

# Periphytic diatoms (Bacillariophyta) in streams from three Conservation Units of central Brazil: *Pinnularia* Ehrenberg<sup>1</sup>

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**ABSTRACT** - (Periphytic diatoms (Bacillariophyta) in streams from three Conservation Units of central Brazil: *Pinnularia* Ehrenberg). This study aimed to survey the genus *Pinnularia* Ehrenberg (Bacillariophyta) in five preserved streams located in three conservation units (Brasília National Park, Chapada dos Veadeiros National Park and Terra Ronca State Park). Periphyton was collected in different substrata during the dry and rainy seasons (years 2012 to 2013), totaling 25 sample units. Altogether, 23 taxa were identified, being *P. subanglica*, *P. angustivalva* and *P. butantanum* the most frequent. Pebble and sand were the richest substrates, with nine taxa each. Among the 23 taxa reported, 13 are cited for the first time for the central Brazil: *P. angusta* var. *angusta*, *P. angustivalva*, *P. butantanum*, *P. divergens* var. *biconstricta*, *P. divergens* var. *mesoleptiformis*, *P. gibba* var. *subundulata*, *P. paulensis*, *P. persudetica* var. *persudetica*, *P. subgibba* var. *angustarea*, *P. subgibba* var. *capitata*, *P. superpaulensis*, *P. viridiformis* var. *minor* and *P. undula* var. *undula*.

**Keywords:** biodiversity, Cerrado, diatom, periphyton, pristine lotic systems

**RESUMO** - (Diatomáceas perifíticas (Bacillariophyta) em riachos de três Unidades de Conservação do Brasil Central: *Pinnularia* Ehrenberg). Este estudo objetivou inventariar o gênero *Pinnularia* Ehrenberg (Bacillariophyta) em cinco riachos preservados localizados em três unidades de conservação (Parque Nacional de Brasília, Parque Nacional da Chapada dos Veadeiros e Parque Estadual de Terra Ronca). O perifíton foi coletado em diferentes substratos durante estações secas e chuvosas (anos de 2012 e 2013), totalizando 25 unidades amostrais. Ao todo 23 táxons foram identificados, sendo *P. subanglica*, *P. Angustivalva* e *P. butantanum* as mais frequentes. Seixos e silte foram os substratos mais ricos em espécies, com nove táxons cada. Entre os 23 táxons, 13 são citados pela primeira vez para o Brasil Central: *P. angusta* var. *angusta*, *P. angustivalva*, *P. butantanum*, *P. divergens* var. *biconstricta*, *P. divergens* var. *mesoleptiformis*, *P. gibba* var. *subundulata*, *P. paulensis*, *P. persudetica* var. *persudetica*, *P. subgibba* var. *angustarea*, *P. subgibba* var. *capitata*, *P. superpaulensis*, *P. viridiformis* var. *minor* e *P. undula* var. *undula*.

**Palavras-chave:** biodiversidade, Cerrado, diatomáceas, perifíton, sistemas prístinos lóticos

## Introduction

Among the various groups of organisms comprising the periphyton, diatoms stand out by its abundance among the autotrophs, due to morphological adaptations that facilitate their fixation on substrates (Stevenson 1997). Several species are able to adhere to surfaces by mucilage secreted through structures present in the valve, as the raphe, pores field apical

and rimoportula (Round *et al.* 1990), providing them adaptive advantages (Passy 2007; Law *et al.* 2014). The substrate variability in lotic environments is particularly important because it affects the structure of periphyton (Cattaneo *et al.* 1997).

The family Pinnulariaceae D.G. Man is composed of unicellular individuals that can form short chains and are characterized by having linear-lanceolate valves, rarely elliptical, with slightly rounded apical

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end, which can be capitate to subcapitate to lightly cuneate (Round *et al.* 1990, Rocha & Bicudo 2008). The striae are alveolate chamber-shaped that extend from the sternum towards the ends of the valve. These alveolate structures are open to the outside through pores with occlusion of hymen type (Round *et al.* 1990). This family comprises genera such as *Caloneis* Cleve, *Diatomella* Greville, *Dimidiata* Hajós, *Ostrupia* Heiden *ex* Hustedt and *Pinnularia* Ehrenberg (Tremarin *et al.* 2010).

*Pinnularia* Ehrenberg is characterized by solitary individuals, rarely colonial. The valves can be linear, lanceolate or elliptical, with straight or wavy edges and rounded apical end, rostrate or capitates (Round *et al.* 1990). According to Guiry & Guiry (2016), 728 taxa have been flagged as taxonomically accepted within this genus. It occurs worldwide in freshwater environments of different pH and trophic states, with preference to slightly acidic oligotrophic environments, and in a smaller proportion, in moist soils and marine coastal environments (Metzeltin & Lange-Bertalot 1998; Krammer 2000).

Despite the high number of species and the frequent occurrence in freshwater environments, there is still scarce information about *Pinnularia* in Brazil (Tremarin *et al.* 2010), mainly in the central region (Silva *et al.* 2011). Some studies can be cited for Amazonian region (Pereira *et al.* 2012, 2013, 2014), São Paulo (Rocha *et al.* 2008) and Paraná States (Brassac & Ludwig 2006, Tremarin *et al.* 2010), and Goiás (Silva *et al.* 2016).

Taxonomic studies on periphytic diatom algal flora in central Brazil are in early stage. The works of Souza & Moreira-Filho (1999), Delgado & Souza (2007) e Silva *et al.* (2016) are so far the only ones with descriptions of *Pinnularia*. Moreover, there is no available information about diatom communities in aquatic systems of the conservation units considered in this study. Present work aimed at surveying the genus *Pinnularia* in the periphyton of preserved streams from central Brazil located in three conservation units.

## Material and methods

This study was carried out in five low order streams located in three conservation units from central Brazil: Brasilia National Park (hereafter, BNP), Chapada dos Veadeiros National Park (hereafter, CVNP) and Terra Ronca State Park (hereafter, TRSP) (figure 1). The region is occupied by the Cerrado domain (Brazilian savanna), where climate is rainy

tropical, with strong seasonality. There is a rainy season from October to April concentrating up to 80% of annual precipitation (mean temperature around 29 °C), and a dry season from May to September when precipitation ranges from zero to below 50 mm (mean temperature around 18 °C) (Silva *et al.* 2008).

Between streams, BNP is located in the Federal District of Brazil, near the Brazilian capital, Brasília. CVNP and TRSP are located in Goiás State (table 1). TRSP comprises the largest cave complex in South America, and the streams sampled in this area crosses caves with their respective names (Lapa and São Mateus). The total number of sampling units was 25, considering different substrates and two seasons, as will be described below.

Periphyton was collected during the dry (August) and rainy (March) seasons, between the years 2012 and 2013, according to the protocols established by the ComCerrado Network (unpublished data). In each stream it was delimited a 50 m longitudinal transect, where the following substrates, wherever possible, were considered: leaf litter (L), macrophytes (M), roots (R), trunk (T), pebble (P) and sand (S) (table 1). It was used a syringe to collect sand; macrophytes were squeezed and the other substrates were scraped with a toothbrush, using distilled water gentle jets. Samples were preserved in 3-5% formalin solution and deposited in the Herbarium of the University of Goiás (UFG). Along with periphyton, some abiotic variables (water temperature, dissolved oxygen, pH and electrical conductivity) were measured in the field using standard electrodes (Yellow Spring Instruments) (table 2).

