variety was previously reported in Brazil by De-Lamonica-Freire & Heckman (1996) for the State of Mato Grosso do Sul. Still, the taxon was just mentioned in a checklist, without any additional taxonomic information (*i.e.*, cell dimensions and illustrations), therefore making it impossible to confirm its identification. Thus, the present record confirms the occurrence of this variety in Brazil.

8. *Cosmarium capitulum* Roy & Bisset, J. Bot. 24: 195. 1886.

(Fig. 3E-H).

Cell dimensions – length 16 µm, breadth 19 µm, breadth of isthmus 5 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.05 mS.cm^{-1}; dissolved oxygen 6.8 mg.L^{-1}; pH 7; total dissolved solids 0.02; water temperature 27.8 ºC; water transparency 0.6 m.

Distribution – Cosmopolitan; South America: Chile, Brazil (Espírito Santo - ?; Bahia - first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 241798, HUEFS 242434).

Note – The occurrence of *C. capitulum* in Brazil has been somewhat uncertain, as the only taxonomic record was performed by Delazari-Barroso *et al.* (2007) as "*Cosmarium* cf. *capitulum*" based on phytoplankton samples from Duas Bocas Reservoir, Espírito Santo State. Analyzing Fig. 53 provided by the referred authors, we noted that the taxon illustrated probably does not correspond to *C. capitulum*, especially the apical view that is more oval than elliptic, differing from the material described and illustrated by Roy & Bisset (1886: 195, Fig. 9). Another taxon that is very similar to *C. capitulum* is *Staurastrum pachyrhynchum* var. *tenerum* Grönblad, which differs primarily in having triangular cells in apical view.

9. *Cosmarium clepsydra* var. *alaskanum* Croasdale, Trans. Amer. Micros. Soc. 75(1): 22. 1956.

(Fig. 3I-K).

Cell dimensions – length 17 µm, breadth 15 µm, breadth of isthmus 5 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.01 mS.cm^{-1}; dissolved oxygen 6.8 mg.L^{-1}; pH 8.1; total dissolved solids 0.01; water temperature 26.7 ºC; water transparency 0.85 m.

Distribution – North America (USA: Alaska), Europe (Norway); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242426); 18/IX/2017, M.A.Santos *et al.* s/n. (HUEFS 242479); 23/X/2018, M.A.Santos *et al.* s/n. (HUEFS 253790).

Note – This variety differs from the nominate variety in the semicells being in general octagonal-elliptic rather than triangular in face view. Croasdale (1956), during the diagnosis of the var. *alaskanum* also mentioned that the median protuberance is 3-dentate, although it is not always easily distinguished. The specimens which we examined had variable protuberance from non-dentade to 3-dentade (rare), therefore we consider the octagonal-elliptic shape of semicells to be the best feature to distinguish from the nominate variety.

It was surprising to find this variety in northeastern Brazil. Its occurrence has been so far known only to the Temperate region (subarctic), where the temperatures are generally relatively low. Despite that, pH conditions from the Marimbus (pH=6.8–8.1) agree with those reported by Croasdale for Alaska samples (6.4–8.6, with pH 8.0 the most typical condition).

10. *Cosmarium columbianum* G.S.West, Mem. Soc. Sci. nat. Neuchatel 5(2): 1036. 1914.

(Fig. 3L-P).

Cell dimensions – length 41.5-42.5 µm, breadth 33.5-36 µm, breadth of isthmus 10.5-12.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Nymphaea amazonum*. Conductivity 0.06 (± 0.023 mS.cm^{-1}); dissolved oxygen 6.3 (± 1.2 mg.L^{-1}); pH 6.9 (± 0.6); total dissolved solids 0.03 (± 0.01); water temperature 30.5 (± 1.1 ºC); water transparency 0.74 (± 0.07 m).

Distribution – South America: Colombia, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242420, HUEFS 242434); 18/IX/2017, M.A.Santos *et al.* s/n. (HUEFS 242479); 09/XII/2011, G.J.P.Ramos & C.A.Ribeiro s/n. (HUEFS 185390).

Note – This is a rare species, known so far only in high altitude mountains from Colombia. It is quite similar to *Cosmarium corumbense* Borge. However, this latter species differs by having a cell with few granules at lower lateral sides, and in apical view, the granules are arranged at margins, not in ring-like as *C. columbianum*. The SEM analysis revealed the punctuations seen under LM, actually, are pores with mucilage remains revesting all the cell.

11. *Cosmarium connatum* var. *truncatum* West, Bot. J. Linn. Soc. 29: 161. 1892.

(Fig. 3Q).

Cell dimensions – length 45 µm, breadth 25 µm, breadth of isthmus 20 µm.

Habitat – This variety was found associated with periphyton of *Nymphaea amazonum*. Conductivity 0.06 mS.cm^{-1}; dissolved oxygen 5.9 mg.L^{-1}; pH 6.9; total dissolved solids 0.03; water temperature 29.9 ºC; water transparency 0.76 m.

Distribution – Europe, Asia; South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253740).

Note – The var. *truncatum* was described by West (1892) based on material from Ireland. It differs from the nominate variety by having truncate apices and deeper median constriction. This variety is rare in the study area, occurring associated with *Nymphaea amazonum*.

12. *Cosmarium granatum* var. *ocellatum* West & G.S.West, Trans. Amer. Micros. Soc. 5: 246. 1896.
(Fig. 3R-V).

Cell dimensions – length 33.5–40 µm, breadth 20.5 µm, breadth of isthmus 8 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.01 mS.cm^{-1}; pH 6.9; total dissolved solids 0.01; water temperature 28.1 ºC; water transparency 0.7 m.

Distribution – North America (Canada, USA), Europe (Italy), Asia (India, Sri Lanka, Japan); South America: Brazil (Paraná - ?, Bahia - first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 29/VI/ 2011, G.J.P.Ramos & C.A.Ribeiro s/n. (HUEFS 178376); Lençóis, Pantanal dos Marimbus (Remanso), 11/II/2012, G.J.P.Ramos & C.A.Ribeiro s/n. (HUEFS 185427).

Note – The only report of this variety in Brazil was performed by Carvalho *et al.* (2015) based on samples from Campo Mourão, Paraná State. However, the main feature of this variety (cell wall with a large median scrobicle, Fig. 3S) was not mentioned in the description, and it is not clearly visible in the figures provided by authors (Carvalho *et al.* 2015: Figs. 9, 10). As the presence of scrobicles is doubtful in those specimens from Paraná, we consider the taxon from Bahia the first confirmed record of var. *ocellatum* in Brazil.

13. *Cosmarium guatemalense* Taylor, Bot. Not. p.117. 1939.
(Fig. 3W-Z).

Cell dimensions – length 57.5-61.5 µm, breadth 47-50 µm, breadth of isthmus 12-14.5 µm.

Habitat – This species was found generally associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 (± 0.008 mS.cm^{-1}); dissolved oxygen 6.6 (± 0.5 mg.L^{-1}); pH 6.9 (± 0.3); total dissolved solids 0.03 (± 0.008); water temperature 27.2 (± 0.4 ºC); water transparency 0.60 (± 0.4 m).

Distribution – Central America (Guatemala, Panama); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et. al.* s/n. (HUEFS 241798, HUEFS 242429, HUEFS 242434, HUEFS 242437).

Note – *Cosmarium guatemalense* is a relatively rare species, described by Taylor (1939) from material collected at Lake Zotz, Guatemala, and known so far only in Central America. This species is identical to *Cosmarium paraguayense* Borge, but it differs from this latter by having smaller cells with many large shallow pits that may be somewhat scattered or forming U-shaped rows (Fig. 3X).

14. *Cosmarium hammeri* var. *sinuatum* Borge, Ark. Bot. 1: 96. 1903.
(Fig. 4A-B).

Cell dimensions – length 25 µm, breadth 20 µm, breadth of isthmus 7 µm.

Habitat – This variety was found associated with periphyton of *Cabomba caroliniana*. Conductivity 0.01 mS.cm^{-1}; dissolved oxygen 6.8 mg.L^{-1}; pH 8.1; total dissolved solids 0.01; water temperature 26.7 ºC; water transparency 0.85 m.

Distribution – South America: Paraguay, Bolivia, Brazil (first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/X/2018, M.A.Santos *et al.* s/n. (HUEFS 253789).

Note – This variety was described by Borge (1903) based on samples collected in Areguá, Paraguay. It differs from the nominate variety in having cells with basal lobes slightly concave and a thickened scrobicle, which is better seen at the lateral view. Biolo & Bicudo (2018) prepared a checklist of *Cosmarium* from Brazil and reported the occurrence of this variety, but not provided additional information on this record (such as paper where taxon came from, taxonomic data, or even its distribution in Brazil). Thus, the specimens from Bahia represent the first confirmed record for Brazilian flora. This variety is probably endemic to South America.

15. *Cosmarium isthmochondrum* var. *asymmetricum* Scott & Grönblad, Acta. Soc. Sc. Fenn. n.s.B 2(8): 18. 1957.
(Fig. 4C-F).

Cell dimensions – length 14.5-18 µm, breadth 12.5-14.5 µm, breadth of isthmus 3.5-7.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.03 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.7 (± 0.3 mg.L^{-1}); pH 7.7 (± 0.6); total dissolved solids 0.01 (± 0.01); water temperature 29.2 (± 3.1 ºC); water transparency 0.66 (± 0.26 m).

Distribution – North America, South America: Brazil (Bahia - first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241798); 18/II/2018, M.A.Santos *et al.* s/n.

(HUEFS 253745); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253756, HUEFS 253757); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253769); 23/X/2018, M.A.Santos & H.M.D.Oliveira s/n. (HUEFS 253790).

Note – This variety was reported in Brazil by Oliveira *et al.* (2011) based on samples from the northern coast of Bahia. Despite this, it is not possible to clearly see the details of the wall in the cell face. The semicell outline of Figure 5 (Oliveira *et al.* 2011) is pyramidate-rectangular, therefore more elongated than the specimens described by Scott & Grönblad (1957). Perhaps the taxon reported by Oliveira *et al.* (2011) is *Cosmarium inaequalinotatum* Scott & Grönblad (1957), another species that also occurs in the Marimbus. Biolo & Bicudo (2018) also mentioned the occurrence of var. *asymmetricum* in a checklist of that genus from Brazil. Still, there is no taxonomic information on that taxon, such as figures or descriptions, making it impossible to re-study.

Nevertheless, independent of the taxon reported by Oliveira *et al.* (2011) and Biolo & Bicudo (2018), the present record confirms the occurrence of that variety in Brazil.

