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Sediment diatoms from Upper Paraná River floodplain lakes: new records

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ABSTRACT – Considering changes in biodiversity over large time scales, the use of sediments to access knowledge about current and past diversity has recently been highlighted as an emerging field for biodiversity science. Therefore, this work aimed to use lake sediments to perform a taxonomic survey of abundant diatoms from two lakes sediments from the Upper Paraná River floodplain and contributes to new species registrations. For diatom flora analysis were selected sediment samples from lakes. The diatoms with relative abundance ≥ 2% in at least one sediment sample were analyzed and identified under light microscopy. The study resulted in the identification of 47 taxa, including 40 at the specific level and seven possible new taxa. Among the taxa identified, 12 taxa (27%) of these had never before been documented in the Upper Paraná River floodplain.

Keywords: Bacillariophyta, Paraná river, sediment, survey, taxonomy.

RESUMO – **Diatomáceas de sedimento de lagos de uma planície de inundação subtropical: novos registros.** Considerando as mudanças na biodiversidade em uma longa escala temporal, o uso de sedimentos para acessar o conhecimento sobre a diversidade atual e passada foi recentemente destacado como um campo emergente para a ciência da biodiversidade. Portanto, este trabalho teve como objetivo utilizar amostras de sedimentos de lagos para realizar um levantamento taxonômico de diatomáceas abundantes de sedimentos de dois lagos da planície de inundação do Alto Rio Paraná e contribuir com o registro de novas espécies. Para análise da flora de diatomáceas amostras de sedimentos dos lagos foram selecionadas. As diatomáceas com abundância relativa ≥ 2%, em pelo menos uma amostra de sedimento, foram analisadas e identificadas sob microscopia óptica. O estudo resultou na identificação de 47 táxons, incluindo 40 no nível específico e sete possíveis novos táxons. Entre os táxons identificados, 12 (27%) deles nunca haviam sido documentados na planície de inundação do Alto Rio Paraná.

Palavras-chave: Bacillariophyta, levantamento, rio Paraná, sedimento, taxonomia.

INTRODUCTION

Due to their fluvial dynamics, floodplains display a remarkable heterogeneity of aquatic habitats, produced by complex interactions between surface water, groundwater, and riparian systems, providing high levels of diversity and productivity (Junk *et al.* 1989, Neiff 1990, Ward & Tockner 2001). In the Upper Paraná River floodplain, studies of the biodiversity and ecological aspects have been demonstrated the relevance of the hydrological regime and the environmental connectivity on the biotic integrity (Agostinho *et al.* 2000). However, this biotic integrity has been undermined by the increased anthropic impacts on these aquatic ecosystems. Besides others, anthropic impacts, the Upper River Paraná floodplain has been suffering the influence of dams located on the main channel and in large tributaries.

The operation of dams has altered the water level fluctuation and periodicity of the hydrological regime (Agostinho *et al.* 2004, Souza-Filho 2009, Thomaz *et al.* 2007). As a result, the known and unknown floodplain freshwater biodiversity has been drastically changed (Dudgeon *et al.* 2006, Souza-Filho *et al.* 2004, Strayer & Dudgeon 2010). Consequently, studies carried out in the Upper Paraná River floodplain have observed processes of species substitution, the introduction of non-native species, changes in native species abundance and decrease in diversity after dam constructions (Algarte *et al.* 2016, Gois *et al.* 2015, Simões *et al.* 2009).

Considering the biodiversity changes in long timescales have become an essential issue of freshwater ecology and conservation, the paleolimnological approach has recently been highlighted as an emerging field for biodiversity science (Gregory-Eaves & Beisner 2011). Lake sediments integrate organisms over time and space from different habitats and from annual to multi-annual assemblages (Bennion 1995, Gregory-Eaves & Beisner 2011). Therefore, a paleolimnological perspective and long-term community data can provide deeper insights into past and modern biodiversity changes than traditional community data from neolimnological studies, which usually does not cover wide temporal ranges (Nevalainen 2010).

Diatoms are an abundant component of primary producers and an important part of the plankton and periphytic freshwater communities (Round *et al.* 1990). These organisms have specific morphological characteristics as biogenic structures constituted of silica that allow their precipitation and incorporation in the sediment (Round *et al.* 1990, Sierra-Arango *et al.* 2014). Due to the exceptional taxonomic, diatoms are among the most species-rich group of algae, and despite the efforts on taxonomic and ecological diatom studies, many species are still unknown or not yet described (Mann & Vanormelingen 2013, Wehr & Sheath 2003). Nevertheless, paleolimnological taxonomic studies have been contributing to several new records and species to Brazilian flora (Almeida *et al.* 2015, Fontana & Bicudo 2009, Wengrat *et al.* 2015).

Despite the anthropic impacts on aquatic ecosystems, and the importance of sediment studies to access the biodiversity knowledge in a greater temporal range, local diversity approach studies remain scarce. Therefore, we presently documented a floristic survey of diatoms of two lakes sediment from Upper Paraná River floodplain, to contribute with new species registrations and possibly new species for the region.

MATERIALS AND METHODS

The study was carried out in two lentic environments, the Garças Lake (22º 43'27.18"S and 53º13'4.56"W) and Patos Lake (22º47'57.6"S and 53º32'29.16"W) located in the Upper Paraná River floodplain, situated between Porto Primavera dam and Itaipu Reservoir, extending about 230 km (Agostinho *et al.* 2008) (Figure 1). Garças Lake is permanently connected to the Paraná River through a narrow channel, is 2.128 m in length, with a perimeter of 4.328 m and an average depth of 2 m. Patos Lake is situated in Taquaruçú, Mato Grosso do Sul state (Brazil), permanently connected to the Ivinhema River by a channel. The Patos Lake has a maximum depth between 2.8 and 4.8 m (Souza Filho & Stevaux 1997). The littoral region of these lakes is dominated by multispecies stands of aquatic macrophytes, including *Eicchornia* Kunth, *Salvinia* Séguier, and *Polygonum* Lineu.

The sediment samples from Patos and Garças Lake were obtained using a polyvinyl chloride tube (7.5 cm diameter). Two sediment cores were collected in September 2017 in Garças Lake and March 2018 in Patos Lake.