Periphyton samples were cleaned using the oxidation method of Simonsen (1974) modified by

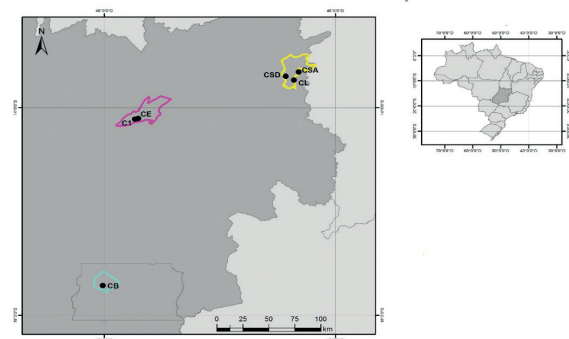


Figure 1. Study area map of the sampling stations in three conservation units (Streams C1- Córrego 1, CE- Estiva, CB: Bananal, CSD- São Mateus after cave, CSA- São Mateus before cave, CL- Lapa) from central Brazil (Brasilia National Park, Chapada dos Veadeiros National and Terra Ronca State Park). — Parque Nacional da Chapada dos Veadeiros, — Parque Estadual Terra Ronca, — Sampling stations.

Table 1. Geographical coordinates of sampling stations and general information about number of samples (CU: conservation unit; substrates: L: leaf litter, M: macrophytes, R: roots, T: trunk, P: pebble, S: sand).

CU	Stream	Geographical coordinates	Altitude (m)	Dry season		Rainy season	
				N	substrates	N	substrates
BNP	Bananal	15°42'50.23"S 48°0'45.03"W	1082	2	M, R	2	M, R
CVNP	Córrego 1	14°06'13.5"S 47°42'19.5"W	1172	6	L, M, R, T, P, S	4	L, M, T, P
CVNP	Estiva	14°06'40.3"S 47°44'02.2"W	1162	3	M, T, S	2	P, S
TRSP	Lapa	13°44'4.38"S 46°21'24.38"W	602	2	T, S	1	S
TRSP	São Mateus	13°39'20.86"S 46°18'58.78"W	712	2	M, R	1	P

Table 2. Abiotic variables in the streams sampled (dry and rainy seasons) (CU: conservation unit).

CU	Stream	Date	Water temperature (°C)	pH	Electrical conductivity ( $\mu\text{S cm}^{-1}$ )	Dissolved oxygen ( $\text{mg L}^{-1}$ )
CVNP	Córrego 1	07/08/2012	18.0	6.65	13.0	6
CVNP	Córrego 1	12/03/2013	21.9	6.53	8.6	6.9
BNP	Bananal	24/07/2012	20.2	5.57	5.4	2.5
BNP	Bananal	28/02/2013	21.5	5.19	13.5	2.4
CVNP	Estiva	08/08/2012	25.1	6.54	3.0	7.2
CVNP	Estiva	13/03/2013	22.1	6.82	4.8	7.6
TRSP	Lapa	28/03/2013	26.4	7.82	26.4	7.9
TRSP	Lapa	16/09/2013	26.4	7.53	8.0	7.8
TRSP	São Mateus	29/03/2013	25.1	5.72	5.5	7.0
TRSP	São Mateus	17/09/2013	24.2	7.25	124.4	7.2

Moreira-Filho & Valente-Moreira (1981). The samples were fixed on permanent mounts with Naphrax® resin. Taxonomical analyzes were performed using a light microscope Leica DM500 equipped with digital camera ICC50Hd. The identification was based on valve morphological and morphometric features, using both classic (e.g., Hustedt 1965, Krammer 2000, Metzeltin & Lange-Bertalot 1998, 2007) and regional literature (e.g., Rocha & Bicudo 2008, Tremarin *et al.* 2010, Pereira *et al.* 2012). We observed at least five individuals of each species to the identification. The classification system used was Round (1991).

## Results and Discussion

Altogether 23 taxa were recorded for genus *Pinnularia* (table 3). This genus is the second with higher species richness in Brazil (125 species) according to Menezes *et al.* (2015), followed only by *Cosmarium ex*

Ralfs (Conjugatophyceae) with 156 species. Our study contributed with the record of 13 taxa not yet reported for the central Brazil, and this number is very representative to *Pinnularia* species compared to 53 species cited by Silva *et al.* (2011) for the Central-West region.

The most frequent species were *P. subanglica*, *P. angustivalva* and *P. butantanum*, present in more than 20% of the samples. Among the streams analyzed, Córrego 1 and Estiva were the richest ones, with 11 and nine taxa, respectively (table 3). These streams are located at CVNP, and presented the highest variety of substrates. Pebble and sand were the richest substrates, with nine taxa of *Pinnularia*, followed by trunk (seven), macrophytes (seven), leaf litter (six) and roots (four).

An identification key is presented with the identified taxa, followed by description, comments, distribution in the central Brazil and illustration of the examined material.

### Identification key of species of *Pinnularia* Ehrenberg

1. Central area rhombic

2. Valves linear

3. Raphe undulate ..... *P. subgibba* var. *capitata*

3. Raphe filiform

- 4. Apices subcapitate
  - 5. Apical axis between 45.22-52.78 ..... *P. divergens* var. *media*
  - 5. Apical axis between 54.44-60.58  $\mu\text{m}$  ..... *P. gibba* var. *subundulata*
- 4. Apices in another shape
  - 6. Apices rostrate ..... *P. microstauron* var. *rostrata*
  - 6. Apices capitate ..... *P. subanglica*
- 2. Valves linear lanceolate
  - 7. Raphe linear complex ..... *P. mesoloptiformis*
  - 7. Raphe undulate
    - 8. Apical axis between 81.52-82.13  $\mu\text{m}$  ..... *P. divergens* var. *biconstricta*
    - 8. Apical axis between 72.4-76.91  $\mu\text{m}$  ..... *P. divergens* var. *protracta*
- 1. Central area in another shape
  - 9. Raphe straight
    - 10. Valves elliptic-lanceolate ..... *Pinnularia* sp. 1
    - 10. Valves lanceolate
      - 11. Apices subcapitate to capitate ..... *P. brauniana*
      - 11. Apices rostrate to cuneate ..... *Pinnularia* sp. 4
  - 9. Raphe in another shape
    - 12. Central area rectangle reaching the valve margins ..... *P. angustivalva*
    - 12. Central area semi-circle to asymmetric
      - 13. Apices rostrate ..... *P. meridiana* var. *meridiana*
      - 13. Apices in another shape
        - 14. Apices rounded-cuneate with valve transapical axis between 14.4-14.88  $\mu\text{m}$ 
          - 15. 9 striae in 10  $\mu\text{m}$  ..... *P. persudetica* var. *persudetica*
          - 15. 10 striae in 10  $\mu\text{m}$  ..... *P. viridiformis* var. *minor*
        - 14. Apices rounded to capitate with valve transapical axis between 7.44-15.77  $\mu\text{m}$ 
          - 16. Central area asymmetric
            - 17. 13 striae in 10  $\mu\text{m}$  ..... *P. angusta* var. *angusta*
            - 17. 12 striae in 10  $\mu\text{m}$  ..... *Pinnularia* sp. 3
          - 16. Central area in circle shape or semi-circle
            - 18. Central area semi-circle in one of the sides of the valve and asymmetric in the other side
              - 19. 11 striae in 10  $\mu\text{m}$  ..... *Pinnularia* sp. 2
              - 19. 14 striae in 10  $\mu\text{m}$ 
                - 21. Apical axis 89.76  $\mu\text{m}$  ..... *P. paulensis*
                - 21. Apical axis between 128.67-129.38  $\mu\text{m}$  ..... *P. superpaulensis*
            - 18. Central area semi-circle in both sides of the valve
              - 20. Apices conic ..... *P. castraregina*
              - 20. Apices in another shape
                - 22. Valves margin straight and the middle region istumescent .....  
..... *P. subgibba* var. *angustera*
                - 22. Valves margin strongly undulate in the middle region ..... *P. undula* var. *undula*

Bacillariophyta

Bacillariophyceae

Naviculales

Pinnulariaceae D.G.Man

*Pinnularia* Ehrenberg

***Pinnularia angusta* var. *angusta*** (Cleve) Krammer,

In Krammer, *Biblioth. Diatomol.* 26:122. 1992.