Cosmarium isthmochondrum var. *asymmetricum* is identical to *C. subdanicum* var. *bigranulatum* Förster, but

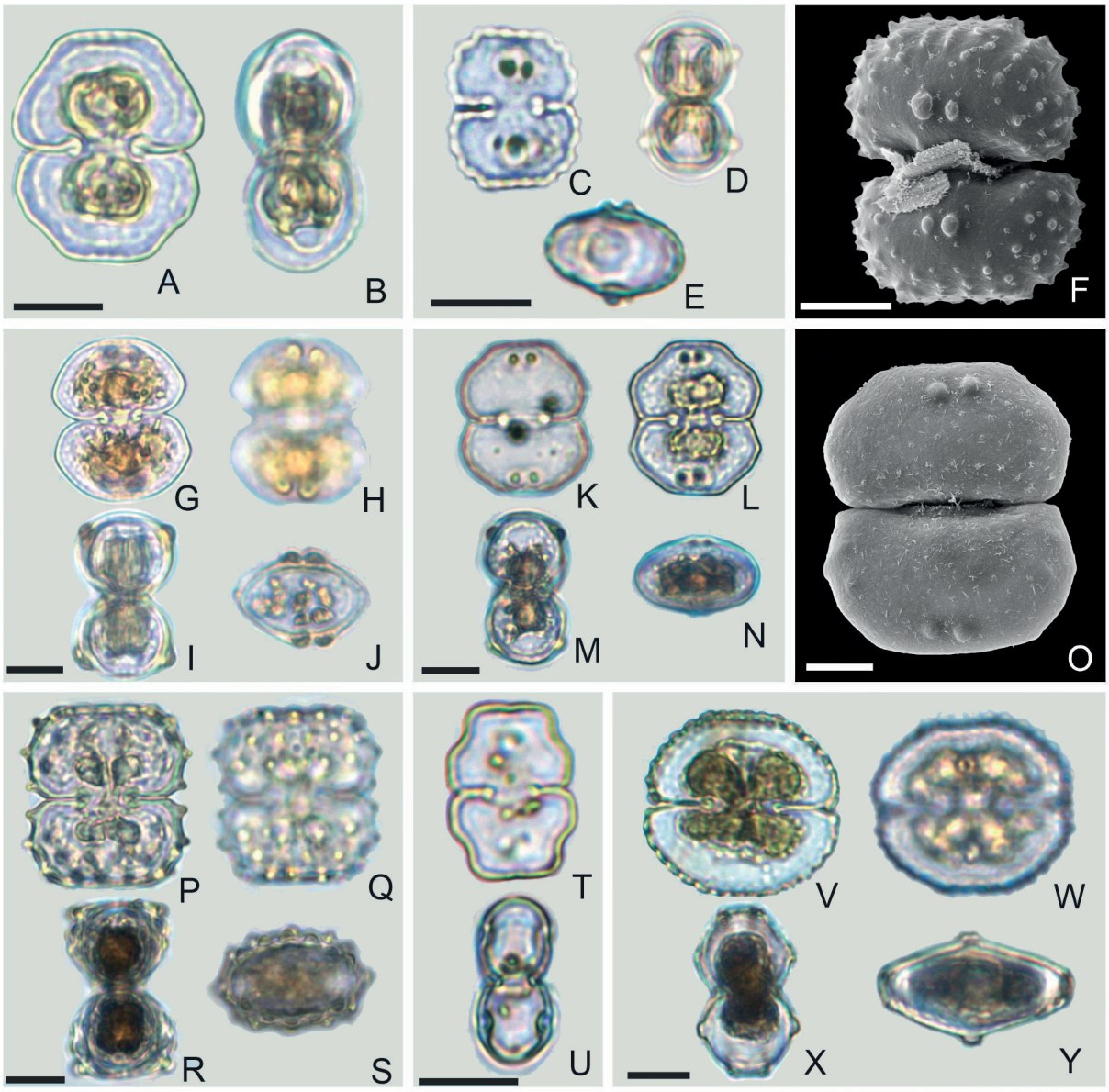

Figure 4. *Cosmarium* from the Pantanal dos Marimbus **A–B.** *Cosmarium hammeri* var. *sinuatum:* frontal view (**A**), lateral view (**B**); **C–F.** *Cosmarium isthmochondrum* var. *asymmetricum:* frontal view (**C**), lateral view (**D**), apical view (**E**), Detail of the cell wall in SEM (**F**); **G–J.** *Cosmarium mamilliferum* var. *bituberculatum*: frontal view (**G–H**), lateral view (**I**), apical view (**J**); **K–O.** *Cosmarium mamilliferum* var. *madagascariense*: frontal view (**K–L**, **O**), lateral view (**M**), apical view (**N**), Detail of the cell wall in SEM (**O**); **P–S.** *Cosmarium mayori*: frontal view (**P–Q**); **T–U.** *Cosmarium miedzyrzecense* var. *monomazum*: frontal view (**T**), lateral view (**U**); **V–Y.** *Cosmarium monomazum*: frontal view (**V–W**), lateral view (**X**), apical view (**Y**). Scale bar 10 µm (LM), 5 µm (SEM).

this latter variety differs from having cells with two central granules which are of the same size, and the isthmus region has no granules. However, we recommend further detailed studies to evaluate the relation of those taxa.

16. *Cosmarium mamilliferum* var. *bituberculatum* (F.E.Fritsch & M.F.Rich) Bourrelly, Bull. Inst. Franç. Afr. Noire, ser. A, 19: 1070. 1957.

≡ *Cosmarium bituberculatum* F.E.Fritsch & M.F.Rich, Trans. Roy. Soc. S. Afr. 25: 181. 1937.

(Fig. 4G-J).

Cell dimensions – length 26-27 µm, breadth 22-23 µm, breadth of isthmus 7-8 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.03 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.4 (± 1.3 mg.L^{-1}); pH 7.2 (± 0.8); total dissolved solids 0.01 (± 0.01); water temperature 31.9 (± 2.4 °C); water transparency 0.67 (± 0.12 m).

Distribution – Africa, South-west Asia (India); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242429, HUEFS 242431); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253747, HUEFS 253750, HUEFS 253751); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253757, HUEFS 253763); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253769, HUEFS 253772).

Note – *Cosmarium mamilliferum* was described by Nordstedt (1870) based on specimens collected in the Lagoa Santa region, southeastern Brazil. Currently, there are seven varieties, generally reported for the Tropical region, including var. *bituberculatum*. During studies on material from Macina, French Sudan, Bourrelly (1957) proposed this variety based on *Cosmarium bituberculatum*. The cell outline of the Brazilian specimens is more similar to those reported by Grönblad & Croasdale (1971, see Fig. 87) from Namibia. Based on the current known distribution, restricted to Africa, India, and Brazil, this variety may have been dispersed yet during the supercontinent Gondwana, when those regions were connected. However, further detailed phylogeographic studies should be performed to verify whether this theory is applied to var. *bituberculatum* and other endemic desmids from those regions.

17. *Cosmarium mamilliferum* var. *madagascariense* West & G.S. West, Trans. Amer. Micros. Soc. 5: 57. 1895.

(Fig. 4K-O).

Cell dimensions – length 23-25.5 µm, breadth 19.5-22 µm, breadth of isthmus 6.5-7.5 µm.

Habitat – This variety was found generally associated with periphyton of *Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.03 mS.cm^{-1}); dissolved oxygen 8.2 (± 0.8 mg.L^{-1}); pH 7.7 (± 0.6); total dissolved solids 0.03 (± 0.01); water temperature 30.5 (± 3.4 °C); water transparency 0.74 (± 0.08 m).

Distribution – Africa, South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241797, HUEFS 241798, HUEFS 242429); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253746); 23/X/2018, M.A.Santos & H.M.D.Oliveira s/n. (HUEFS 253788).

Note – The var. *madagascariense* is a rare taxon, with available records so far only for the African continent. It differs from the nominate variety in having larger cells with rounded margins, cell wall slightly thickened, and punctate.

18. *Cosmarium mayori* G.S.West, Mem. Soc. Sci. nat. Neuchatel 5(2): 1038. 1914.

(Fig. 4P-S).

Cell dimensions – length 32-33.5 µm, breadth 27-27.5 µm, breadth of isthmus 7.5-9.5 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.02 mS.cm^{-1}; dissolved oxygen 6.3 mg.L^{-1}; pH 6.6; total dissolved solids 0.01; water temperature 32 °C; water transparency 0.64 m.

Distribution – South America: Colombia, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241797);); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253748).

Note – *Cosmarium mayori* is a rare taxon, known so far only for Colombia. It was described by West (1914) based on samples from Laguna de Ubaque, Eastern Andes, and posteriorly reported by Coesel (1992) also from the Andes region. Both records were from samples collected in high-altitude mountains (>2000 m), whereas the Brazilian specimens occurred at a much lower altitude (320 m).

This species is very similar to *Cosmarium areguense* Borge, another taxon endemic to South America. We have found it also in the study area, and it is somewhat difficult to separate those species as they have the same cell outline and cell dimensions. The only morphological feature to separate both taxa is the cell wall arrangement; *C. mayori* differs in having cells with three rows of granules, which are surrounded by conspicuous pores, whereas the *C. areguense* has two rows, which are more curved.

19. *Cosmarium miedzyrzecense* var. *monomazum* Grönblad, Acta Soc. Fauna et Flora Fenn. 49(7): 40. 1921.

(Fig. 4T-U).

Cell dimensions – length 18-19 µm, breadth 13-14 µm, breadth of isthmus 4-5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.04 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.3 (± 0.7 mg.L^{-1}); pH 6.8 (± 0.4); total dissolved solids 0.02 (± 0.02); water temperature 31.9 (± 2 ºC); water transparency 0.73 (± 0.11 m).

Distribution – Europe (Finland), North America (USA); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253747, HUEFS 253750); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253756); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253778).

Note – The var. *monomazum* was proposed by Grönblad (1921) based on specimens from Finland. It differs from the nominate variety in having subtrapeziform semicells, retuse apices, and no granules at the isthmus region. Overall, this variety is quite rare, known only for its type-locality and Mississippi (USA) (Prescott & Scott 1942). The only distinct morphological feature of Brazilian specimens is the scrobicles thickening, which is not as prominent as those reported from the northern hemisphere.

20. *Cosmarium monomazum* P.M.Lundell, Nova Acta Regiae Soc. Sci. Upsal. ser. 3, 8(2): 32. 1871.

(Fig. 4V-Y).

Cell dimensions – length 27 µm, breadth 31 µm, breadth of isthmus 11 µm.

Habitat – This species was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.04 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.6 (± 1.6 mg.L^{-1}); pH 7.4 (± 0.6); total dissolved solids 0.02 (± 0.01); water temperature 30.5 (± 2.1 ºC); water transparency 0.69 (± 0.19 m).

Distribution – Cosmopolitan; South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/IX/2017, M.A.Santos *et al.* s/n. (HUEFS 241804); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253744, HUEFS 253745, HUEFS 253747, HUEFS 253748, HUEFS 253750); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253753, HUEFS 253756, HUEFS 253762, HUEFS 253763, HUEFS 253766); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253768, HUEFS 253769, HUEFS 253772); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253781, HUEFS 253784).

Note – *Cosmarium monomazum* was described by Lundell (1871) based on material from Sweden. Although the reports are somewhat scarce in South America, it is considered a species with a cosmopolitan distribution. In Brazil, in addition to the typical variety reported in the present study, there are records of the two varieties, *dimazum* Willi Krieger and *brasiliense* (Kurt Först. & Eckert) G.J.P.Ramos & I.B.Oliveira, the latter also occurring in the study area.

21. *Cosmarium orthostichum* var. *compactum* West & G.S.West, A monograph of the British Desmidiaceae. III: 169. 1908.

(Fig. 5A-C).