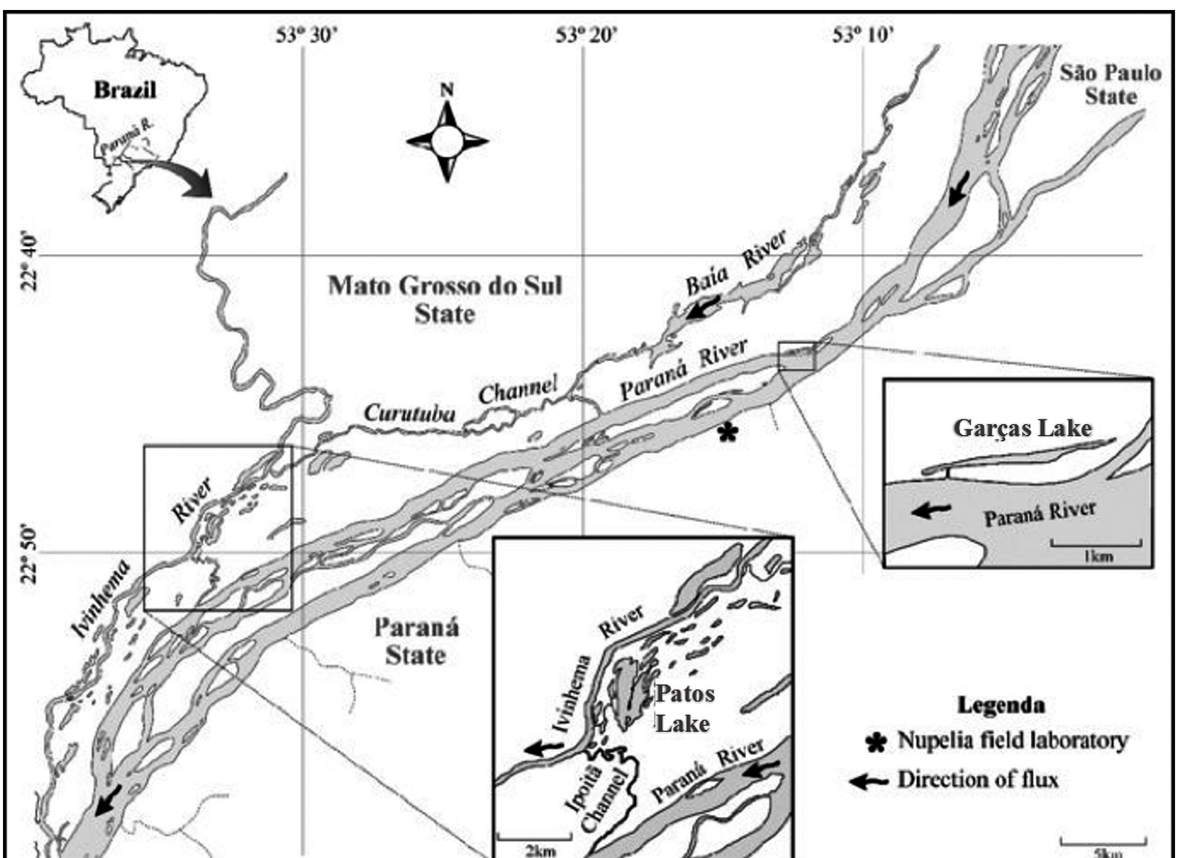

Figure 1. Study area in the Upper Paraná River floodplain: Garças and Patos lakes.

The sampling was conducted in the central and deepest region of lakes. Approximately 50 cm and 84 cm of sediment were recovered in Patos and Garças Lake, respectively. The sediment cores were separated into 1 cm slices (with an interval of 2 cm). The first 5 cm of Garças Lake sediment from the top of core was disregard due the presence of a lot of organic matter not yet decomposed. Totalizing 32 samples of Garças Lake and 25 samples of Patos Lake for diatoms flora analysis. This methodology was used to access as much information as possible about the composition of the diatoms species. From each slice, 0.01 g subsample was removed for the oxidation of the organic matter using hydrogen peroxide (H_2O_2 35%) and hydrochloric acid (HCl 37%) according to Battarbee *et al.* (2001). Permanent slides were prepared using Naphrax® as an inclusion medium.

The quantitative analysis was performed according to the method of Battarbee *et al.* (1986) with the count of at least 500 valves in an optical microscope. The slides were analyzed qualitatively (measurements and micrographs) under an optical microscope (under 1000× magnification) equipped with a digital camera. We presented those taxa with a relative abundance ≥ of 2% in at least one sediment sample. All species were represented on photo boards. New records for Upper Paraná River were identified based on recent works of Dunck *et al.* (2018), Osório *et al.* (2017), and Ruwer & Rodrigues (2018). Descriptions, relevant taxonomical and ecological comments were provided for new records, *conferatur* taxa, and taxa identified until the genus level. The samples were deposited in the herbarium of Nupélia at the Universidade Estadual de Maringá (18065 to 18122 - *supplementary material*). Taxonomy and nomenclature followed specific publications (*e.g.* Metzeltin *et al.* 1998, 2007), and has been adopted the Round *et al.* (1990) for the taxonomic classification of species, except for genera after this bibliography.

RESULTS AND DISCUSSION

The biodiversity of diatoms with a relative abundance of ≤ 2% was represented by 47 taxa distributed in 19 genera, of which 40 were identified at the species level or lower and 7 did not coincide with other materials in the literature studied, so they were identified at the genus level. *Eunotia* Ehrenberg was the genera with a higher number of taxa (13 species) followed by *Aulacoseira* Thwaites (6 species) and *Gomphonema* Ehrenberg (5 species). From described species, 12 taxa were firstly recorded for the Upper Paraná River floodplain. Taxons considered as a new record for Upper Parana River floodplain, in *conferatur*, and identified to infrageneric level are described in detail, information on the rest of the identified taxons is shown in Table 1.

Bacillariophyta Karsten 1928

Coscinodiscophyceae Round & Crawford 1990

Aulacoseirales Crawford 1990

Aulacoseiraceae Crawford 1990

Aulacoseira Thwaites 1848

Aulacoseira pusilla (Meister) Tuji & Houki, Bull. Natl. Sci. Mus, Ser. B (Botany), 30: 38, fig. 161. 2004.

(Figs. 17, 18)

Valves cylindrical. The cells form short chains linked by small marginal spines. Rows of pervalvar areolae are curved to the right (dextrorse). Rounded areolae. Sulcus slightly pronounced. The ratio of the mantle height to valve diameter is usually close to or slightly less than one µm. Mantle height: 2.5-3.0 µm, diameter: 5.0-5.5 µm, striae: 17.3-20.1 in 10 µm. The specimens were consistent and identified according to Brazilian studies Bertolli *et al.* (2010), Bicudo *et al.* (2016), and Cavalcante *et al.* (2013). *A. pusilla* differs from other species due to the short chains, presence of curved striae (dextrorse), and delicate areola (Bicudo *et al.* 2016).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM 18098-103, 18106).

Occurrence: first citation for Upper Paraná River floodplain.

Bacillariophyceae Haeckel 1878

Fragilariales Silva 1962

Fragilariaceae Kützing 1844

Fragilariforma brasiliensis (Grunow) Almeida, Wetzel, Morales & Bicudo in Almeida *et al.*, Fottea, 17: 277-292, figs. 37-50. 2017.

(Figs. 19-23)

Valves linear to lanceolate, constricted in the middle. Subcapitate to rostrate ends. Axial and central area absent. Striae uniseriate, parallel, composed by circular areolae, extending onto the mantle. Length: 22.1-54.7 µm; width: 4.2-6.3 µm; striae <20 in 10 µm. Species erroneously identified as *Fragilariforma javanica* Hustedt in taxonomic and ecological Brazilian studies. The morphological differences between these two species are the shape and width of apices and kind of spines (Almeida *et al.* 2017).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18098-104, 18106-107, 18109, 18113-115).