Figure 2

The valves are linear with triundulate margins and a slight inflation in the middle region; apices are capitate to subcapitate; raphe filiform; central area asymmetric; Striae are often slightly bent, radiate near the valve center and become convergent in the end. Apical axis: 48.88  $\mu\text{m}$ ; transapical axis: 7.74  $\mu\text{m}$ ; rate apical axis/transapical: 6.31  $\mu\text{m}$ ; 13 striae in 10  $\mu\text{m}$ .

*Pinnularia angusta* var. *angusta* has morphological characteristics such as frustule shape and similar striae

Table 3. Occurrence of *Pinnularia* Ehrenberg in Cerrado streams during dry and rainy seasons, in different substrates and species richness by stream (L: leaf litter, M: macrophytes, P: pebble, R: roots, S: sand, T: trunk).

| Species   | Bananal |   | Córrego 1 |   |     |   |   | Estiva |   |   | Lapa |   |       | São Mateus |   |       |   |   |   |   |   |   |   |   |   |
|---|---------|---|-----------|---|-----|---|---|--------|---|---|------|---|-------|------------|---|-------|---|---|---|---|---|---|---|---|---|
|   | Dry     |   | Rainy     |   | Dry |   |   | Rainy  |   |   | Dry  |   | Rainy | Dry        |   | Rainy |   |   |   |   |   |   |   |   |   |
|   | M       | R | M         | R | L   | M | R | T      | P | S | L    | M | T     | P          | M | T     | S | P | S | T | S | S | M | R | P |
| <i>P. angusta</i>                               |         |   |           |   |     |   |   |        |   |   |      |   | X     |            |   |       |   |   |   |   |   |   |   |   |   |
| <i>P. angustivalva</i>                          |         |   |           |   | X   | X |   | X      | X |   | X    |   |       |            |   |       |   |   |   |   |   |   |   |   |   |
| <i>P. brauniana</i>                             |         |   |           |   |     |   |   | X      |   |   | X    | X |       |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>P. butantanum</i>                            |         |   |           |   | X   |   | X | X      | X |   |      |   |       | X          | X |       |   |   |   |   |   |   |   |   |   |
| <i>P. divergens</i> var. <i>biconstricta</i>    |         |   |           |   |     |   |   |        |   |   |      |   | X     |            |   |       |   |   |   |   |   |   |   |   |   |
| <i>P. divergens</i> var. <i>media</i>           |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   | X |   |
| <i>P. divergens</i> var. <i>mesoleptiformis</i> |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   |   |   |
| <i>P. gibba</i> var. <i>subundulata</i>         |         |   |           |   |     |   |   |        |   |   |      |   | X     |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>P. meridiana</i> var. <i>meridiana</i>       |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   |   |   | X |   |   |
| <i>P. microstrauron</i>                         |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   |   |   |   | X |   |
| <i>P. paulensis</i>                             |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>P. persudetica</i> var. <i>persudetica</i>   |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>P. subanglica</i>                            |         |   |           |   |     |   |   | X      |   | X | X    | X | X     | X          |   |       | X |   |   |   | X |   |   |   |   |
| <i>P. subgibba</i> var. <i>angustarea</i>       |         |   |           |   |     |   |   |        |   |   |      |   | X     |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>P. superpaulensis</i>                        |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   |   |   |
| <i>P. viridiformis</i> var. <i>minor</i>        |         |   |           |   |     |   |   | X      |   |   |      |   | X     |            |   |       |   |   |   |   |   |   |   |   |   |
| <i>P. undula</i> var. <i>undula</i>             |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | X | X |   |   |   |   |   |   |   |
| <i>Pinnularia</i> sp.1                          |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   |   |   |
| <i>Pinnularia</i> sp.2                          |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   |   |   |
| <i>Pinnularia</i> sp.3                          |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | X |   |   |   |   |   |   |   |   |
| <i>Pinnularia</i> sp.4                          |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       |   |   |   |   | X |   |   |   |   |
| <i>Pinnularia</i> sp.5                          |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | X | X |   |   |   |   |   |   |   |
| <i>Pinnularia</i> sp.6                          |         |   |           |   |     |   |   | X      |   | X | X    |   |       |            |   |       |   |   |   |   |   |   |   |   |   |
| Species richness                                |         |   |           |   |     |   |   |        |   |   |      |   |       |            |   |       | 4 |   |   |   |   |   |   |   |   |

as *Pinnularia grunowii* Krammer and *Pinnularia pluvianiformis* Krammer. These two species have differences mainly in the the rate apical axis/transapical. Krammer (2000) describes the rates between 3.7-5.4 for *Pinnularia grunowii* and 4.5 for *Pinnularia pluvianiformis*, and *P. angusta* is between 5.5-8.5. In northern Europe, the distribution related to this species is mainly in oligotrophic environments with low electrolytes (Krammer 2000).

Midwest region records: pioneer reference.