Cell dimensions – length 19-22 µm, breadth 18-19 µm, breadth of isthmus 6-7 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 (± 0.01 mS.cm^{-1}); dissolved oxygen 7.1 (± 0.5 mg.L^{-1}); pH 6.8 (± 0.3); total dissolved solids 0.02 (± 0.007); water temperature 27.3 (± 0.6 ºC); water transparency 0.60 m.

Distribution – Europe, North America (USA, Canada); South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241798, HUEFS 242434).

Note – In Brazil, there are reports of nominate variety and var. *pumilum* P.Lundell so far. The var. *compactum* differs from the typical variety in having smaller cells, deeper constriction, sinus more narrowly linear, oblong-elliptic semicells, granules in 9 vertical and 3 or 4 horizontal series, vertical series upwardly divaricating, granules in the mid-region of the semicells larger than those near the sides (West & West 1908). In the study area, this variety is rare, occurring in general associated with *Utricularia foliosa*.

22. *Cosmarium panamense* Prescott, Trans. Amer. Micros. Soc 55: 504. 1936.

(Fig. 5D-F).

Cell dimensions – length 67 µm, breadth 53 µm, breadth of isthmus 18 µm.

Habitat – This species was found generally associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 (± 0.01 mS.cm^{-1}); dissolved oxygen 7.1 (± 0.5 mg.L^{-1}); pH 6.8 (± 0.3); total dissolved solids 0.02 (± 0.007); water temperature 27.3 (± 0.6 ºC); water transparency 0.60 m.

Distribution – Asia, Middle East, Central America (Panama); South America: Brazil (first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241798, HUEFS 242434).

Note – Felisberto & Rodrigues (2010) and Biolo & Bicudo (2018) reported in checklists the occurrence of *C. panamense* for Brazil. Still, they did not provide taxonomic data such as description, cell dimensions, or figures, making the re-study of that species impossible, including the confirmation of its identification. Thus, the present record confirms the occurrence of *C. panamense* in Brazilian territory.

23. *Cosmarium phaseolus* var. *subbireme* Racib. Pam. Akad. Umiej. Krakowie, Mat.-Przyr. 17: 83. 1889.

(Fig. 5G-I).

Cell dimensions – length 17 µm, breadth 20 µm, breadth of isthmus 5.5 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.02 mS.cm^{-1}; dissolved oxygen 6.3 mg.L^{-1}; pH 6.6; total dissolved solids 0.01; water temperature 32 °C; water transparency 0.64 m.

Distribution – Europe (France), Africa, South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242431); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 242479); 09/IV/2018, M.A.Santos *et al.* s/n (HUEFS 253763).

Note – The var. *subbireme* was proposed by Raciborski (1889) based on specimens associated with *Chara coronata* Ziz ex Bisch. (= *Chara braunii* C.C.Gmelin) from northern Italy. This variety differs from the nominate variety in having cells with larger median papillae, oblong semicells in apical view, and smooth cell wall. The few records of var. *subbireme* generally are from alkaline environments, *i.e.*, Krieger & Gerloff (1962) reported specimens occurring at pH 8,5–8,8. In the Marimbus, that variety typically occurred under circumneutral conditions with pH ranging from 7 to 7.5.

24. *Cosmarium polygonum* var. *acutius* Messik, Beitr. Geobot. Landesaufnahme Schweiz 24: 148. 1942.

(Fig. 5J-L).

Cell dimensions – length 9-11 µm, breadth 9-11.5 µm, breadth of isthmus 2.5-3 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.03 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.5 (± 1.3 mg.L^{-1}); pH 7 (± 0.7); total dissolved solids 0.01 (± 0.01); water temperature 31.4 (± 2.2 °C); water transparency 0.67 (± 0.14 m).

Distribution – Europe (Netherlands), South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.*

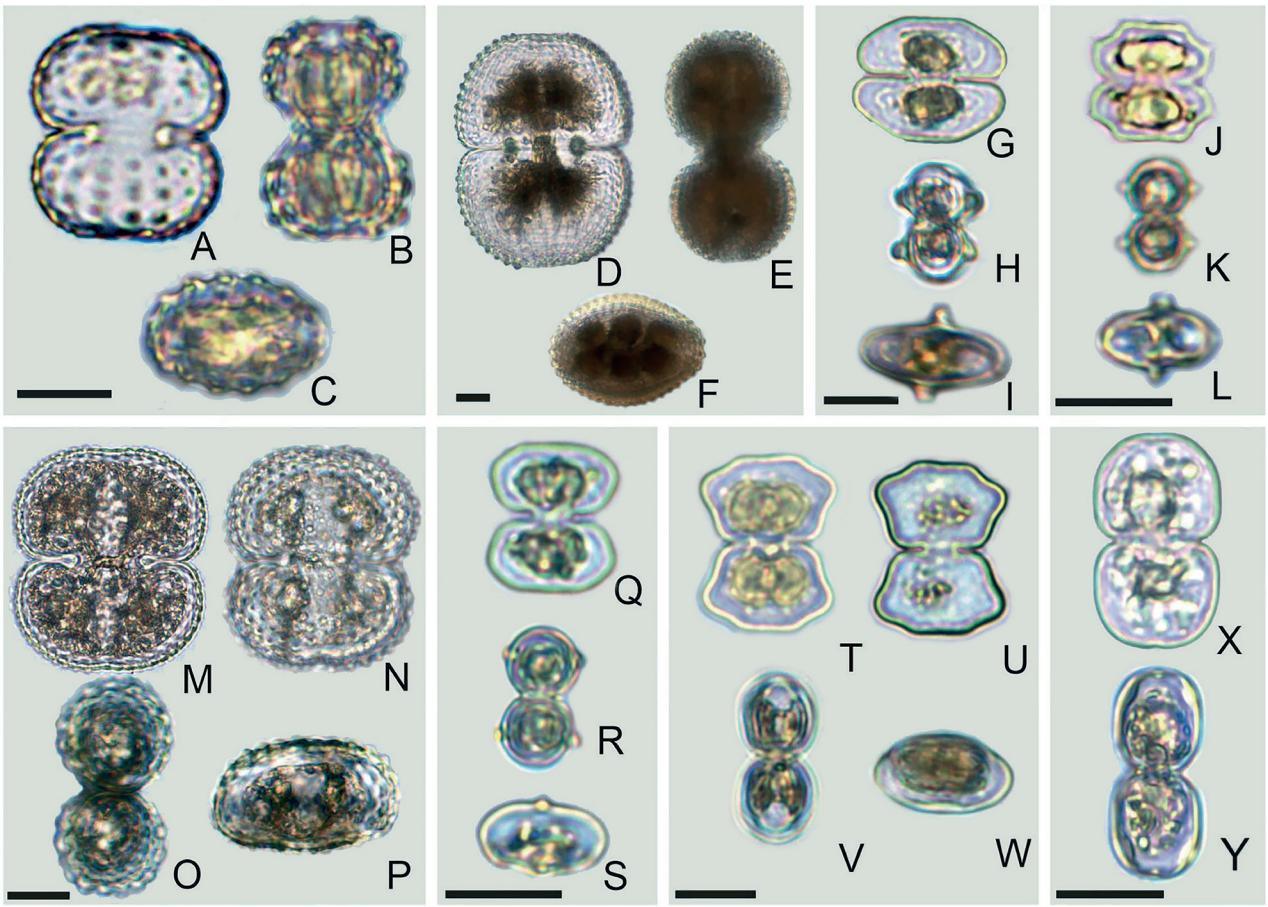

Figure 5. *Cosmarium* from the Pantanal dos Marimbus **A–C.** *Cosmarium orthostichum* var. *compactum:* frontal view (**A**), lateral view (**B**), apical view (**E**); **D–F.** *Cosmarium panamense*: frontal view (**D**), lateral view (**E**), apical view (**F**); **G–I.** *Cosmarium phaseolus* var. *subbireme*: frontal view (**G**), lateral view (**H**), apical view (**I**); **J–L.** *Cosmarium polygonum* var. *acutius*: frontal view (**J**), lateral view (**K**) apical view (**L**); **M–P.** *Cosmarium pseudoinsigne*: frontal view (**M-N**). lateral view (**O**), apical view (**P**); **Q–S.** *Cosmarium pseudoprotuberans* var. *kossinskajae*: frontal view (**Q**), lateral view (**R**), apical view (**S**); **T–W.** *Cosmarium pseudoprotuberans* var. *retusiforme*: frontal view (**T-U**), lateral view (**V**), apical view (**P**); **X–Y.** *Cosmarium rectangulare* var. *cambrense*: frontal view (**X**), lateral view (**Y**). Scale bar 10 µm.

s/n. (HUEFS 253745, HUEFS 253747, HUEFS 253748, HUEFS 253751); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253755, HUEFS 253756, HUEFS 253760); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253766, HUEFS 253768, HUEFS 253769, HUEFS 253771, HUEFS 253772, HUEFS 253774); 23/X/2018, M.A.Santos & H.M.D.Oliveira s/n. (HUEFS 253777, HUEFS 253778, HUEFS 253780, HUEFS 253779, HUEFS 253781, HUEFS 253783, HUEFS 253784).

Note – This taxon is similar to *Cosmarium sinostegos* and its varieties, differing by having cells with a wide blunt wart in the center, which is best visualized in apical view.

25. *Cosmarium pseudoinsigne* Prescott in G.W. Prescott, H.T. Croasdale, W.C. Vinyard, & C. E. Bicudo, N. Amer. Desmids 2(3): 238. 1981.

(Fig. 5M-P).

Cell dimensions – length 45 µm, breadth 30 µm, breadth of isthmus 10 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Water temperature 27 °C; water transparency 2.2 m.

Distribution – Europe, North America; South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Lençóis, Pantanal dos Marimbus (Remanso), 11/II/2012, G.J.P.Ramos & C.A.Ribeiro s/n (1HUEFS 185427).

Note – The name *Cosmarium pseudoinsigne* was proposed by Prescott (Prescott *et al.* 1981), as the previous name (*Cosmarium insigne* Schmidle, nom. illeg. 1893) was considered invalid because there is another species with the same name described previously by Turner (1893). Thus, the taxon proposed by Schmidle (1893) is considered a later homonym (ICN Art. 53.1, Turland *et al*. 2018).

Cosmarium pseudoinsigne is somewhat rare in the study area, only reported in the northern region of Marimbus, known as "Marimbus do Remanso", located at the Municipality of Lençóis. Unlike the "Marimbus do Baiano", which the wetland is predominantly lentic, the Remanso area is generally characterized by a faster flow of the Santo Antonio River.

26. *Cosmarium pseudoprotuberans* var. *kossinskajae* Willi Krieger & Gerloff, Die Gattung Cosmarium. Lieferung 2: 232. 1965.

(Fig. 5Q-S).

Cell dimensions – length 13 µm, breadth 12 µm, breadth of isthmus 3.5 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.07 $mS.cm^{-1}$; dissolved oxygen 7.5 $mg.L^{-1}$; pH 6.5; total dissolved solids 0.03; water temperature 27 °C.

Distribution – Europe, Asia, Arctic, North America (Canada); South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 241798).

Note – The var. *kossinskajae* was proposed by Krieger & Gerloff (1965) to accommodate minor forms of *Cosmarium pseudoprotuberans* and *Cosmarium phaseolus* Bréb. forma Schmidle (1898, 37, Taf. 1, Fig. 55). This variety differs from the nominate variety in having smaller cells with a median intumescence, sometimes almost rhombic.