Occurrence: first citation for Upper Paraná River floodplain.

Staurosiraceae Medlin 2016

Pseudostaurosira cf. ***brevistriata*** (Grunow) Williams & Round, Diatom Res., 2: 276, figs. 28-31. 1988.

(Figs. 24-27)

Table 1. Herbarium number, morphometric and figure data of diatom species from Upper Paraná River floodplain, Brazil (D = diameter; MH = mantle height; L = length; W = width; S = striae; SI = striae inconspicuous). Garça Lake = GL; Patos Lake = PL

Taxon	Dimension (µm) and striae (in 10 µm)	Figure	GL; PL	Herbarium number
Stephanodiscaceae				
Discostella stelligera (Cleve & Grunow) Houk & Klee	D: 7.5-13.0; S: 10-15	2-3	GL	18065-76; 18083; 18086; 18089
Aulacoseiraceae				
Aulacoseira ambigua (Grunow) Simonsen	MH: 3.8-12.1; D: 4.1-14.0; S: 14-20	4-6	GL; PL	18065-76; 18083-84; 18086-87; 18089; 18092-93; 18095; 18098-119; 18121-122
Aulacoseira distans (Ehrenberg) Simonsen	D: 7.5-10.0	7-9	GL; PL	18065-76; 18083; 18098-110; 18112-115; 18118; 18120
Aulacoseira granulata (Ehrenberg) Simonsen	MH: 6.2-19.1; D: 4.6-18.6; S: 8-13	10-11	GL; PL	18065-76; 18083; 18086-87; 18098-122
Aulacoseira herzogii (Lemmermann) Simonsen	MH: 10.5-20.0; D: 4.5-8.5; SI	14-16	PL	18098-104; 18106-110; 18112-113; 18116-118
Aulacoseira italica (Ehrenberg) Simonsen	MH: 14.5-20.0; D: 7.5-15; SI	12-13	PL	18099-122
Staurosiraceae				
Staurosirella crassa (Metzeltin & Lange-Bertalot) Ribeiro & Torgan	L: 13.9-53.3; W: 4.6-13.5; S: 5-7	38-40	GL	18068-76; 18084-97
Staurorirella sp. 1	L: 6.1-8.3; W: 3.3-4.8; S: 10-12	32-37	GL	18065-76; 18083-84; 18087; 18090-97
Staurosirella sp. 2	L: 5.6-15.9; W: 2.1-3.1; S: 10-12	41-46	GL	18085-18097
Eunotiaceae				
Eunotia bilunaris (Ehrenberg) Schaarschmidt	L: 80.0-100.0; W: 4.0-4.5; S: 17	53	PL	18098-102; 18106-122
Eunotia deformis Metzeltin & Lange-Bertalot	L: 14.0-83.9; W: 7.0-9.4; S: 10-14	54-58	PL	18098-110; 18112-119
Eunotia formica Ehrenberg	L: 24.0-72.0; W: 7.0-9.0; S: 8-12	50-52	PL	18099-122
Eunotia longicamelus Costa, Bicudo & Wetzel	L: 22.0-61.0; W: 5.0-7.0; S: 10-13	59-61	GL; PL	18065-76; 18083; 18092
Eunotia monodon Ehrenberg	L: 25.2-76.1; W: 6.0-10.0; S: 8-13	62-65	PL	18098-122
Eunotia cf. *neomundana* Metzeltin & Lange-Bertalot	L: 25.0-80.8; W: 8.5-12.2; S: 7-10	66-68	PL	18101-120
Eunotia pseudosudetica Metzeltin, Lange-Bertalot & García- Rodríguez	L: 12.5-40.0; W: 5.0-8.0; S: 10-15	74-75	GL; PL	18065; 18067-76; 18083; 18084-87; 18090-91; 18093-96
Eunotia sp. 1	L: 56.6-21.1; W: 5.0-6.8; S: 11-14	78-82	PL	18102-122
Eunotia sp. 2	L: 37.5-65.0; W: 7.0-9.5; E: 7-13	83-85	PL	18109; 18111-118
Achnanthidiaceae				
Achnanthidium exiguum (Grunow) Czarnecki	L: 9.0-15.0; W: 4.5-7.0; S: <20	86-94	GL	18066-67; 18072-76; 18083-97
Achnanthidium minutissimum (Kützing) Czarnecki	L: 10.0-17.5 - W: 2.5-3.5; SI	95-97	GL; PL	18065-76; 18083-84; 18086-88; 18091-100
Planothidium bagualensis Wetzel & Ector	L: 11.0-22.5; W: 6.0-7.5; S: 13-15	98-101	GL	18067; 18069; 18074; 18076; 18084-87; 18089-97
Planothidium dubium (Grunow) Round & Bukhtiyarova	L: 10.5-16.0; W: 6.5-8.5; S: 12-15	110-113	GL	18065-66; 18074; 18076; 18083; 18086-97
Cocconeidaceae				
Cocconeis sp. 1	L: 9.0-11.0; W: 5.5-6.0; SI	106-109	GL	18085-18097
Gomphonemataceae				
Placoneis ovillus Metzeltin, Lange-Bertalot & García-Rodríguez	L: 11.0-16.5; W: 6.7-8.5; S: 14-19	102-105	GL	18072; 18074-75; 18085-97
Encyonema silesiacum (Bleisch) Mann	L: 30.0-38.0; W: 6.0-8.0; S: 11-12	114-116	GL	18065; 18067-71; 18073; 18076; 18083-86; 18090-93

Table 1. Cont.

Taxon	Dimension (µm) and striae (in 10 µm)	Figure	GL; PL	Herbarium number
Gomphonema angustatum	L: 13.9-20.0; W: 3.4-4.5; S: 12-16	117-120	GL	18065; 18067; 18072-76; 18083-84; 18086-87; 18091; 18093-94
Gomphonema brasiliense Grunow	L: 15.2-22.0; W: 3.5-4.5; S: 13-15	121-125	GL	18067; 18069; 18071-76; 18083; 18086
Gomphonema lagenula Kützing	L: 13.5-23.0; W: 5.0-7.0; S: 14-18	129-132	GL	18068; 18070-76; 18083-84; 18086-87; 18091
Gomphonema sp. 1	L: 16.4-25.0; W: 3.5-4.1; S: 13-15	133-136	GL	18068; 18072; 180086; 18090; 18093; 18095
Naviculaceae				
Naviculadicta sp. 1	L: 8.0-16.0; W: 4.0-5.5; S: 16-20	140-152	GL	18073; 18085-97
Diadesmidaceae				
Diadesmis confervaceae Kützing	L: 16.0-18.0; W: 6.0-7.0; S: 12-14	153-155	PL	18098-108
Luticola mutica (Kützing) D.G.Mann	L: 12.5-15.0; W: 6.0-7.0; S: <20	164-166	GL; PL	18067-69; 18071; 18074-76; 18084-85; 18087; 18091; 18093; 18098; 18100-101; 18103; 18105-106; 18108-120; 18122
Luticola muticoides (Hustedt) Mann	L: 9.5-16.0; W: 6.0-8.0; S: <20	167-169	PL	18099-102; 18104; 18108-109; 18115; 18119
Luticola simplex Metzeltin, Lange-Bertalot & García-Rodríguez	L: 20.0-23.5; W: 6.5-8.0; S: <20	170-173	PL	18098-105; 18107-112; 18114-122
Bacillariaceae				
Nitzschia amphibia Grunow	L: 17.5-30.0; W: 3.0-4.5; S: 17-19	174-181	GL	18065-76; 18083-84; 18086-87; 18089-96