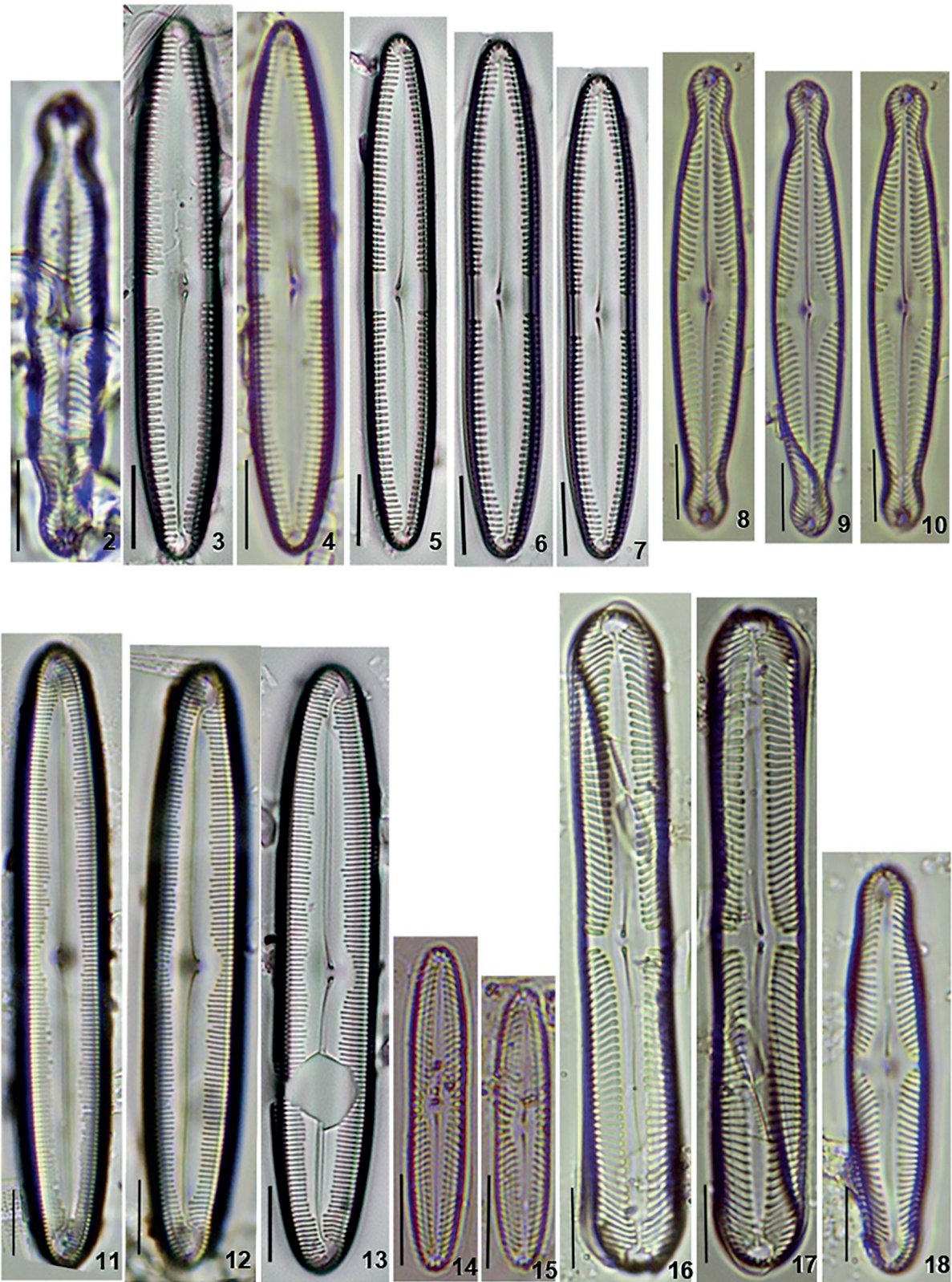
Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, A. A. França 9 (UFG 50251).

***Pinnularia angustivalva*** Krammer & Metzeltin, In Lange-Bertalot, Iconographia Diatomologica 5:164, pl. 190, figs. 10-11. 1998.

Figures 3-7

The valves are lanceolate with parallel margins to slightly convergent; the middle region has inflation; Apices are cuneate-rounded; raphe is lateral with distal ends deflected; central area is a rectangle reaching the valves margins; shorter and parallel striae. Apical axis: 51.86-65.41 µm; transapical axis: 8.33-11.01 µm; rate apical axis/transapical: 5.19-7.29 µm; 11-13 striae in 10 µm.

*Pinnularia instabiliformis* Krammer & Metzeltin shows similar valves shape and striation as *Pinnularia angustivalva*, however the difference is on the apical and transapical axis' measures that are larger. *Pinnularia acuminata* var. *guyanensis* quite confused with *P. instabiliformis*, but the first one has bigger valves (apical axis 70-110 µm and transapical axis 15-6 µm) and the apices are less cuneiform (Metzeltin



Figures 2-18. *Pinnularia* species in Cerrado streams. 2. *Pinnularia angusta* var. *angusta*. 3-7. *Pinnularia angustivalva*. 8-10. *Pinnularia brauniana*. 11-13. *Pinnularia butantanum*. 14-15. *Pinnularia* sp.5. 16-17. *Pinnularia divergens* var. *biconstricta*. 18. *Pinnularia divergens* var. *media*. Scale = 10  $\mu$ m.

& Lange-Bertalot 2007). The observed individuals had bigger transapical axis than the specimens found on Negro river (transapical axis 32-54  $\mu\text{m}$ ) by Metzletín & Lange-Bertalot (1998; 2007), but the dimensions fit with the description of the species and the original illustrations.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França* 9 (UFG 50251); Córrego 1, *A.A. França* 7 (UFG50249); Córrego Estiva, *A.A. França* 18 (UFG50260); *A.A. França* 21 (UFG50263).

***Pinnularia brauniana*** (Grunow) Studnicka, In Verhandlungen der Kaiserlich-Königlichen Zoologisch-Botanischen Gesellschaft in Wien 38:737. 1888.

Figures 8-10

The valves are lanceolate with a slightly convex side; apices are subcapitate to capitate; raphe is straight with a narrow sternum; axial area is lanceolate widening into the middle region; central area is semi-rhombic formed by shortening of the middle striae and a siliceous space reaching the valve margin; striae are radiate and convergent near the apices. Apical axis: 53.18-63.32  $\mu\text{m}$ ; transapical axis: 9.18-10.86  $\mu\text{m}$ ; rate apical axis/transapical: 5.18-6.34  $\mu\text{m}$ ; 10-12 striae in 10  $\mu\text{m}$ .

*Pinnularia subcapitata* Gregory is close to *P. brauniana* because their valves are lanceolate with subcapitate to capitate apices, but they differ on a narrow axial area and a small transapical axis (Krammer 1992).

Midwest region records: Federal District (Delgado & Souza 2007).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França* 5 (UFG50247); Córrego 1, *A.A. França* 5 (UFG50251); Córrego 1, *A.A. França* 7 (UFG50249); Córrego Estiva, *A.A. França* 18 (UFG50260); Córrego Estiva, *A.A. França* 21 (UFG50263).

***Pinnularia butantanum*** (Krasske) Metzletín, Iconographia Diatomologica 5:628, pl. 197, figs 1-3. 1998.

Figures 11-13

The valves are lanceolate to elliptic-lanceolate with apices lightly rounded; raphe is straight formed

by a deflected hook shape on the apices; central area is slightly rounded and asymmetric. Apical axis: 73.47-91.32  $\mu\text{m}$ ; transapical axis: 11.18-14.22  $\mu\text{m}$ ; rate apical axis/transapical: 5.92-8.16  $\mu\text{m}$ ; 13-15 striae in 10  $\mu\text{m}$ .

According to Lange-Bertalot (1998) *Caloneis westii* (Wm. Smith) Hendey has a morphologic valve and striation similar to *P. butantanum*, although *C. westii* differs mainly because of the attenuated form of the apices and the raphe sternum is narrower.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França* 7 (UFG 50 249); Córrego 1, *A.A. França* 1 (UFG 50 243); Córrego 1, *A.A. França* 4 (UFG 50 246); Córrego 1, *A.A. França* 3 (UFG 50 245); Córrego Estiva, *A.A. França* 23 (UFG 50 248).

***Pinnularia divergens*** var. ***biconstricta*** (Cleve-Euler)

Cleve-Euler, In Cleve-Euler, Die Diatomen von Schweden und Finnland 5(4):1-232, figs. 971-1306. 1955.