27. *Cosmarium pseudoprotuberans* var. *retusiforme* F.E.Fritsch & M.F.Rich, Trans. Roy. Soc. S.Afr. 25: 193. 1937.

(Fig. 5T-W).

Cell dimensions – length 19-20 µm, breadth 14-15 µm, breadth of isthmus 4.5-5.5 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa, Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.03 $mS.cm^{-1}$); dissolved oxygen 5.9 (± 0.3 $mg.L^{-1}$); pH 6.4 (± 0.4); total dissolved solids 0.03 (± 0.02); water temperature 28.3 (± 1.1 °C); water transparency 0.8 (± 0.05 m).

Distribution – Africa (South Africa); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242431, HUEFS 242434); 22/VIII/2018, M.A.Santos *et al.* s/n (HUEFS 253778); 23/X/2018, M.A.Santos & H.M.D.Oliveira (HUEFS 253791, HUEFS 253795).

Note – This variety was proposed by Fritsch & Rich (1937) based on specimens from Africa. It differs from the nominate variety in having elliptical semicells in apical view without the median intumescence. Probably, the only country where this rare variety is known is South Africa (type locality). Therefore, the current record from Brazil expanses its geographic distribution also to South America.

28. *Cosmarium rectangulare* var. *cambrense* (W.B.Turner) West & G.S. West, J. Bot. 34: 379. 1896.

(Fig. 5X-Y).

Cell dimensions – length 24 µm, breadth 13.5 µm, breadth of isthmus 5.5µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 $mS.cm^{-1}$; dissolved oxygen 5.9 $mg.L^{-1}$; pH 6.9; total dissolved solids 0.03; water temperature 29.9 °C; water transparency 0.76 m.

Distribution – Africa, Europe, Asia, Oceania; South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 22/VIII/2018, M.A.Santos *et al.* s/n (HUEFS 253741).

Note – This variety was proposed by West & West (1896) during a taxonomic discussion on *C. rectangulare*

var. *africanum* West & G.S. West reported from Central Africa. The var. *cambrense* differs from the nominate variety in having cells relatively longer, the lower part of the cell sometimes is a little divergent, and the apex is often narrower. It was observed at the Brazilian specimens a thickening in the cell wall, well visible in the lateral view.

29. *Cosmarium refringens* W.R.Taylor, Pap. Mich. Acad. Sc. Arts Lett. 19: 265. 1934.
(Fig. 6A-C).

Cell dimensions – length 34 µm, breadth 22 µm, breadth of isthmus 7 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa, Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.04 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.6 (± 0.3 mg.L^{-1}); pH 7.4 (± 0.6); total dissolved solids 0.02 (± 0.01); water temperature 30.5 (± 2.1 °C); water transparency 0.7 (± 0.17 m).

Distribution – Europe, Asia, North America (Canada); South America: Argentina, Brazil (Mato Grosso - ? , – Bahia - first confirmed record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242431); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 242474); 19/VIII/2011, G.J.P.Ramos & C.W.N. Moura s/n (HUEFS 185352); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253744, HUEFS 253751); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253755, HUEFS 253754, HUEFS 253757, HUEFS 253759);); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253765, HUEFS 253766, HUEFS 253768, HUEFS 253771, HUEFS 253772, HUEFS 253774); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253780).

Note – The occurrence of this species in Brazil was reported by De-Lamonica-Freire & Heckman (1996) and Freitas & Loverde-Oliveira (2013), both for the state of Mato Grosso. However, there is no taxonomic data in these papers, such as description, cell dimensions, or figures to confirm the identification of this species. Thus, the taxon from Bahia represents the first confirmed taxonomic record of *C. refringens* for Brazil.

30. *Cosmarium regnellii* var. *chondrophorum* Skuja, Nova Acta R. Soc. Sc. Upsal., ser. 4, 14(5): 139. 1949.
(Fig. 6D-G).

Cell dimensions – length 15-16 µm, breadth 11-12 µm, breadth of isthmus 3-4 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa* and *Nymphaea amazonum*. Conductivity 0.015 (± 0.024 mS.cm^{-1}); dissolved oxygen 6.5 (± 1 mg.L^{-1}); pH 6.7 (± 0.7); total dissolved solids 0.01 (± 0.012); water temperature 29.3 (± 3.8 °C); water transparency 0.76 (± 0.1 m).

Distribution – Africa, Middle East, Asia, South America: Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242423); 18/IX/2017, M.A.Santos *et al.* s/n. (HUEFS 242471); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253746); 23/X/2018, M.A.Santos & H.M.D.Oliveira (HUEFS 253788, HUEFS 253791).

Note – This variety differs primarily from the nominate variety in having larger cells with a central wart. Our SEM analysis also revealed that the cell wall is entirely scrobiculate, therefore another important morphological feature distinct from the typical variety, which has a smooth cell wall.

31. *Cosmarium regnesi* var. *tritum* West, J. Linn. Soc. London. Botany 29: 149. 1892.
(Fig. 6H-I).

Cell dimensions – length 11 µm, breadth 10.5 µm, breadth of isthmus 5 µm.

Habitat – This variety was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.01 mS.cm^{-1}; dissolved oxygen 6.0 mg.L^{-1}; pH 7.2; total dissolved solids 0.01; water temperature 27.8 °C; water transparency 1.4 m.

Distribution – Europe, Asia; South America, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253772).

Note – It differs from the nominate variety by having no granules and cells more robust. This variety was relatively rare in the study area, and just a few cells were observed occurring associated with *Utricularia foliosa*.

32. *Cosmarium subgranatum* var. *borgei* Willi Krieger, Ber. Deutsch. Bot. Ges. 61: 269. 1944.
(Fig. 6J-L).

Cell dimensions – length 21-23 µm, breadth 14-15 µm, breadth of isthmus 5-5.5 µm.

Habitat – This variety was found generally associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.02 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.8 (± 0.8 mg.L^{-1}); pH 7 (± 0.7); total dissolved solids 0.01 (± 0.01); water temperature 28.3 (± 2.3 °C); water transparency 0.8 (± 0.11 m).

Distribution – Europe, Asia; South America, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 09/XII/2011, G.J.P.Ramos & C.A.Ribeiro s/n (HUEFS 185390); 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242423, HUEFS 242434, HUEFS 242437); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253747); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253753).

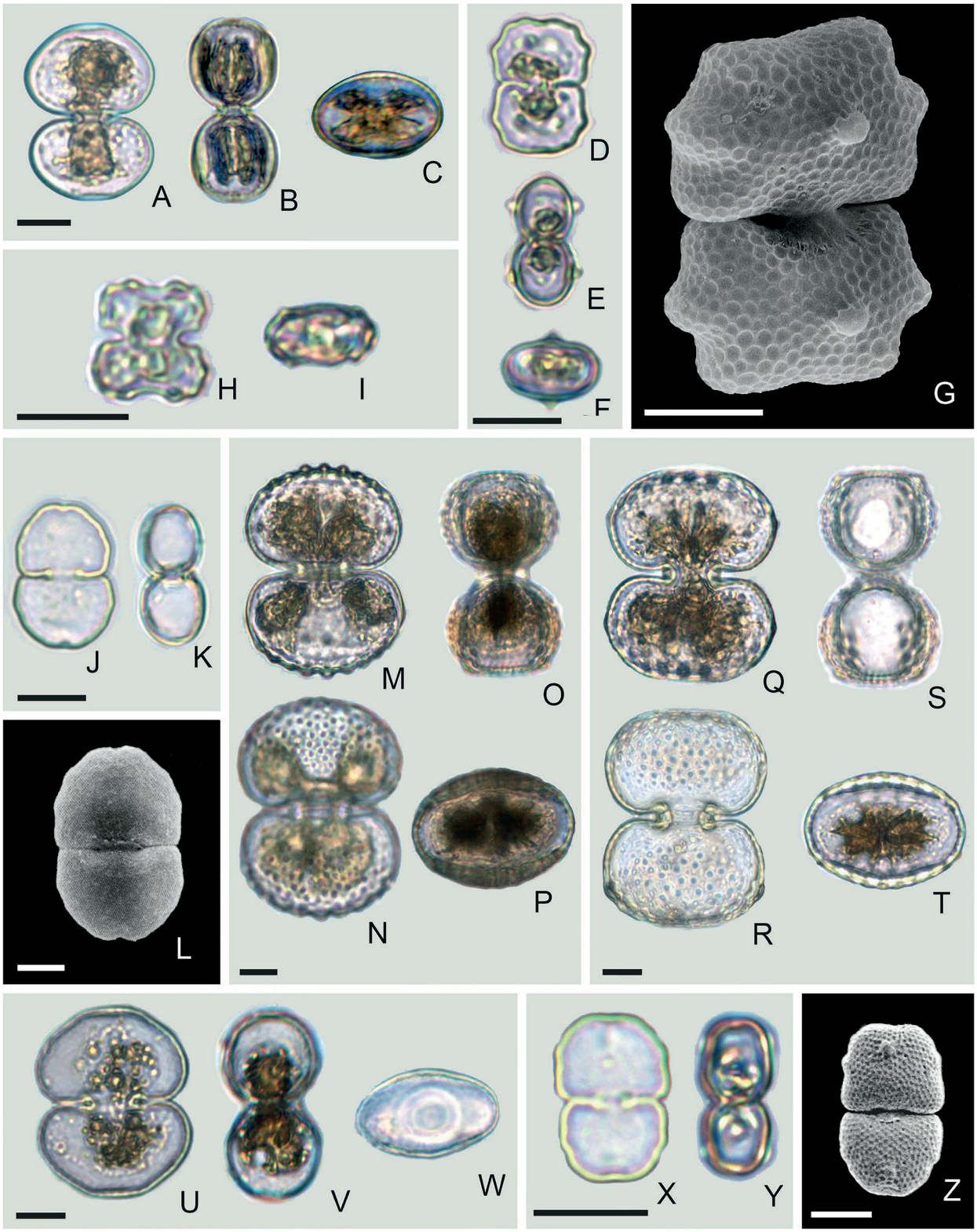

Figure 6. *Cosmarium* from the Pantanal dos Marimbus **A–C**. *Cosmarium refringens:* frontal view (**A**), lateral view (**B**), apical view (**C**); **D–G**. *Cosmarium regnellii* var. *chondrophorum:* frontal view (**D**), lateral view (**E**), apical view (**F**), Detail of the cell wall in SEM (**G**); **H–I**. *Cosmarium regnesi* var. *tritum*: frontal view (**H**), apical view (**I**); **J–L**. *Cosmarium subgranatum* var. *borgei*: frontal view (**J, L**), lateral view (**K**), Detail of the cell wall in SEM (**L**); **M–P**. *Cosmarium subnudiceps*: frontal view (**M–N**), lateral view (**O**), apical view (**P**); **Q–T**. *Cosmarium subnudiceps* var. *angulare*: frontal view (**Q–R**), lateral view (**S**), apical view (**T**); **U–W**. *Cosmarium subphaseolus*: frontal view (**U**), lateral view (**V**) apical view (**W**); **X–Z**. *Cosmarium subreinschii* var. *tholiforme*: frontal view (**X, Z**), lateral view (**Y**), Detail of the cell wall in SEM (**Z**). Scale bar 10 µm (LM), 5 µm (SEM).