Valves are lanceolate in larger specimens to elliptical in smaller specimens. Rostrate ends to rounded ends in smaller specimens. Presence of a broad lanceolate axial area and short striae found near the edge of the valve. Striae parallel to radiate in the central of the valve to slightly radiate toward the valve ends. Length: 6.2-19 µm; width: 2.9-4.3 µm; striae 12-16 in 10 µm. This taxon differs from other *Pseudostaurosira* Williams & Round and *Staurosirella* Williams & Round species by the presence of delicate and shortened marginal striae. The specimens observed are similar to those registered by Brassac *et al.* (2003) and Taylor *et al.* (2007). The study specimens are similar to the *Staurosirella krammeri* Morales, Chávez & Ector and *Pseudostaurosira sajamaensis* Morales & Ector; however, *P. brevistriata* differs concerning the length and shape valve (Morales *et al.* 2010, 2012). For a clear separation of these taxa, an ultra-structural analysis is required.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18071-72, 18074, 18076, 18084-97); Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18119).

Occurrence: first citation for Upper Paraná River floodplain.

***Staurosira* sp. 1**

(Figs. 28-31)

Valves lanceolate dilated in the middle. Cuneate, subrostrate ends. Axial area narrow and lanceolate. The central area is lanceolate. Striae alternate and short, slightly radiated to the central area. Length: 11-21 µm; width: 3.9- 5.0 µm; striae 15-17 in 10 µm. The specimens observed are similar to *Pseudostaurosira decipiens* Morales, Chávez & Ector. Nevertheless, the *P. decipiens* are different from the studied population, due the lower striae density, ends rostrate in smaller individuals, and presence of a slight swelling in the region between the ends and the central area (Morales *et al.* 2012). The studied population is consistent with the type of material described by Metzeltin *et al.* (2005), except for valve length values.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18085 - 95, 18097).

Occurrence: first citation for Upper Paraná River floodplain.

***Staurosirella* sp. 1**

(Figs. 32-37)

Valves ovoid to elliptic. Ends rounded. Axial area linear and narrow, central area absents. Striae alternated and slightly radiate. Length: 6.1-8.3 µm; width: 3.3-4.8 µm; striae 10-12 in 10 µm. The specimens documented resemble *Staurosira kjotsunarum* Morales, Novais & Ector in valve morphology and dimensions; except for striae density (*S. kjotsunarum* has 14-16 striae in 10 µm, Morales *et al.* 2012). The specimens were consistent with *Staurosirella* sp. 1 registered in Bartozek *et al.* (2018) for Brazilian samples. Bartozek *et al.* (2018) suggest further studies to identify this taxon.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18065-76, 18083-84, 18087, 18090-97).

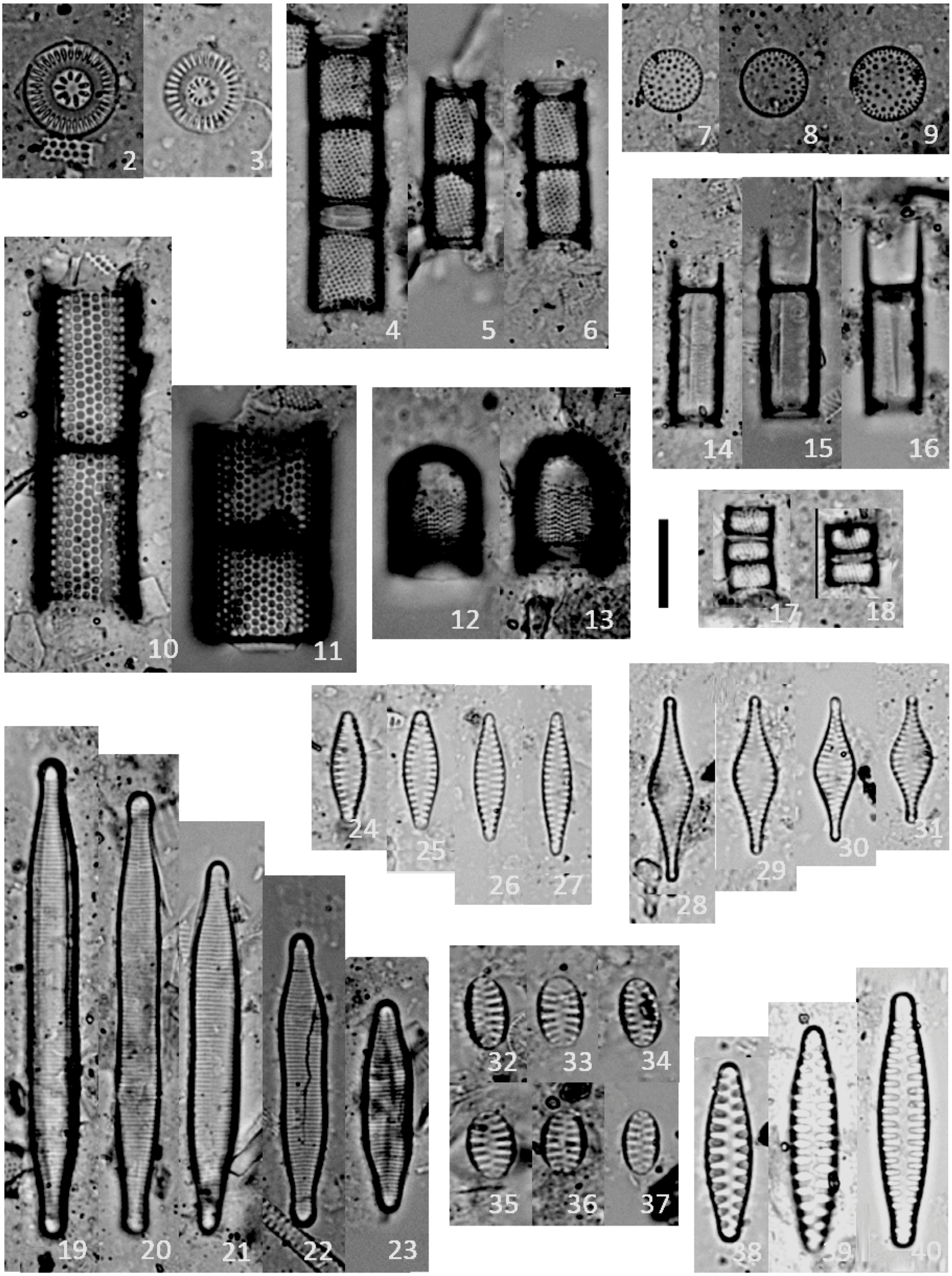

Figure 2-40. Sediment diatoms from subtropical floodplain lakes (LM). **2-3**. *Discostella stelligera*; **4-6**. *Aulacoseira ambigua*; **7-9**. *Aulacoseira distans*; **10-11**. *Aulacoseira granulata*; **12-13**. *Aulacoseira italica*; **14-16**. *Aulacoseira herzogii*; **17-18**. *Aulacoseira pusilla*; **19-23**. *Fragilariforma brasiliensis*; **24-27.** *Pseudostaurosira* cf. *brevistriata*; **28-31**. *Staurosira* sp.1; **32-37**; *Staurosirella* sp.1; **38-40**. *Staurosirella crassa*. (Scale bar: 10 µm).