Figures 16-17

The valves are linear lanceolate with apices rounded; raphe is slightly undulate with deflected distal ends; the valve middle region has a slight inflation; central area is rhombic widening to a small siliceous fascia; striae are radiate to convergent on the apices. Apical axis: 81.52-82.13  $\mu\text{m}$ ; transapical axis: 11.39-11.91  $\mu\text{m}$ ; rate apical axis/transapical: 6.89-7.15  $\mu\text{m}$ ; 10-11 striae in 10  $\mu\text{m}$ .

The specimens of this study are smaller than that illustrated by Tremarin *et al.* (2010) for *P. divergens* var. *biconstricta*. They are similar in the valves characteristics, striation and rhombic central area. According to Krammer (2000), the valves are linear and the valves margins commonly parallel, similar to that found in our study. The specimens differ from *P. divergens* var. *malayensis* mainly by the undulation on the valves margin, as illustrated by Tremarin *et al.* (2010) and Rocha *et al.* (2008) for *P. divergens* var. *malayensis*. *Pinnularia divergens* var. *biconstricta* have planktonic habitat and is found in standing water, but can occur running water (Moro & Fürstenberger 1997).

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França* 5 (UFG 50 247).

*Pinnularia divergens* var. *media* Krammer, In Lange-Bertalot, Diatoms of Europe 1:61, pl.34, figs. 1-5. 2000.

Figure 18

The valves are linear with apices subcapitate; raphe is filiform; central area is rhombic reaching the edges of the valve; striae are radiate to convergent on the apices. Apical axis: 45.22-52.78 µm; transapical axis: 8.89-10.44 µm; rate apical axis/transapical: 5.05-5.08 µm; 10-11 striae in 10 µm.

This variety differs from the variety type, by presenting a smaller apical and transapical axis (Krammer 2000). *Pinnularia divergens* var. *media* prefers oligotrophic environments with low mineral contents (Krammer 2000). The observed specimens had shown a bigger transapical axis and less striae compared with specimens found in Guaraguaçu's river (apical axis 33.1-49.4 µm; 12-14 striae in 10 µm) by Tremarin *et al.* (2010), but the dimensions fit with the description of the species and the original illustrations.

Midwest region records: District Federal (Delgado & Souza 2007); Goiás (Delgado & Souza, 2007).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Terra Ronca, Córrego Lapa, *A.A. França* 25 (UFG 50 267); Córrego São Mateus, *A.A. França* 15 (UFG 50 257).

*Pinnularia divergens* var. *mesoleptiformis* Krammer & Metzeltin, In Lange-Bertalot, Iconographia Diatomologica 5:170, pl. 173, figs. 1-4. 1998.

Figure 19

The valves are linear-lanceolate, with triundulate margins and the central undulation is wider than the distal undulation; apices are capitate; raphe is linear and complex; central area is rhombic with a siliceous space on the middle region of the valve; striae are radiate and convergent towards the apices. Apical axis: 76.71 µm; transapical axis: 12.54 µm; rate apical axis/transapical: 6.11 µm; 11 striae in 10 µm.

The original description of *P. divergens* var. *mesoleptiformis* put this species similar to *P. divergens* var. *laticeps* Franquelli, showing only difference on the transapical axis' measures, which in *Pinnularia divergens* var. *laticeps* always is smaller, 13,4 µm against 20 µm. Although, illustrated in Metzeltin & Lange-Bertalot (1998) and Frenguelli (1933) we realize that besides the length range of the valves, both varieties differs on the apices' shape and type of the raphe. At *Pinnularia divergens* var. *laticeps* the

apices are capitate with a small flatness and the raphe is filiform, yet *Pinnularia divergens* var. *mesoleptiformis* has apices capitate and stretched and the raphe is complex.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Terra Ronca, Córrego Lapa, *A.A. França* 25 (UFG 50 267).

*Pinnularia gibba* var. *subundulata* (Mayer ex Hustedt) Frenguelli, In Anales Del Museo Nacional de História Natural 37:365-475, pl. 9. 1933.

Figures 21-23

The valves are linear with slight undulations on the margins; apices are subcapitate; raphe is filiform with distal end deflected to the same direction and in a hook shape; central area is rhombic reaching the margins; striae are strongly radiate to convergent on the apices. Apical axis: 54.44-60.58 µm; transapical axis: 8.74-9.19 µm; rate apical axis/transapical: 6.14-7.06 µm; 10-11 striae in 10 µm.

*Pinnularia subgibba* var. *undula* Krammer differs from *P. gibba* var. *subundulata* (Mayer) Frenguelli for having slightly capitate apices and a wide sternum (Krammer 1992).

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França* 5 (UFG 50 247); Córrego Estiva, *A.A. França* 21 (UFG 50 263).

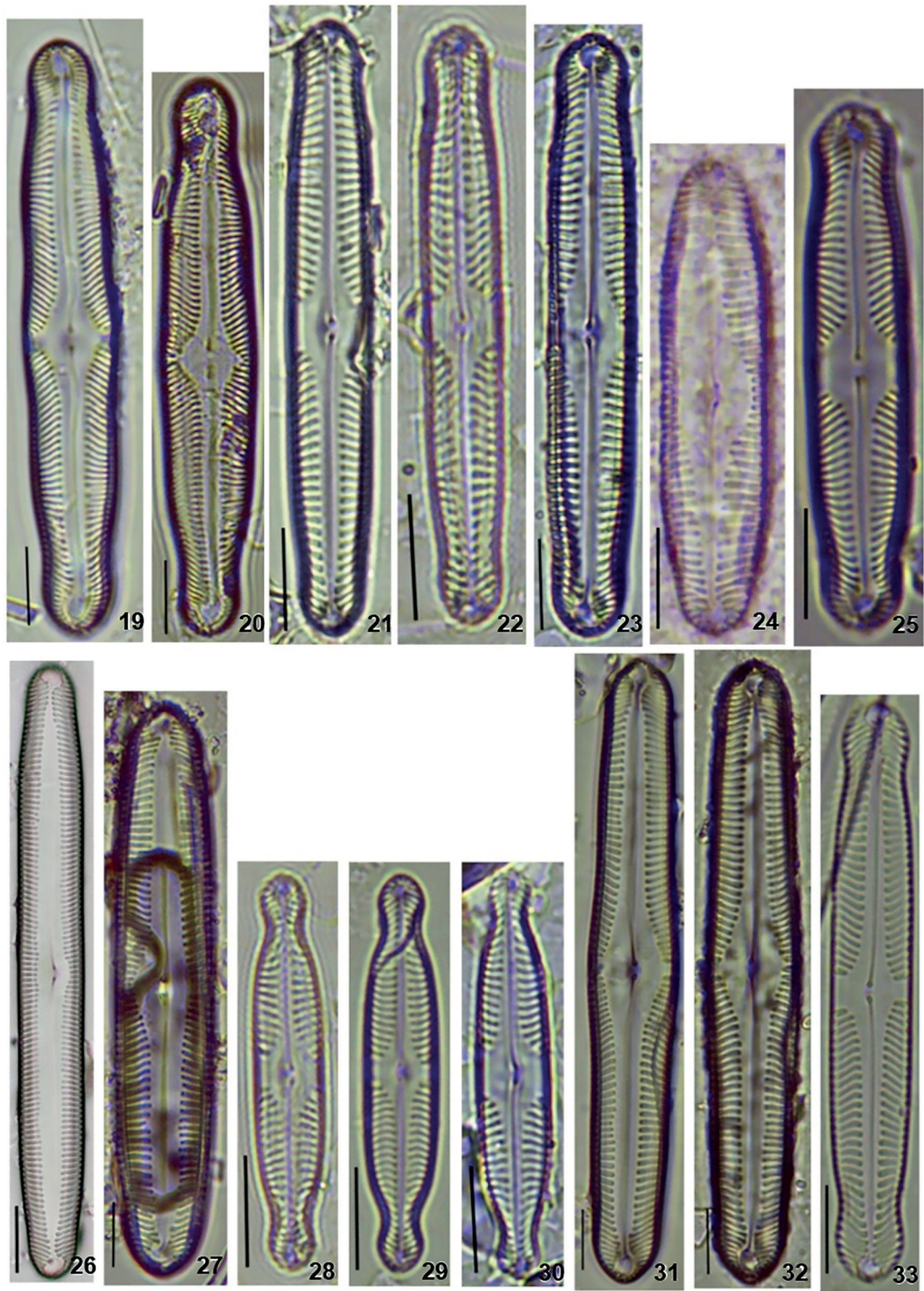
*Pinnularia meridiana* var. *meridiana* Metzeltin & Krammer, In Lange-Bertalot, Iconographia Diatomologica 5: 180, pl. 181, figs. 1-5. 1998.