Note – Krieger (1944) proposed the var. *borgei,* which was validated years later by Krieger & Gerloff (1965) based on the phenotypical variation of six taxa, including some intraspecific representatives of *Cosmarium granatum* Bréb. ex Ralfs, *C. laeve* Rabenh. and *C. meneghinii* Bréb. ex Ralfs. This variety differs from the nominate variety in having semicircular semicells with margins crenate (10 roughly equal waves, as described by Krieger 1944). The Brazilian specimens generally have slightly crenate margins, not always well visible in LM. Among the taxa transferred to var. *borgei*, the taxon from Marimbus resembles more the morphotype designed by Krieger (1932) as "*Cosmarium laeve* var. *septentrionale* Wille".

33. *Cosmarium subnudiceps* West & G.S.West, J. Linn. Soc., London. Botany 33: 306. 1898.
(Fig. 6M-P).

Cell dimensions – length 54 µm, breadth 43 µm, breadth of isthmus 12 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.04 (± 0.03 $mS.cm^{-1}$); dissolved oxygen 6.3 (± 1 $mg.L^{-1}$); pH 6.8 (± 0.3); total dissolved solids 0.02 (± 0.018); water temperature 30.1 (± 3.8 °C); water transparency 0.75 (± 0.08 m).

Distribution – North America (USA, Canada), Europe (Italy); South America: (Argentina, Bolivia), Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242434, HUEFS 242437); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253748); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253759, HUEFS 253760); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253778).

Note – This species is characterized in having ellipsoid semicells with cell wall ornamented by granules surrounded by scrobicles, which are variable from circular to triangular. It was described by West & West (1898) from material collected in Laconia, New Hampshire (USA). Couté & Tell (1981), based on specimens from Argentina, provided for the first time SEM images for this species, evidencing the heterogeneous pattern of cell wall including smooth part, granules and scrobicles, and detailed dimensions of those ornamentations.

34. *Cosmarium subnudiceps* var. *angulare* Scott & Grönblad, Acta Soc. Sc. Fenn. N. s. B, 2(8): 23. 1957.
(Fig. 6Q-T).

Cell dimensions – length 55-60 µm, breadth 42-46 µm, breadth of isthmus 13-14 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.03 (± 0.018 $mS.cm^{-1}$); dissolved oxygen 6.5 (± 1 $mg.L^{-1}$); pH 7 (± 0.7); total dissolved solids 0.01 (± 0.015); water temperature 31.4 (± 1.5 °C); water transparency 0.66 (± 0.15 m).

Distribution – North America (USA), South America (Argentina), Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n (HUEFS 242434); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253745, HUEFS 253748, HUEFS 253751); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253753, HUEFS 253757, HUEFS 253766, HUEFS 253774).

Note – The var. *angulare* was described by Scott & Grönblad (1957) based on material from Florida (USA). It differs from the nominate variety in having subhexagonal semicells, with cell wall ornamented by granules interspersed with triangular or circular scrobiculations connected by lines forming triangles. This variety is similar to *Cosmarium hexagonum* Nordst.; however, this species differs by having elliptical-hexagonal semicells, convex margins, and cell wall finely punctate with subapical granules.

35. *Cosmarium subphaseolus* Kouwets, Arch. Hydrobiol. Suppl. 137 (Algol. Stud. 101): 44. 2001.
(Fig. 6U-W).

Cell dimensions – length 35-37 µm, breadth 30-31 µm, breadth of isthmus 7-8 µm.

Habitat – this species was found associated with periphyton of *Utricularia foliosa*. Water temperature 25 °C; water transparency 2.2 m.

Distribution – Europe (France); Brazil (first record).

Material examined – BRAZIL. Bahia: Lençóis, Pantanal dos Marimbus (Remanso), 11/II/2012, G.J.P.Ramos & C.A.Ribeiro s/n (HUEFS 185418).

Note – *Cosmarium subphaseolus* is a rather rare species, described by Kouwets (2001) based on specimens from three France areas. So far, it was only known in those areas. Its occurrence in northeastern Brazil is interesting because evidencing that the species also is adapted to conditions of the Tropical Region. The Brazilian specimens have precisely the same morphological pattern, although slightly larger, from those reported by Kouwets (2001). According to this author, this species should be compared with *C. phaseolus* Bréb. ex Ralfs and *C. subtumidum* Nordst. In addition to these taxa, we recommend comparing *C. retusiforme* var. *major* Gutw., which differs by having cells with upper lateral margin slightly concave.

36. *Cosmarium subreinschii* var. *tholiforme* (W.R.Taylor) G.W.Prescott, Syn. N. Amer. Desmids 2(3): 312. 1981.
≡ *Cosmarium impressulum* f. *tholiforme* W.R.Taylor, Pap. Mich. Acad. Sci. Arts Lett. 19: 255. 1934.
(Fig. 6X-Z).

Cell dimensions – length 14 µm, breadth 8 µm, breadth of isthmus 3.5 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa, Nymphaea amazonum* and

Cabomba caroliniana. Conductivity 0.04 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.6 (± 0.3 mg.L^{-1}); pH 7.4 (± 0.6); total dissolved solids 0.02 (± 0.01); water temperature 30.5 (± 2.1 °C); water transparency 0.7 (± 0.17 m).

Distribution – North America (Canada); Asia (Myanmar), South America, Brazil (first record). **Material examined** – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242423); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 242479); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253744, HUEFS 253743, HUEFS 253745, HUEFS 253746, HUEFS 253747); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253753, HUEFS 253754, HUEFS 253755, HUEFS 253757, HUEFS 253759, HUEFS 253760, HUEFS 253762, HUEFS 253761, HUEFS 253763); 12/VI/2018, M.A.Santos *et al.* s/n. HUEFS (253765, HUEFS 253768, HUEFS 253771, HUEFS 253772, HUEFS 253774, HUEFS 253775); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253777, HUEFS 253778, HUEFS 253781).

Note – It differs from the nominate variety in having smaller cells, with apices slightly concave and scrobiculate cell wall. The Brazilian specimens have some variations only regarding the position of verrucae, which are generally in the subapical region.

37. *Cosmarium subspeciosum* var. *argentinense* Couté & Tell, Beth. Nova Hedwigia 68: 94. 1981.

(Fig. 7A-F).

Cell dimensions – length 76 µm, breadth 58 µm, breadth of isthmus 16 µm.

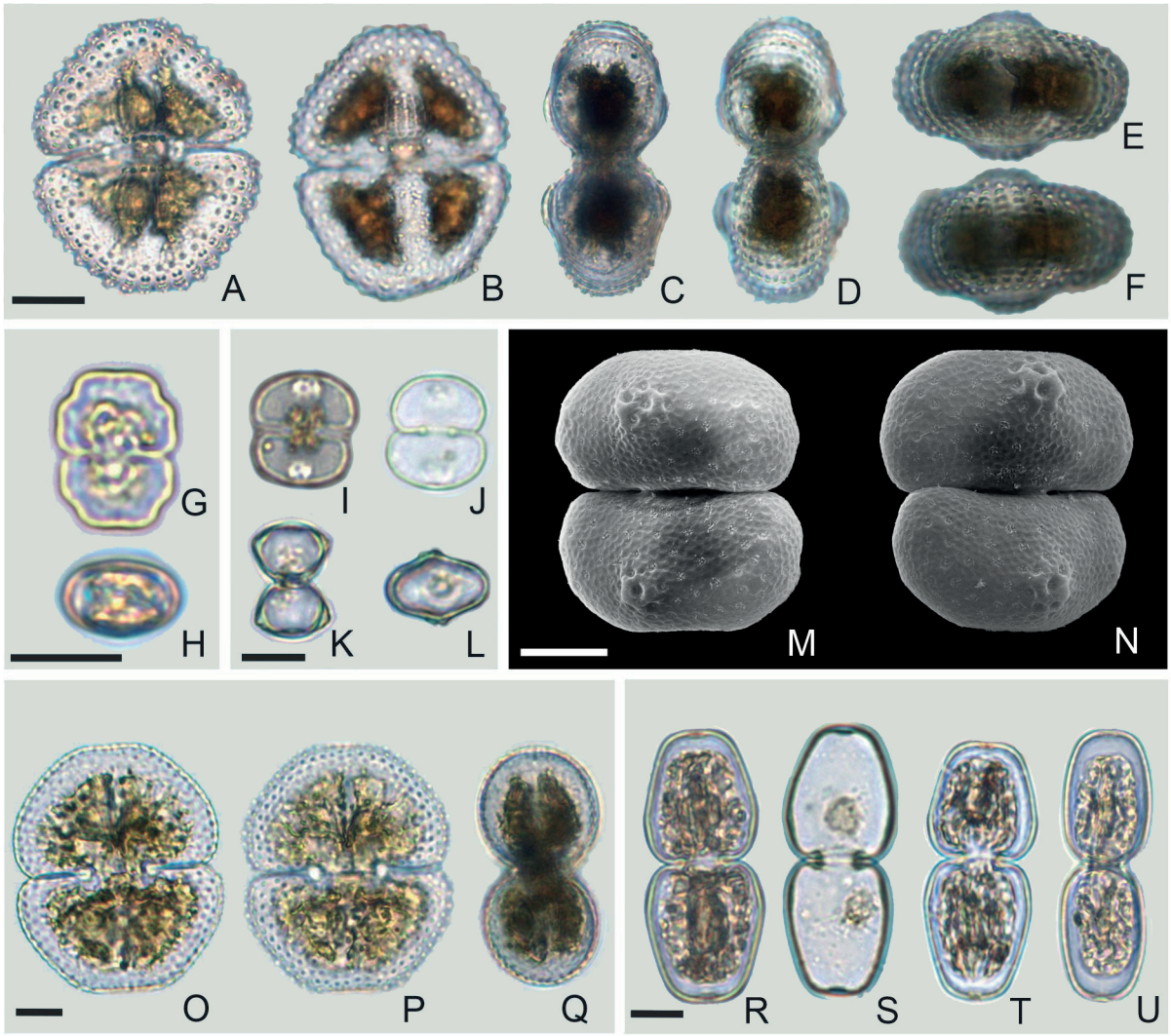

Figure 7. *Cosmarium* from the Pantanal dos Marimbus **A–F.** *Cosmarium subspeciosum* var. *argentinense:* frontal view (**A-B**), lateral view (**C-D**), apical view (**E-F**); **G–H.** *Cosmarium trilobulatum* var. *minus:* frontal view (**G**), apical view (**H**); **I–N.** *Cosmarium tumidum* var. *inflatum*: frontal view (**I–J**), lateral view (**K**), apical view (**L**), Detail of the cell wall in SEM (**M-N**); **P–Q.** *Cosmarium vexatum* var. *rotundatum*: frontal view (**O-P**), lateral view (**Q**); **R–U.** *Cosmarium zonatum* var. *angustum*: frontal view (**R-T**), lateral view (**U**). Scale bar 10 µm (LM), 5 µm (SEM).

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.05 mS.cm^{-1}; dissolved oxygen 6.8 mg.L^{-1}; pH 7; total dissolved solids 0.02; water temperature 27.8 °C; water transparency 0.6 m

Distribution – South America (Argentina); Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 241798).