***Staurosirella* sp. 2**

(Figs. 41-46)

Valves heteropolar, ovate to clavate. Ends rounded, with apices slightly subcapitate and bases attenuate. Axial area linear and narrow, central area absents. Striae parallel and alternated slightly radiate at the ends in some specimens. Length: 5.6 - 15.9 µm; width: 2.1-3.1 µm; striae 10-12 in 10 µm. The specimens documented resemble *Pseudostaurosira clavatum* Morales (Morales 2002) in valve morphology. *Staurosirella* sp. 2 can be distinguished from this taxon by lower values of valve length and less attenuate ends. *Staurosirella* sp. 2 is similar to species from the *Opephora* Petit genus concerning valve shape; however, *Opephora* presents predominant marine habit (Round *et al.* 1990).

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18085-18097).

Eunotiales Silva 1962

Eunotiaceae Kützing 1844

Eunotia* cf. *bidens Ehrenberg, Ber. K. Akad. Wiss. Berlin, 1841: 413. 1843.

(Figs. 69-71)

Valves with dorsal margin convex with two slightly prominent undulations, ventral margin slightly concave. Ends truncated, detached from the valve body. Striae parallel to radiate. Length: 33-76 µm; width: 10-13 µm; striae 10-14 in 10 µm. The population observed are consistent concerning some valve morphology features and dimensions with *Eunotia bidens* presented in Metzeltin & Lange-Bertalot (1998) and Metzeltin *et al.* (2005). However, the studied population was maintained as a conferatur due to variation in the morphology of the ends. *E. bidens* has subcapitate, obtusely rounded apices, and slightly detached.

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18098-122).

Occurrence: first citation for Upper Paraná River floodplain.

Eunotia deficiens Metzeltin, Lange-Bertalot & García-Rodríguez, Iconogr. Diatomol, 15: 48, pl. 22, fig. 5. 2005.

(Figs. 47-49)

Valves with dorsal margin convex, and slightly concave ventral margin. Ends rounded, slightly subcapitate, not detached from the valve body. Striae are parallel to slightly radiate, equidistant, and more concentrated at the ends. Length: 30-63 µm; width: 7.5-9.5 µm; striae 8-11 in 10 µm. The studied population is consistent with the type of material described in Metzeltin *et al.* (2005). *E. deficiens* resembles *E. luna* var. *aequalis* Hustedt but they differing in valve dimensions and striae density. *E. luna* var. *aequalis* present larger width values (12.6-15.3), dorsal margin more convex, and higher striae density (12-14) (Bicca *et al.* 2009, Metzeltin *et al.* 2005, Simonsen 1987).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18098-99, 18101-122).

Occurrence: first citation for Upper Paraná River floodplain.

Eunotia* cf. *neomundana Metzeltin & Lange-Bertalot, Iconogr. Diatomol., 5: 69, pl. 19, figs 1-6, pl. 22, figs 1-3. 1998.

(Figs. 66-68)

Valves almost linear, with a slightly triundulate ventral and dorsal margins. Ends apiculate, cuneate-apiculate, and attenuate-rounded. Striae parallel to slightly radiate at the ends, equidistant. Length: 25.2-76.1 µm; width: 6-10 µm; striae 8-13 in 10 µm. The studied population is similar to the type material described in Metzeltin & Lange Bertalot (1998) however; specimens documented have lower values of length and width.

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18101-120).

Occurrence: Paú Veio Lake, Upper Paraná River floodplain, (Biolo & Rodrigues 2013).

Eunotia papilio (Ehrenberg) Grunow, Alg. Novara, 94. 1868.

(Figs. 72-73)

Valves with dorsal margin convex with two prominent undulations, ventral margin tightly concave. Ends cuneate, dorsally deflected. Striae parallel to radiate towards the ends. Length: 25-35 µm; width: 7-12 µm; striae 8-10 in 10 µm. The population observed is consistent with specimens from Metzeltin *et al.* (2005) and Brazilian studies of Costa *et al.* (2017) and Oliveira *et al.* (2012). This taxon differs from other *Eunotia* species by the presence of two prominent undulations on the dorsal margin and cuneate ends.

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18098-18099, 18101-122).

Occurrence: first citation for Upper Paraná River floodplain.

Eunotia rabenhorstii* var. *monodon Cleve & Grunow in Van Heurck, Syn. Diat. Belg., pl. XXXV, fig. 12B. 1881.

(Figs. 76, 77)