Figure 24

The valves are linear-elliptic with parallel margins to slightly convex; apices are slightly rostrate to rounded; raphe is lightly lateral with terminal indistinct fissures; a semi-circle is formed in the central are by shortening of the striae on the middle region; transapical striae parallels to slightly radiate on the center of the valve. Apical axis: 45.02 µm; transapical axis: 9.87 µm; rate apical axis/transapical: 4.56 µm; 10 striae in 10 µm.

*P. meridiana* var. *meridiana* distinguishes from *P. var. parallela*, by showing parallel to slightly convex margins and apices are slightly rounded, while *P. var. parallela* has parallel margins and apices strongly





Figures 19-33. *Pinnularia* species in Cerrado streams. 19. *Pinnularia divergens* var. *mesoleptiformis*. 20. *Pinnularia* sp. 6. 21-23. *Pinnularia gibba* var. *subundulata*. 24. *Pinnularia meridiana* var. *meridiana*. 25. *Pinnularia microstrauron*. 26. *Pinnularia paulensis*. 27. *Pinnularia persudetica* var. *persudetica*. 28-30. *Pinnularia subanglica*. 31-32. *Pinnularia subgibba* var. *angustarea*. 33. *Pinnularia subgibba* var. *capitata*. Scale = 10  $\mu$ m.

rounded (Metzeltin & Lange-Bertalot 1998). The specimen of *P. meridian* var. *meridian* found on this study has similarity with the illustrated in Metzeltin & Krammer (1998), differing on the transapical axis, which according to the author are 12 to 13 µm.

Midwest region records: Silva *et al.* (2016).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Terra Ronca, Córrego São Mateus, *A.A. França 17* (UFG 50 259).

***Pinnularia microstrauron*** (Ehrenberg) Cleve, The diatoms of Finland, Acta Societatis pro Fauna et Flora Fennica 8(2): 1-68, pls 1-3. 1891.

Figure 25

The valves are linear with slightly convex margins; apices are rostrate; raphe is filiform; central area is rhombic reaching the margins due to a siliceous space formed by shortening of the striae on the center; striae are radiate and convergent towards the apices. Apical axis: 45.26 µm; transapical axis: 8.61 µm; rate apical axis/transapical: 5.25 µm; 13 striae in 10 µm.

The specimens are similar to that illustrated by Krammer & Metzeltin (1998, table 172 pg 578, figs. 6-8) mainly in the valve format, striae and the straight proximal raphe ends. This is cosmopolite species, have been found in oligotrophic waters with low electrolytes (Krammer 2000).

Midwest region records: Silva *et al.* (2016).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Terra Ronca, Córrego São Mateus, *A.A. França 17* (UFG 50 259).

***Pinnularia paulensis*** Grunow, In Cleve, K. Svenka Vet.-Akad.Handl. 27(3):86, pl.1, fig. 20. 1895.

Figure 26

The valves are linear-lanceolate without undulations on the margins; apices are acuminate-rounded; raphe is slightly undulate with terminal ends deflected to the same directions in bayonet shape; central area slightly circle on the center of the dorsal side; striae are shortened throughout all the valve complex; parallel and slightly radiate on the center. Apical axis: 89.76 µm; transapical axis: 9.44 µm; rate apical axis/transapical: 9.44 µm; 14 striae in 10 µm.

*P. paulensis* shows linear-lanceolate valves and similar apices as *P. superpaulensis* (Hustedt) Metzeltin & Lange-Bertalot, but differs by showing simple raphe and shorter striae.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego Estiva, *A. A. França 22* (UFG 50 264).

***Pinnularia persudetica*** var. *persudetica* Krammer, In Lange-Bertalot, Diatoms Europe 1:134, pl. 109, figs 1-6. 2000.

Figure 27

The valves are linear to elliptic-lanceolate with sides lightly convex; apices are cuneate-rounded; raphe is lateral; central area is slightly round in one side of the valve, formed by shortening of the striae on the center; striae are radiate on the center and convergent on the apices. Apical axis: 86.65 µm; transapical axis: 14.4 µm; rate apical axis/transapical: 5.80 µm; 9 striae in 10 µm.

*P. persudetica* var. *persudetica* and *P. persudetica* var. *silvatica* has elliptic-lanceolate valves with convex sides and cuneate rounded apices. *P. persudetica* var. *persudetica* distinguishes from *P. persudetica* var. *silvatica* for showing a small transapical axis and robust striae (Krammer 2000). Abundant in some oligotrophic lakes in Finland, where there is low electrolytes (Krammer 2000).

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Brasília, Córrego Bananal, *A.A. França 10* (UFG 50 250).

***Pinnularia subanglica*** Krammer, In Lange-Bertalot, Diatoms Europe 1:108, pl. 84, figs. 1-7. 2000.

Figures 28-30

The valves are linear; apices are capitate; central area is rhombic, almost reaching of the valves margins; raphe is filiform; striae are radiate on the center and convergent on the apices. Apical axis: 30.73-39.2 µm; transapical axis: 5.03-7.33 µm; rate apical axis/transapical: 4.28-6.79 µm; 12-14 striae in 10 µm.

*Pinnularia subanglica* has similar valve shape as *Pinnularia rumrichae* Krammer, but differs showing less capitate apices, width between 7-8 µm and rate apical /transapical axes of 5,8 µm (Krammer 2000). This species is not rare, can be found in water with low electrolytes and higher levels of oxygen (Krammer 2000).

Midwest region records: Federal District (Delgado & Souza 2007); Goiás (Delgado & Souza 2007).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 5* (UFG 50 247); Córrego 1, *A.A. França 13* (UFG 50 255); Córrego 1, *A.A. França 9* (UFG 50 251); Córrego 1, *A.A. França 3* (UFG 50 245); Córrego Estiva, *A.A. França 18* (UFG 50 260); Córrego Estiva, *A.A. França 21* (UFG 50 265); Córrego Estiva, *A.A. França 19* (UFG 50 261). Parque Estadual Terra Ronca, Córrego Lapa, *A.A. França 26* (UFG 50 248).