Note – The var. *argentinense* was described by Couté & Tell (1981) based on material from Corrientes, Argentina. It differs from the nominate variety in having triangular semicells. Overall, this a rather rare taxon, known so far only for its type-locality and probably endemic to South America. The Brazilian specimens are identical to those from Argentina, although they seem to have cells with fewer rows of intramarginal granules (up to three).

38. *Cosmarium trilobulatum* var. *minus* (Wille) Willi Krieger & Gerloff, Die Gattung Cosmarium. Lieferung 1: 100. 1962.

≡ *Cosmarium trilobulatum* f. *minus* Wille, Forth. Vid.-Selsk. Christiania 1880(11):32 (1880).

(Fig. 7G-H).

Cell dimensions – length 76 µm, breadth 58 µm, breadth of isthmus 16 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.01 mS.cm^{-1}; dissolved oxygen 6 mg.L^{-1}; pH 7.2; total dissolved solids 0.01; water temperature 28 °C; water transparency 2.4 m.

Distribution – Europe; South America: French Guiana, Argentina, Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253772).

Note – It differs from the nominate variety in having smaller semicells. Due to this, it might be easily confused with representatives of *Cosmarium regnellii* Wille. Still, this latter species differs in having a divergent lower side margin and concave upper side margin.

39. *Cosmarium tumidum* var. *inflatum* (Schmidle) Willi Krieger & Gerloff, Die Gattung Cosmarium. Lieferung 1: 58. 1962.

≡ *Cosmarium tumidum* f. *inflatum* Schmidle, Bih. K. Svenska Vet.-Akad. Vetyx handl. 24(Afd. III): 24 (1898).

(Fig. 7I-N).

Cell dimensions – length 16 µm, breadth 15 µm, breadth of isthmus 4 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.02 mS.cm^{-1}); dissolved oxygen 7.5 (± 2.1 mg.L^{-1}); pH 7 (± 0.7); total dissolved solids 0.02 (± 0.01); water temperature 30.3 (± 2.9 °C); water transparency 0.75 (± 0.14 m).

Distribution – Europe (Sweden, Austria), North America, Asia (India); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano) 23/V/2017, G.J.P.Ramos *et al.* s/n. (HUEFS 242434); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 242474); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253750, HUEFS 253760, HUEFS 253762); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS HUEFS 253783).

Note – It differs from the nominate variety in having subapical swelling more pronounced, from clearer pores interspersed, while the remaining cell wall is slightly scrobiculate. In LM, sometimes the swelling seems two verrucae surrounded by scrobicles. This is the first time that this variety is reported for South America.

40. *Cosmarium vexatum* var. *rotundatum* Messik., Beitr. Geobot. Landesaufnahme Schweiz 24: 159. 1942.

(Fig. 7O-Q).

Cell dimensions – length 49-55µm, breadth 42-46 µm, breadth of isthmus 4 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa, Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.02 mS.cm^{-1}); dissolved oxygen 6.6 (± 1.5 mg.L^{-1}); pH 6.9 (± 0.4); total dissolved solids 0.02 (± 0.008); water temperature 31.4 (± 1.3 °C); water transparency 0.74 (± 0.17 m).

Distribution – North America, Europe; South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253741, HUEFS 253745, HUEFS 253747); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253752, HUEFS 253762); 23/X/2018, M.A.Santos & H.M.D.Oliveira s/n (HUEFS 253790); 04/XII/2018, M.A.Santos & E.Santos s/n (HUEFS 253805).

Note – It differs from the nominate variety in having cells with basal side margins more rounded, granules subacute, and some granules on the isthmus. From the present record, besides the nominate variety, *Cosmarium vexatum* is represented in Brazil by two varieties: var. *rotundatum* and var. *lacustre* Messik.

41. *Cosmarium zonatum* var. *angustum* Grönblad & Scott, Acta Bot. Fenn. 58: 35. 1958.

(Fig. 7R-U).

Cell dimensions – length 50-55µm, breadth 22-24 µm, breadth of isthmus 7.5-8.5 µm.

Habitat – This species was found associated with periphyton of *Utricularia foliosa, Nymphaea amazonum* and *Cabomba caroliniana*. Conductivity 0.06 (± 0.03 mS.cm^{-1}); dissolved oxygen 6.2 (± 0.9 mg.L^{-1}); pH 7 (± 0.4); total

dissolved solids 0.01 (± 0.017); water temperature 29.9 (± 2.1 °C); water transparency 0.76 (± 0.13 m).

Distribution – Europe (Netherlands), Africa (Sudan, Uganda, Kongo); South America: Brazil (first record).

Material examined – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 29/VI/ 2011, G.J.P.Ramos & C.A.Ribeiro s/n (HUEFS 178376); 20/VIII/2011, G.J.P.Ramos & C.W.N. Moura s/n (HUEFS 185359); 26/X/2011, G.J.P.Ramos & C.A.Ribeiro s/n (HUEFS 185368); 18/IX/2017, M.A.Santos *et al.* s/n (HUEFS 241804); 18/II/2018, M.A.Santos *et al.* s/n. (HUEFS 253741, HUEFS 253749); 09/IV/2018, M.A.Santos *et al.* s/n. (HUEFS 253755, HUEFS 253756); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253765); 12/VI/2018, M.A.Santos *et al.* s/n. (HUEFS 253772, HUEFS 253773); 22/VIII/2018, M.A.Santos *et al.* s/n. (HUEFS 253778, HUEFS 253779, HUEFS 253780).

Note – It differs from the nominate variety in having cells more elongated, narrowed toward the apices, which are ellipsoid in apical view. This is the first record of this variety in the American continent.

42. *Cosmarium imperiale* G.J.P.Ramos & C.W.N.Moura, sp. nov.
(Fig. 8A-K).

Cells 1.1. to 1.2 times longer than broad, deeply constricted, sinus open. Semicells subrectangular to subtrapeziform, elliptic in apical view, circular in lateral view. Cell wall ornamented with a crown of granules on the subapical margin, 3 granules surrounded by scrobicles on the median face of the semicell, and 1 granule on the middle of lateral margin. Chloroplast axial with 2 pyrenoids per semicell.

Cell dimensions – length 64–66.5 µm, width 55.5–57 µm, breadth of isthmus 17–18.5 µm, thickness 35–35.5 µm.

Type – BRAZIL. Bahia: Andaraí, Pantanal dos Marimbus (Baiano), 12º 45' 53.4" S, 41º 18' 36.1" W, 23/V/2017, G.J.P.Ramos, F.M.Costa & C.W.N.Moura s/n (Holotype, HUEFS 241798! [pro parte]). Population partially illustrated here in LM (Fig 8A-K).
Etymology – The pattern of the subapical row of granules resembles that of jewels of an imperial crown.

Distribution – Endemic to Chapada Diamantina, Bahia, Brazil.

Habitat – The new species was found associated with periphyton of *Utricularia foliosa*. Conductivity 0.06 (± 0.007 $mS.cm^{-1}$); dissolved oxygen 7.8 (± 0.5 $mg.L^{-1}$); pH 7.1 (± 0.8); total dissolved solids 0.05 (± 0.03); water temperature 28.7 (± 2.4 °C); water transparency 0.75 m; PO_4-P 0.02 mg L^{-1}; NO_2-N 0.02 mg L^{-1}; Silicate 0.33 mg L^{-1}.

Note – This new species is one of the rarest *Cosmarium* taxa found in the Marimbus. It is morphologically close to *C. cyathiforme* West & G.S.West; however, the latter differs in that it has no granule on the middle of the lateral margin, nor scrobicles on the wall, besides being half the cell size (length 35 µm, width 34 µm, isthmus 7.5 µm, thickness 21 µm). There are some other taxa with similar cell outline, differing especially in the ornamentation arrangement of the cell wall, such as *Cosmarium subnudiceps* var. *angulare*, and *Cosmarium hexagonum*. In addition to morphology, *Cosmarium imperiale* and all those mentioned taxa have the same distribution as they are endemic to the American continent.

Richness of Cosmarium

The taxonomic richness of *Cosmarium* was highest in *Utricularia foliosa* with 38 taxa, followed by *Cabomba caroliniana* (20) and *Nymphaea amazonum* (10). In terms of the species richness in the different macrophytes studied, those on *U. foliosa* contained 17 exclusive taxa, followed by *C. caroliniana* (two) and *N. amazonum* (one). Only six taxa occurred in all three macrophyte species: *Cosmarium zonatum* var. *angustum*, *C. vexatum* var. *rotundatum*, *C. subreinschii* var. *tholiforme*, *C. anisochondrum* var. *isthmolatum*, *C. refringens*, *C. pseudoprotuberans* var. *retusiforme*. The list of all taxa of *Cosmarium* and the richness in each macrophyte species is represented in the Venn diagram (Fig. 9).

Ecological aspects

Overall, throughout 2018 the water conditions were characterized by having circumneutral pH, with low electrical conductivity and low concentration of total suspended solids, besides being generally well oxygenated. The highest water transparency values were recorded in the dry months (April, August, and October), whereas the highest depth values were in the rainy months (February, June, and December). The limnological variables of samples from 2018 are summarized in the Table 1.

Aiming to verify the relation between the environmental variables and the taxa of *Cosmarium*, we have performed the Redundancy Analysis (RDA) (Fig. 10, Tab. 2). The analysis explained 17.3 % of the observed variation in the first two axes (12.8 % on-axis 1 and 4.5 % on-axis 2), but only the axis 1 was significant ($p<0.01$). The species and sampling units on axis 1 were ordered in the function of the temperature and depth ($r=0.75$ and $r=0.54$, respectively). Although not significant, axis 2 represented the variation in rainfall in 2018, with the sampling units in the rainy months (February, June, and December) being ordered on the positive side of the axis, and those in the dry months (April, August, and October), mostly, on the negative side. The taxa *Cosmarium bireme* var. *barbadense*, *Cosmarium mamilliferum* var. *madagascariense*, *Cosmarium mayori*, *Cosmarium subnudiceps*, and *Cosmarium subnudiceps* var. *angulare* were associated with higher temperature values, being grouped on the negative side of the axis 1 ($r> -0.5$). *Cosmarium zonatum* var. *angustum* was correlated mainly with depth ($r>0.4$). Mostly the taxa showed the highest densities in the months with low precipitation when the conductivity and transparency of the water were greater.