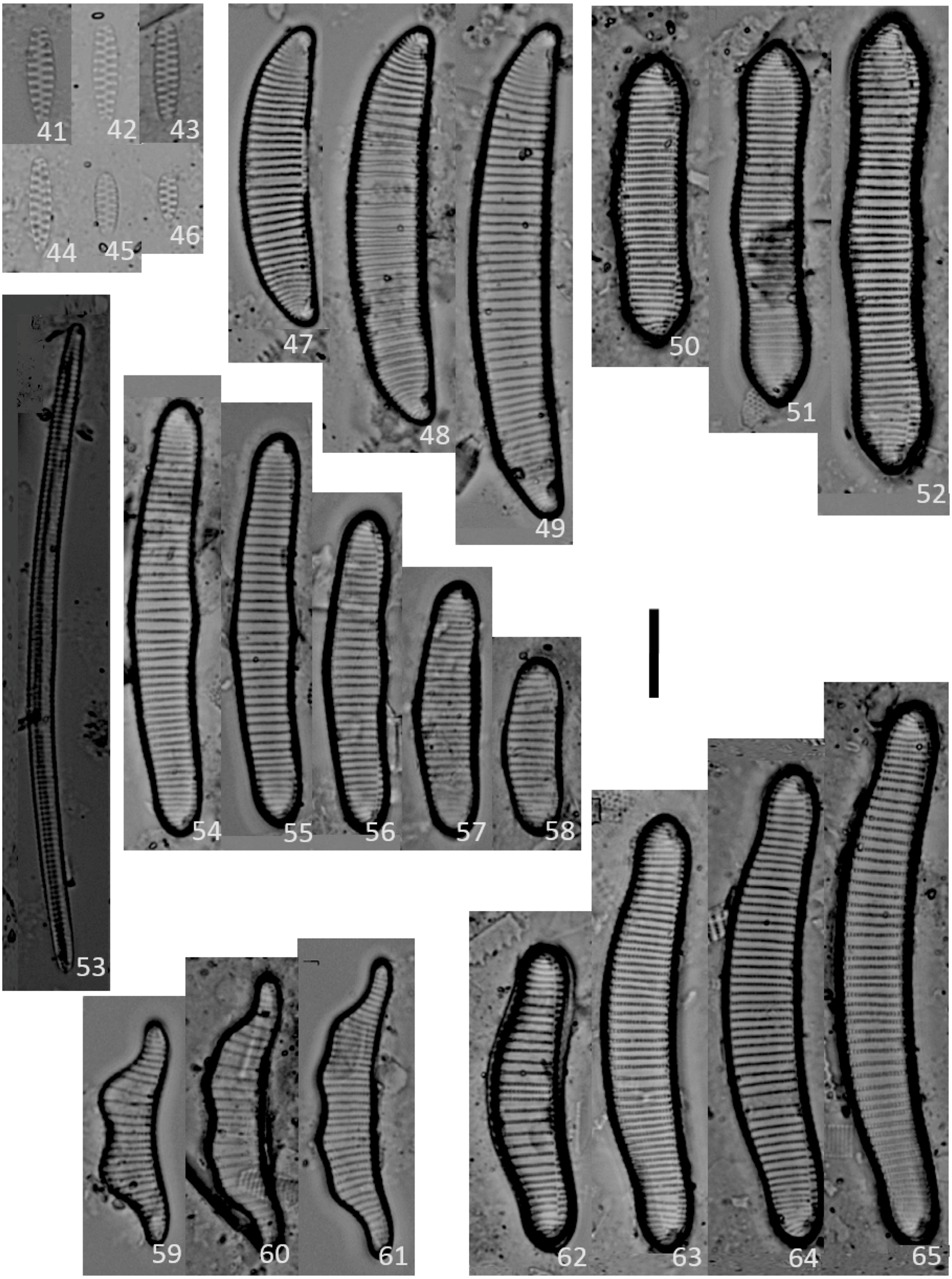

Figure 41-65. Sediment diatoms from subtropical floodplain lakes (LM). 41-46. *Staurosirella* sp. 2; **47-49**. *Eunotia deficiens*; **50-52**. *Eunotia formica*; **53**. *Eunotia bilunaris*; **54-58**. *Eunotia deformis*; **59-61**. *Eunotia longicamelus*; **62-65**. *Eunotia monodon*. (Scale bar: 10 µm).

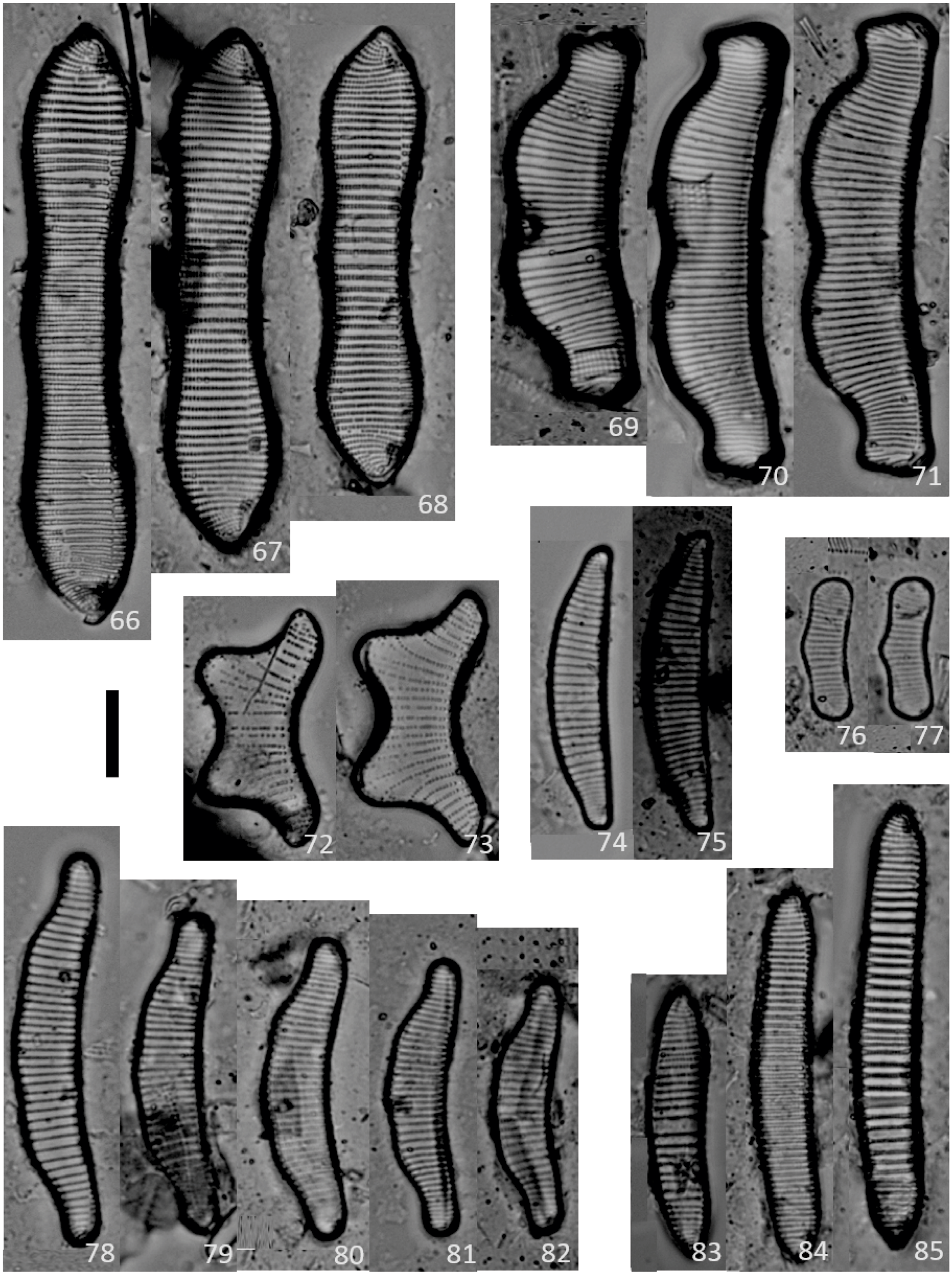

Figure 66-85. Sediment diatoms from subtropical floodplain lakes (LM). **66-68**. *Eunotia* cf. *neomundana*; **69-71**. *Eunotia* cf. *bidens*; **72-73**. *Eunotia papilio*; **74-75**. *Eunotia pseudosudetica*; **76-77**. *Eunotia rabenhortii* var. *monodon*; **78-82**. *Eunotia* sp. 1; **83-85**. *Eunotia* sp. 2. (Scale bar: 10 µm).

Valves with dorsal margin convex with an attenuated-rounded undulation in the middle region, ventral margin concave. Ends rounded, widely dilated. Striae parallel to radiate towards the ends. Length: 9.0-25.5 µm; width: 5-9 µm; striae 13-16 in 10 µm. *E. rabenhorstii* var. *monodon* resembles *E. rabenhorstii* var. *triodon* Cleve & Grunow, differ by the number of undulations on the dorsal margin. *E. rabenhorstii* var. *monodon* presents one undulation while *E. rabenhorstii* var. *triodon* has three undulations on the dorsal margin (Van Heurck 1881). The specimens observed are similar to those registered by Costa *et al.* (2017).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18098, 18101-102, 18104, 18106-107, 18109-111, 18113-121.