***Pinnularia subgibba* var. *angustarea*** Krammer & Metzelin, In Lange-Bertalot, *Iconographia Diatomologica* 5:191, pl. 184, figs 1-3. 1998.

Figures 31-32

The valves are linear with straight margins; apices are slightly protracted and rounded; raphe is straight with some undulations; central area rounded formed by shortening of the striae on the center; stria and transapical are aveolar slightly radiate and convergent on the apices. Apical axis: 89.24-123.36  $\mu\text{m}$ ; transapical axis: 13.99-15.77  $\mu\text{m}$ ; rate apical axis/transapical: 6.37-8.06  $\mu\text{m}$ ; 7-9 striae in 10  $\mu\text{m}$ .

The illustrated individuals in this study, shows morphological characteristics as valves shape, apices, raphe, central area and striae similar to the description in Krammer (2000), but differs on the transapical axis measure (11.6-13.7  $\mu\text{m}$ ).

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 9* (UFG 50 251); Córrego Estiva, *A.A. França 21* (UFG 50 251); Parque Nacional de Brasília, Córrego Bananal, *A.A. França 10* (UFG 50 250).

***Pinnularia subgibba* var. *capitata*** Metzeltin & Krammer, In Lange-Bertalot, *Iconographia Diatomologica* 5:191, pl. 176, figs 1-3. 1998.

Figure 33

The valves are linear; apices are capitate-rounded; raphe has slight undulations; central area is rhombic with a small siliceous space reaching the margins; striae are radiate on the center and convergent on the apices. Apical axis: 49.95-75.64  $\mu\text{m}$ ; transapical axis: 5.89-7.97  $\mu\text{m}$ ; rate apical axis/transapical: 6.83-8.98  $\mu\text{m}$ ; 7-9 striae in 10  $\mu\text{m}$ .

According to Krammer (1998) *Pinnularia subgibba* var. *capitata* differs from the complex species type *P. subgibba*, by presenting an undulation

to triundulation on the margins with a slightly inflation in the middle region, apices are slightly rounded.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 9* (UFG 50 251)

***Pinnularia superpaulensis*** (Hustedt) Metzeltin & Lange-Bertalot, In Metzeltin & Lange-Bertalot, *Iconographia Diatomologica* 18:226, pl. 257, figs. 1-3. 2007.

Figure 34

The valves are linear with an expansion in the center of the valve; apices are slightly cuneate-rounded; raphe is straight and filiform with distal end in a hook shape; central area is slightly rounded in one side of the valve; striae are shorter throughout all the complex of the valve, slightly radiate and convergent. Apical axis: 128.67-129.38  $\mu\text{m}$ ; transapical axis: 14.49-14.63  $\mu\text{m}$ ; rate apical axis/transapical: 8.84-8.87  $\mu\text{m}$ ; 14 striae in 10  $\mu\text{m}$ .

According to Krammer (2000) *Pinnularia paulensis* Grunow differs from *Pinnularia superpaulensis* because the raphe is simple and the striae are shorter.

Midwest region records: pioneer reference.

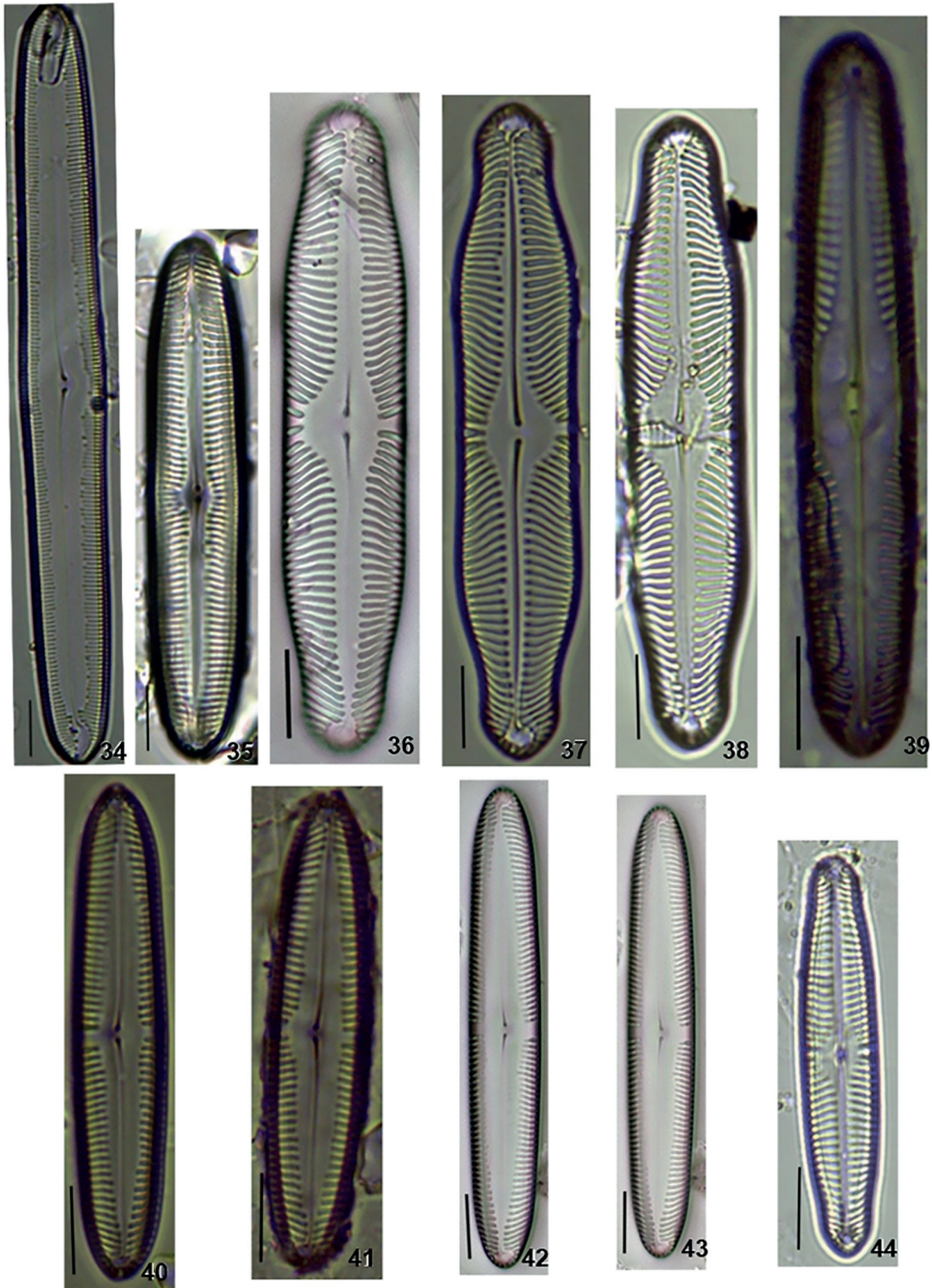
Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 9* (UFG 50 251); Córrego 1, *A.A. França 1* (UFG 50 243).

***Pinnularia viridiformis* var. *minor*** Krammer, In Lange-Bertalot, *Diatoms of Europe* 1:168, pl. 138, figs. 1-5. 2000.