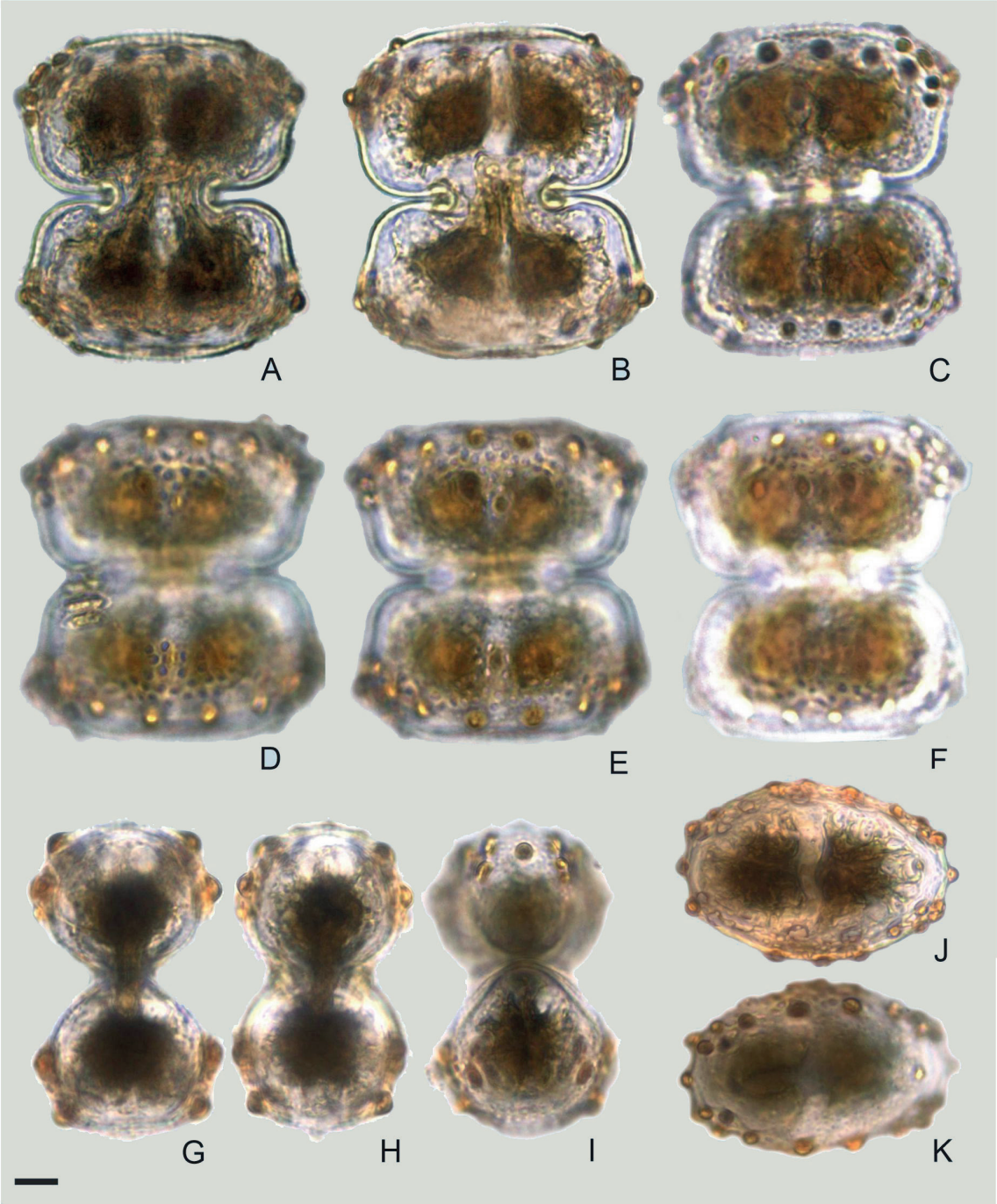

Figure 8. *Cosmarium imperiale* sp. nov. **A–F.** frontal view; **G–I.** lateral view; **J–K.** apical view. Scale bar 10 μm.

Table 1. Mean values and standard deviation of limnological variables during 2018 in the Pantanal dos Marimbus (Baiano), Bahia, Brazil.

Limnological variables	2018					
	February	April	June	August	October	December
Depth (m)	1.6 ± 0.2	2.0 ± 0.5	2.4 ± 0.04	1.9 ± 0.3	1.9 ± 0.3	3.5 ± 0.7
Dissolved oxygen (mg.L^{-1})	6.1 ± 0.5	8.3 ± 1.0	6.1 ± 0.5	8.4 ± 1.7	6.5 ± 0.7	7.0 ± 1.4
Electric conductivity (mS.cm^{-1})	0.04 ± 0.02	0.6 ± 0.1	0.02 ± 0.01	0.07 ± 0.0	0.03 ± 0.02	0.00 ± 0.00
pH	6.7 ± 0.3	7.3 ± 0.4	7.7 ± 1.0	7.6 ± 0.3	6.8 ± 0.9	6.6 ± 2.0
Total dissolved solids (ppt)	0.01 ± 0.01	0.03 ± 0.0	0.0 ± 0.0	0.03 ± 0.00	0.01 ± 0.01	0.0 ± 0.0
Total precipitation (mm)	109.1	65.4	106.4	18.5	11.4	181.5
Water temperature (°C)	31.3 ± 1.0	32.5 ± 1.4	28.3 ± 1.4	28.6 ± 0.3	26.9 ± 1.0	29.9 ± 0.8
Water transparency (cm)	60.6 ± 17.3	77.1 ± 7.0	61.0 ± 9.8	92.8 ± 10.2	83.1 ± 8.3	51.1 ± 3.9

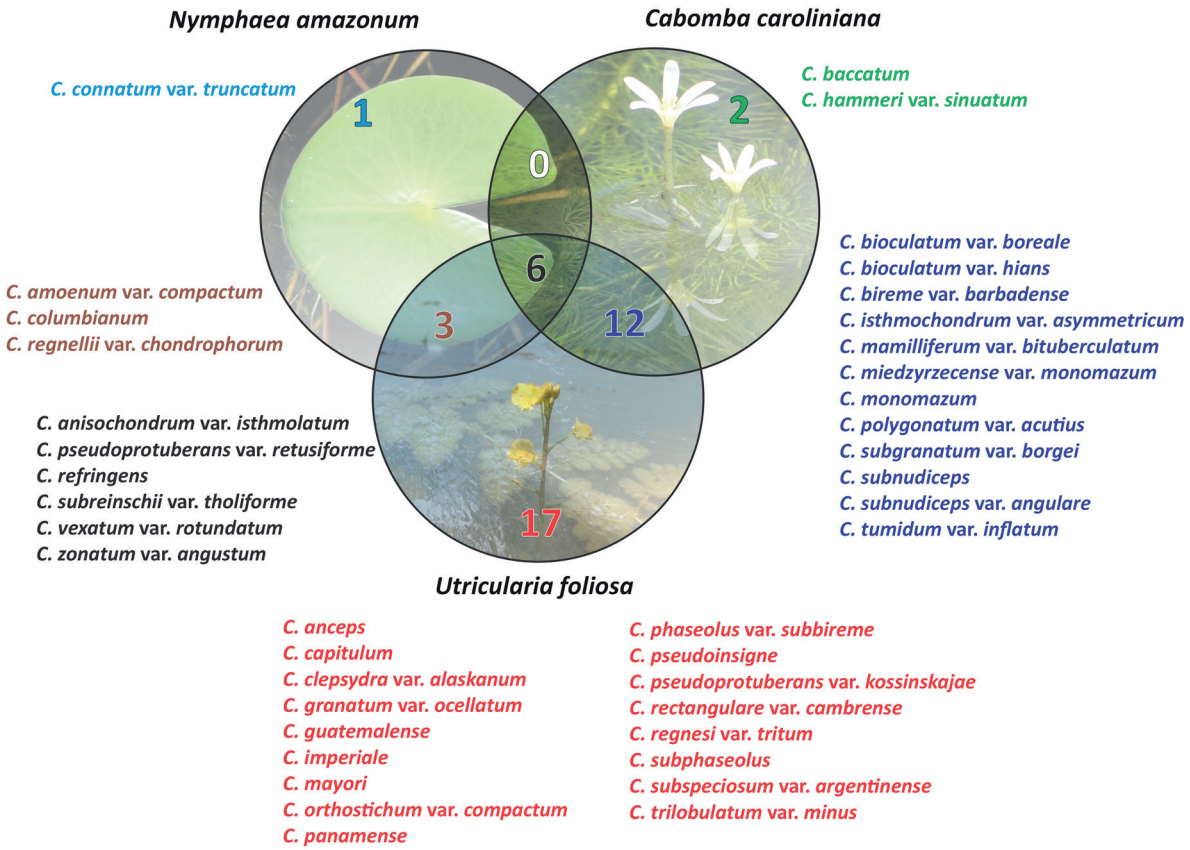

Figure 9. Venn diagram showing the number of taxa and taxa occurring in three aquatic macrophytes (*Nymphaea amazonum*, *Cabomba caroliniana*, *Utricularia foliosa*) from the Pantanal dos Marimbus.

Conservation

The Pantanal dos Marimbus comprises a wide floodplain area within Caatinga domain (Fig. 11A, B), and is subdivided into four areas (Fig. 11C), from north region to south: (1) Marimbus do Remanso, (2) Marimbus da Fazenda Velha, (3) Marimbus do Ferreira, (4) Marimbus do Baiano. These wetlands are currently partially protected by gubernatorial decrees and incorporated into Marimbus-Iraquara EPA and Chapada Diamantina National Park (PARNA Chapada Diamantina). However, Pantanal dos Marimbus is not fully protected since only the first three regions are officially within environmental conservation areas: Marimbus do Remanso is into the Marimbus-Iraquara EPA, whereas Marimbus da Fazenda Velha and Ferreira are areas within PARNA Chapada Diamantina. Hence, the south region (Marimbus do Baiano), where most of the present study samples were gathered, is the only one officially unprotected (Fig 11B). Some papers are reporting the rich biodiversity from that area, including plants and fishes (Moura & Marques 2007; França *et al*. 2010; Lima *et al*. 2012), as well as a number of endemic and rare species of algae, especially chlorophytes and desmids (Ramos *et al*. 2015; 2020; Costa *et al*. 2018; 2020). Currently, that area has been quite used also for tourist activities, such as Stand-Up paddle or paddle yourself with Canadian canoes. Thus, we have suggested the expansion of the Marimbus-Iraquara EPA limits to cover the Marimbus do Baiano, as this area harbors outstanding aquatic biodiversity and should also be a priority for conservation (Fig. 11B).

Conclusion

The genus *Utricularia* is considered an excellent substrate to the occurrence of periphytic desmids, especially by having leaves that are highly cropped (Hall & McCourt 2017). Since they are finely dissected, the leaves of this macrophyte favor the heterogeneity of habitat and provide a larger area for colonization of algae, including desmids (McAbendroth *et al*. 2005; Santos *et al*. 2013). The morphology of its leaves facilitates the penetration and availability of light for the adhered algae, contributing to the development of that community (Cattaneo *et al*. 1998). Many interesting desmids, including rare and new species, have been reported occurring associated with those plants in Brazil since the 18th century (Nordstedt 1878; Lemmermann 1914; Förster 1964; Menezes *et al*. 2013). In the present study, the highest richness of *Cosmarium* in *Utricularia foliosa* (38 taxa: 17 are exclusive) confirms the important role of these plants in forming the periphytic community. Most of the *Cosmarium* taxa found in this macrophyte has some type of ornamentation in the cell wall, mainly granules;

Table 2. Scores and codes of the *Cosmarium* taxa obtained by tb-RDA.