Occurrence: first citation for Upper Paraná River floodplain.

***Eunotia* sp. 1**

(Figs. 78-82)

Valves with dorsal margin convex with three slightly undulations in all cell cycle stages, ventral margin concave. Ends rounded subcapitates, slightly dorsally deflected. Striae parallel to radiate towards the ends. Length: 21.1-56.6 µm; width: 5.0-6.8 µm; striae 11-14 in 10 µm. The specimens observed are morphologically similar to the lectotype *E. tridentula* Ehrenberg from Reichardt (1995), both species present three undulations on dorsal margin, however; *Eunotia* sp. 1 can be distinguished from this taxon by the less width valve values and by the less prominent undulations. Despite the similarity of *Eunotia* sp. 1 with *E. tridentula* registered in the Brazilian study of Faustino *et al.* (2016), *Eunotia* sp. 1 differs morphologically from *E. tridentula* in the Brazilian studies of Bes *et al.* (2012), Bicca *et al.* (2011), Costa *et al.* (2017) and Fontana & Bicudo (2012). The great morphological variability of *E. tridentula*, exposed mainly in the work of Metzeltin *et al.* (2005), emphasizes the necessity for a taxonomic revision of this group.

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18102-122).

***Eunotia* sp. 2**

(Figs. 83-85)

Valves with dorsal margin slightly convex, ventral margin straight to slightly concave. Slight swelling in the median region of two or only in one valve. Ends cuneate, slightly detached from the valve body. Striae predominantly parallel. Length: 37.5-65.0 µm; width: 7.0-9.5 µm; striae 7-13 in 10 µm. *Eunotia* sp. 2 resembles *Eunotia formica* Ehrenberg and *Eunotia myrmica* Lange-Bertalot, concerning the presence of slight swelling in the median region, the shape, and the striae pattern at the ends. However, these taxa have capitate ends detached from the valve body and different length/width ratios (Lange-Bertalot 2011, Metzeltin & Lange-Bertalot 1998).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18109, 18111-118).

Cocconeidales Cox 2015

Cocconeidaceae Kützing 1844

***Cocconeis* sp. 1**

(Figs. 106-109)

Valves elliptic, ends rounded. Valve with raphe: axial area linear and narrow, central area narrow, raphe filiform. Striae delicate interrupted by submarginal hyaline line. Valve without raphe: axial area linear and narrow. Striae slightly radiate. Areolae inconspicuous. Length: 9-11 µm; width: 5.5-6.0 µm; striae 24-26 in 10 µm in both valves. This taxon differs from other *Cocconeis* Ehrenberg species by the very small dimensions and the presence of delicate striae, hardly visible in LM.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18085-18097).

Cymbellales Mann 1990

Gomphonemataceae Kützing 1844

Gomphonema brasiliense* ssp. *pacificum Moser, Lange-Bertalot & Metzeltin, Biblioth. Diatomol., 38: 185, pl. 50, figs. 1-6. 1998.

(Figs. 126-128)

Valves heteropolar, narrowly lanceolate. Apical and basal ends attenuate-rounded. Axial area wide and lanceolate, central area indistinct. Raphe straight, with proximal ends, slightly dilated to pores. Transapical striae short, parallel to radiate toward the ends. Stigma absent. Length: 21-31µm; width: 3.5-5.3 µm; striae 13-14 in 10 µm. *Gomphonema brasiliense* ssp. *pacificum* resembles *G. brasiliense* concerning shape valve and the short striae. *G. brasiliense* ssp. *pacificum* differ morphologically by the presence of ends more attenuate and lower valve dimensions, mainly the width values (Metzeltin *et al.* 2005). This taxon was registered in Brazilian studies of Marquardt & Bicudo (2014) and Medeiros *et al.* (2018).

Material examined: BRAZIL, MATO GROSSO DO SUL: Taquaruçú, Patos Lake, 23.III.2018, sediment, D.T. Ruwer (Nupélia UEM - 18099-106, 18109, 18113-122).

Occurrence: first citation for Upper Paraná River floodplain.