Figure 35

The valves are elliptic-lanceolate with lightly convex margins; apices are acuminate-rounded; raphe is lateral and slightly undulate with distal ends deflected to the same direction in bayonet shape; central area is rounded; striae are radiate and slightly convergent on the apices. Apical axis: 78.61  $\mu\text{m}$ ; transapical axis: 14.88  $\mu\text{m}$ ; rate apical axis/transapical: 5.28  $\mu\text{m}$ ; 10 striae in 10  $\mu\text{m}$ .

*P. viridiformis* var. *minor* differs from *Pinnularia viridiformis* var. *viridiformis* Krammer because the valve size is different and the raphe is complex. The illustrated individuals in this study showed less striae, when compared with the original description by Krammer (2000) which has between 7-9 striae in



Figures 34-44. *Pinnularia* species in Cerrado streams. *Pinnularia superpaulensis*. 35. *Pinnularia viridiformis* var. *minor*. 36-38. *Pinnularia undula* var. *undula*. 39. *Pinnularia* sp.1. 40-41. *Pinnularia* sp.2. 42-43. *Pinnularia* sp.3. 44. *Pinnularia* sp.4. Scale = 10  $\mu$ m.

10  $\mu\text{m}$ . According to Krammer (2000) *P. viridiformis* var. *minor* is cosmopolite species, that can be found in different environment conditions.

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 1* (UFG 50 243).

***Pinnularia undula* var. *undula*** (Schumann) Krammer, In Lange-Bertalot, Diatoms of Europe 1:122, pl. 92, figs. 3-12. 2000.

Figures 36-38

The valves are linear with slightly undulation on the margins, more evident on the center; apices are slightly subcapitate to truncate; raphe is filiform with a distal fissure in bayonet shape; central area is large and slightly rounded; striae are radiate in the center and strongly convergent on the apices. Apical axis: 73.51-79.2  $\mu\text{m}$ ; transapical axis: 13.81-15.73  $\mu\text{m}$ ; rate apical axis/transapical: 5.03-5.37  $\mu\text{m}$ ; 8-9 striae in 10  $\mu\text{m}$ .

*P. undula* var. *undula* differs from other varieties showing parallel sides or undulates, apices are subcapitate to truncate in some individuals. Commonly, this species can be found in oligotrophic waters poor in electrolytes (Krammer 2000).

Midwest region records: pioneer reference.

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional da Chapada dos Veadeiros, Córrego Estiva, *A.A. França 22* (UFG 50 264); Córrego Estiva, *A.A. França 21* (UFG 50 263).

***Pinnularia* sp. 1**

Figure 39

The valves are elliptic-lanceolate; apices are rounded slightly cuneate; raphe is straight with distal ends deflected to the same direction; central area slightly rhombic and asymmetric, formed by shortening of the striae in the center; striae are widely spaced, slightly radiate and shorter towards the center. Apical axis: 61.59  $\mu\text{m}$ ; transapical axis: 10.1  $\mu\text{m}$ ; rate apical axis/transapical: 6.09  $\mu\text{m}$ ; 10 striae in 10  $\mu\text{m}$ .

Occurrence in the samples: BRAZIL. GOIÁS. Parque Estadual de Terra Ronca, Córrego Lapa, *A.A. França 24* (UFG 50 266).

***Pinnularia* sp. 2**

Figures 40-41

The valves are lanceolate; apices are rounded and slightly cuneate; raphe is filiform slightly

undulate with distal ends in hook shape; central area is slightly rounded in one side of the valve and a small siliceous space in the center; striae are shorter in an irregular form, slightly radiate to convergent on the apices. Apical axis: 48.67-54.33  $\mu\text{m}$ ; transapical axis: 9.7-9.92  $\mu\text{m}$ ; rate apical axis/transapical: 4.90-5.60  $\mu\text{m}$ ; 11 striae in 10  $\mu\text{m}$ .

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional da Chapada dos Veadeiros, *A.A. França 21* (UFG 50 263).

***Pinnularia* sp. 3**

Figures 42-43

The valves are linear-lanceolate; apices are rounded to slightly cuneate; raphe is filiform; central area is asymmetric with a slightly siliceous spacing; striae are shorter and slightly radiate. Apical axis: 73.18  $\mu\text{m}$ ; transapical axis: 10.92  $\mu\text{m}$ ; rate apical axis/transapical: 6.70  $\mu\text{m}$ ; 12 striae in 10  $\mu\text{m}$ .

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional da Chapada dos Veadeiros, *A.A. França* (UFG 50 264).

***Pinnularia* sp. 4**

Figura 44

The valves are linear; apices are rostrate to cuneate; raphe is straight with distal ends in bayonet shape and deflected to the same side; central area is asymmetric formed by a slightly shortening of the striae in the center; striae are radiate in the center and slightly convergent on the apices. Apical axis: 47.39  $\mu\text{m}$ ; transapical axis: 9.39  $\mu\text{m}$ ; rate apical axis/transapical: 5.04  $\mu\text{m}$ ; 11 striae in 10  $\mu\text{m}$ .

Occurrence in the samples: BRAZIL. GOIÁS. Parque Nacional de Brasília, *A.A. França 11* (UFG 50 253).

***Pinnularia* sp. 5**

Figures 14-15

The valves are linear to elliptic-lanceolate and weakly convex; the apices are conic and does not differentiated; raphe is filiform; central area is rounded developed in a fascia that can appear in one side or both sides; striae are weakly radiate in the middle region turning into weakly convergent towards to the apices. Apical axis: 28.82-34.92  $\mu\text{m}$ ; transapical axis: 5.51-5.95  $\mu\text{m}$ ; rate apical axis/transapical: 4.96-6.06  $\mu\text{m}$ ; 12-13 striae in 10  $\mu\text{m}$ .

The illustrated individuals on this study shown similarity with *Pinnularia castraregina* on the

raphe, valve morphologic and apices as the species type, however, there is a slightly difference on the transapical axis and striation, which is described on the species type by Krammer (2000) are 7.5-8.9  $\mu\text{m}$  and 9-10 striae in 10  $\mu\text{m}$ .

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional de Brasília, Córrego Bananal, *A.A. França 7* (UFG 50 252); Córrego Bananal, *A.A. França 7* (UFG 50 253).

### *Pinnularia* sp. 6

Figure 20

The valves are linear lanceolate with slightly undulate margins; apices are capitate to slightly rostrate; raphe is slightly undulate with slightly deflected distal ends; the middle region of the valve has a slight inflation; central area is rhombic widening to a small siliceous fascia; striae are radiate. Apical axis: 72.4-76.91  $\mu\text{m}$ ; transapical axis: 12.32-13.25  $\mu\text{m}$ ; rate apical axis/transapical: 5.50-6.24  $\mu\text{m}$ ; 11-12 striae in 10  $\mu\text{m}$ .

The illustrated individuals on this study shown similarity with *P. divergens* var. *protracta*, however the transapical axis and the number of striae are smaller than the presented by Krammer & Metzeltin (1998) for this species (16-6,8  $\mu\text{m}$  and 9 striae in 10  $\mu\text{m}$ ).

Occurrence in the samples: BRAZIL. GOIÁS: Parque Nacional da Chapada dos Veadeiros, Córrego 1, *A.A. França 7* (UFG 50 249); Córrego 1, *A.A. França 4* (UFG 50 246); Córrego 1, *A.A. França 6* (UFG 50 248).

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