Taxa	Code	RDA 1	RDA 2
Cosmarium amoenum var. *compactum* West & G.S.West	Cac	-0.30	0.10
C. anceps P.Lundell	Can	-0.15	-0.15
C. anisochondrum var. *isthmolatum* Thérézien	Cai	-0.11	0.31
C. bioculatum var. *boreale* (Børgesen) Willi Krieg. & Gerloff	Cbb	-0.17	0.22
C. bioculatum var. *hians* West & G.S.West	Cbh	0.64	-0.11
C. bireme var. *barbadense* G.S.West	Cbi	-0.54	-0.01
C. clepsydra var. *alaskanum* Croasdale	Cca	0.23	0.11
C. columbianum G.S.West	Cco	0.05	-0.20
C. connatum var. *truncatum* West	Ccn	-0.15	-0.15
C. hammeri var. *sinuatum* Borge	Chs	0.28	0.06
C. isthmochondrum var. *asymmetricum* Scott & Grönblad	Cia	-0.42	-0.29
C. subgranatum var. *borgei* Willi Krieg.	Csb	0.12	-0.20
C. mamilliferum var. *bituberculatum* (F.E.Fritsch & M.F.Rich) Bourrelly	Cmb	-0.31	0.18
C. mamilliferum var. *madagascariense* West & G.S.West	Cmm	-0.52	-0.11
C. mayori G.S.West	Cmay	-0.50	0.05
C. miedzyrzecense var. *monomazum* Grönblad	Cmied	-0.46	0.13
C. monomazum P.Lundell	Cmon	-0.48	0.18
C. orthostichum var. *compactum* West & G.S.West	Coc	0.03	0.07
C. phaseolus var. *subbireme* Racib.	Cpha	-0.07	-0.01
C. polygonum var. *acutius* Messik.	Cpoly	-0.35	-0.21
C. pseudoprotuberans var. *retusiforme* F.E.Fritsch & M.F.Rich	Cpr	0.08	-0.28
C. rectangulare var. *cambrense* (W.B.Turner) West & G.S. West	Crec	-0.32	-0.02
C. refringens W.R.Taylor	Cref	-0.16	0.53
C. regnellii var. *chondrophorum* Skuja	Creg	-0.01	-0.12
C. imperiale sp. nov.	Cimp	-0.19	-0.13
C. regnesi var. *tritum* West	Crt	0.11	0.14
C. subnudiceps var. *angulare* Scott & Grönblad	Csa	-0.59	0.07
C. subnudiceps West & G.S.West	Csubn	-0.58	-0.08
C. subreinschii var. *tholiforme* (W.R.Taylor) Prescott	Csubr	-0.24	-0.22
C. trilobulatum var. *minus* (Wille) Willi Krieg. & Gerloff	Ctri	-0.15	-0.15
C. tumidum var. *inflatum* (Schmidle) Willi Krieg. & Gerloff	Cti	-0.09	-0.30
C. vexatum var. *rotundatum* Messik.	Cvr	0.11	-0.29
C. zonatum var. *angustum* Grönblad & Scott	Cza	0.42	0.19

therefore, those cell structures might also have contributed to adherence of the taxa in those plants.

Some rare *Cosmarium* taxa known so far only in their type localities had their distribution enlarged to Brazil or South America, such as *Cosmarium pseudoprotuberans* var. *retusiforme*, *C. subspeciosum* var. *argentinense*, *C. subphaseolus*. The former has not been reported since 1937 from Africa, the second one since 1981(Argentina), whereas *C. subphaseolus* since 2001 (France). In addition to enlarge their known distribution, these new records help understand the current conservation status and which habitat conditions these species are currently occurring.

Regarding ecological aspects, the oligotrophic conditions and low conductivity were favorable for the development of *Cosmarium* and other desmids in the Marimbus. The water transparency was somewhat low due to the high concentration of humic substances giving the brown aspect to the water. This color is typical of the most aquatic ecosystems from the Chapada Diamantina region, including the Santo Antônio River, which is considered the main river that supplies the Pantanal dos Marimbus.

The desmids form a highly diverse group, especially in tropical regions, where they usually have high densities (Coesel 1996). These algae need higher temperatures (25-30 °C) for their ideal growth. Some genera, such as *Cosmarium*, can adapt quickly to adverse conditions of temperature and light, which makes them stand out, especially in warm and transparent waters (Coesel & Wardenaar 1990; Stamenkovic & Hanelt 2017). This explains the higher density of *Cosmarium* taxa in the drier months because, besides interfering in the hydrodynamics and turbidity of the aquatic body, changing the availability of light, the precipitation can also cause the detachment and loading of periphytic algae, impairing the development of the community (Cavati & Fernandes 2008, Domitrovic *et al.* 2013).

From the present study, our knowledge on desmids from South America has been expanded, especially in the Caatinga domain, the only biome exclusive from Brazil, which now has 55 taxa known of *Cosmarium*. Our results also have implications for the biogeographic studies on the group since some taxa were known only to other continents such as Europe and Africa, as well as other areas from South

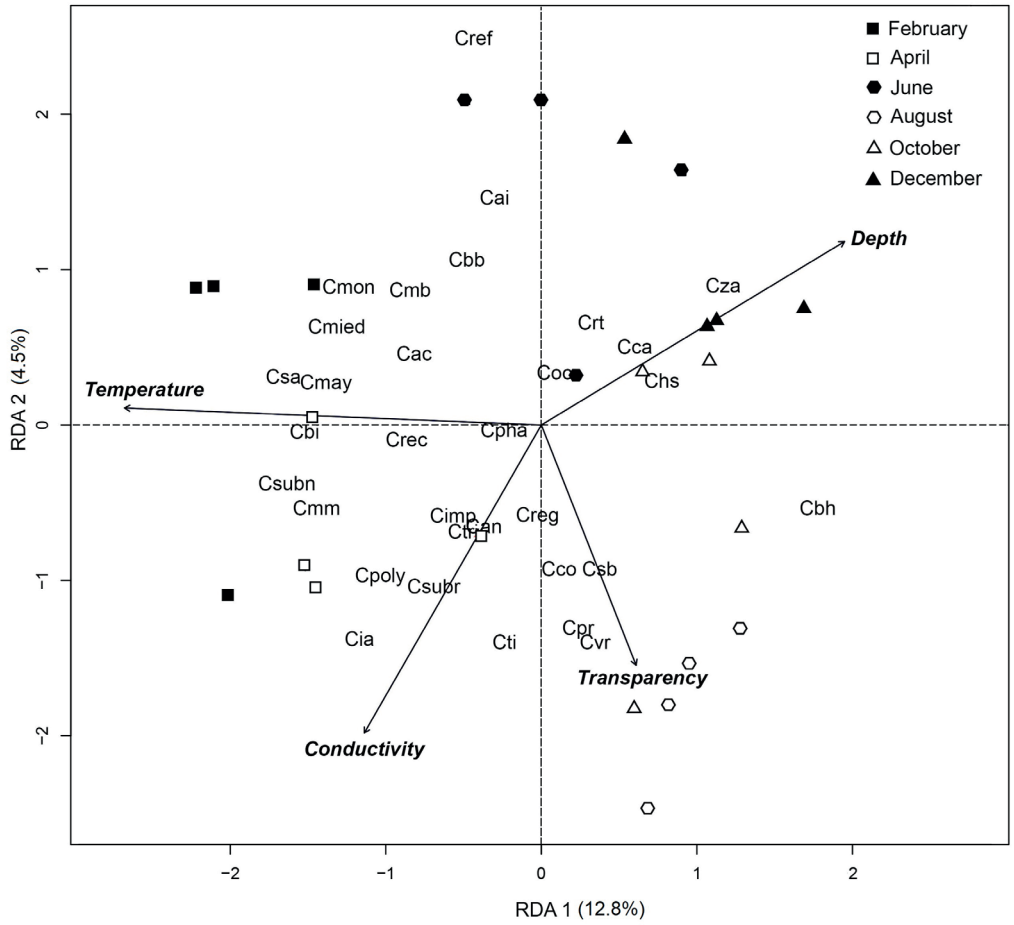

Figure 10. Ordination diagram yielded by tb-RDA for the complete selected model with limnological variables and *Cosmarium* taxa occurring in the Pantanal dos Marimbus (Baiano) during 2018. Dry months (April, August and October), rainy months (February, June and December).

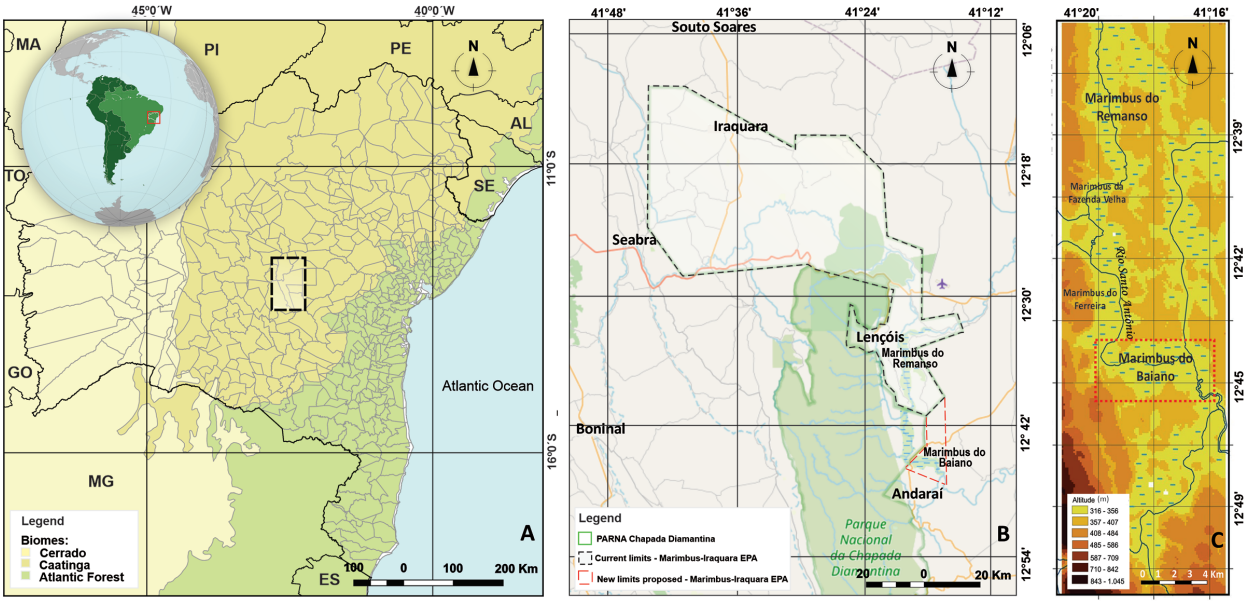

Figure 11. A. Map of the Pantanal dos Marimbus region within the Caatinga domain. **B.** Limits of the Marimbus-Iraquara EPA, Chapada Diamantina National Park (Parna Chapada Diamantina), and new limits proposed for the Marimbus-Iraquara EPA (modified from OpenStreetMap 2020) **C.** Four areas of the Pantanal dos Marimbus (modified from França *et al.* 2010).

America. It is highly recommended to expand the limits of the Marimbus-Iraquara EPA to cover the "Marimbus do Baiano", an area with rich aquatic biodiversity that is not included in the EPA neither Chapada Diamantina National Park. Also, more taxonomic studies should be performed at other areas from the Caatinga, as other interesting desmid species might occur in that biome. The taxonomic data analyzed here corroborate the theory that the Chapada Diamantina is one of the main biodiversity centers within the Caatinga domain.

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