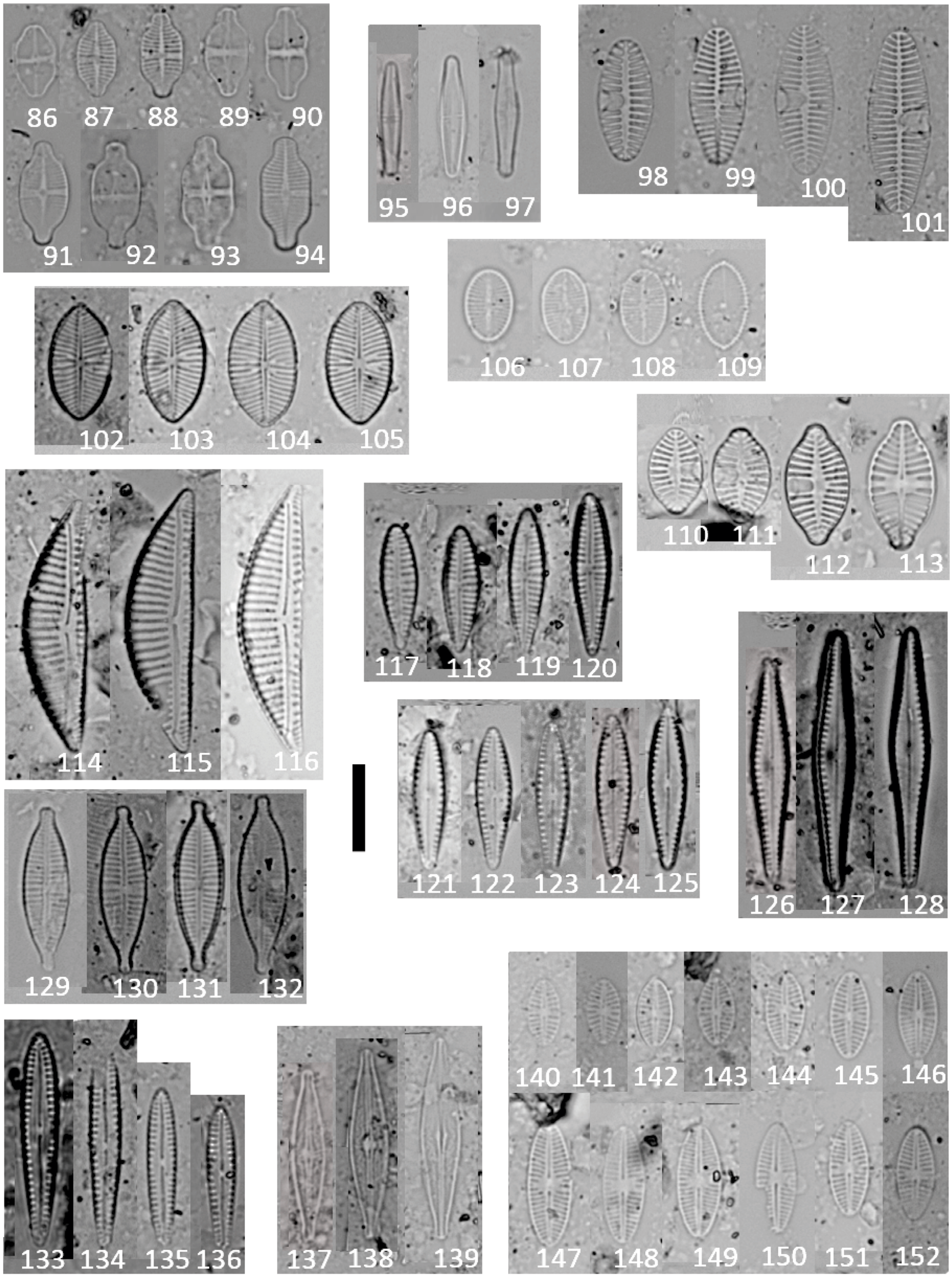

Figure 86-152. Sediment diatoms from subtropical floodplain lakes (LM). **86-94**. *Achnanthidium exiguum*; **95-97**. *Achnanthidium minutissimum*; **98-101**. *Planothidium bagualensis*; **102-105**. *Placoneis ovillus*; **106-109**. *Cocconeis* sp. 1; **110-113**. *Planothidium dubium*; **114-116**. *Encyonema silesiacum*; **117-120**. *Gomphonema angustatum*; **121-125**. *Gomphonema brasiliense*; **126-128**. *Gomphonema brasiliense* spp. *pacificum*; **129-132**. *Gomphonema lagenula*; **133-136**. *Gomphonema* sp. 1; **137-139**. *Brachysira neoexilis*; **140-152**. *Naviculadicta* sp.1. (Scale bar: 10 µm).

***Gomphonema* sp. 1**

(Figs. 133-136)

Valves heteropolar, lanceolate, slightly linear. Apical ends cuneate, and basal ends attenuate-rounded. Axial are lanceolate, central area rectangular limited by a shortened striae. Raphe straight, with proximal ends, slightly dilated to pores. Striae short, parallel to slightly radiate toward the ends. Stigma absent. Length: 16.4 - 25 µm; width: 3.5 - 4.1 µm; striae 13 - 15 in 10 µm. The specimens observed are morphologically similar to *G. rhombicum* Fricke from Metzeltin *et al.* (2005), concerning valve shape and striae pattern. Besides that, *G. rhombicum* has a stigma and cuneate-rounded ends.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18068, 18072, 180086, 18090, 18093, 18095).

Naviculales Bessey 1907

Brachysiraceae Mann 1990

Brachysira neoexilis Lange-Bertalot in H. Lange-Bertalot & G. Moser, Biblioth. Diatomol., 29: 51, pls. 5-6, 17, 32, 46, figs. 1-6, 7-11, 19-30. 1994.

(Figs. 137-139)

Valves lanceolate. Ends subcapitate. Axial area linear and narrow. Central area rounded. Raphe filiform. Striae inconspicuous, parallel to radiate, interrupted by longitudinal hyaline line. Areolae elongated, difficult to visualize in LM. Length: 22-25 µm; width: 4.5-5.0 µm. The population observed is consistent with specimens registered from Brazilian studies of Marra *et al.* (2016).

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18066, 18071, 18076, 18083-84, 18086-87, 18093).

Occurrence: first citation for Upper Paraná River floodplain.

Naviculaceae Kützing 1844

***Naviculadicta* sp. 1**

(Figs. 140-152)

Valves elliptical or linear-lanceolate with rounded ends. Axial area narrow and linear. Central area rectangular limited by a shortened striae, asymmetrical, wider in larger individuals. Raphe filiform. Striae parallel to slightly radiate toward the central area. Length: 8-16 µm; width: 4.0-5.5 µm; striae 16-20 in 10 µm. The specimens observed are morphologically similar to *Naviculadicta* sp. 1 from Metzeltin & Lange-Bertalot (2007). Besides that, *Naviculadicta* sp. 1 from Metzeltin & Lange-Bertalot (2007) differ by the central area wider and symmetric. The population from this study resemble *Sellaphora saugerresii* (Desmazières) Wetzel & Mann and *Navicula minima* Grunow registered by Wetzel *et al.* (2015), however; *Naviculadicta* sp. 1 differs concerning central area shape and striae density.

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18073, 18085-97).

Sellaphoraceae Mereschkowsky 1902

Sellaphora paenepupula Metzeltin & Lange-Bertalot, Iconogr. Diatomol., 11: 66, pl. 31, figs. 9-15. 2003.

(Figs. 156-157)

Valves elliptical lanceolate, tidy. Ends subcapitate. Axial area linear and narrow. Central area laterally expanded, limited by irregular short striae. Raphe filiform. Striae radiate, more widely spaced about the central area. Length: 18.5-22.9 µm; width: 5.9-7.4 µm; striae <20 in 10 µm. The specimens were consistent and identified according to the type of *Sellaphora paenepupula* from Metzeltin & Lange-Bertalot (2002) and Metzeltin *et al.* (2005) specimens. *Sellaphora pupula* (Kützing) Mereschkovsky can be distinguished from *Sellaphora paenepupula* by the dimensions, ends short-protracted ends, and pseudoblunt shape valves (Mann *et al.* 2008).

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18072-75, 18083).

Occurrence: first citation for Upper Paraná River floodplain.

Sellaphora sassiana (Metzeltin & Lange-Bertalot) Wetzel in Wetzel *et al.*, Fottea, 15: 228. 2015.

(Figs. 158-163)

Valves elliptical lanceolate. Ends capitate. Axial area linear and narrow. Central area narrow, limited by irregular shorter striae. Raphe filiform. Striae radiate toward to central area, limited by longitudinal hyaline line. Length: 11.9-14.9 µm; width: 3.8-5.0 µm; striae <20 in 10 µm. The specimens were consistent and identified according to the type of *Sellaphora sassiana* from Wetzel *et al.* (2015), and Metzeltin & Lange-Bertalot (1998) identified as *Naviculadicta sassiana* Metzeltin & Lange-Bertalot. This taxon was registered in Brazilian studies of Marra *et al.* (2016) and Marquardt *et al.* (2018).

Material examined: BRAZIL, MATO GROSSO DO SUL: Batayporã, Garças Lake, 21.IX.2017, sediment, D.T. Ruwer (Nupélia UEM - 18072-76, 18083, 18086-18087).

Occurrence: first citation for Upper Paraná River floodplain.

Some studies have already shown differences in algal communities between floodplain environments (Algarte *et al.* 2006, 2009, Bichoff *et al.* 2018, Rodrigues & Bicudo 2001). Confirming that local environmental factors (as physical and chemical characteristics) are fundamental to determine patterns of diatom community distribution (Algarte *et al.* 2009, Bichoff *et al.* 2018, Soininen 2007,

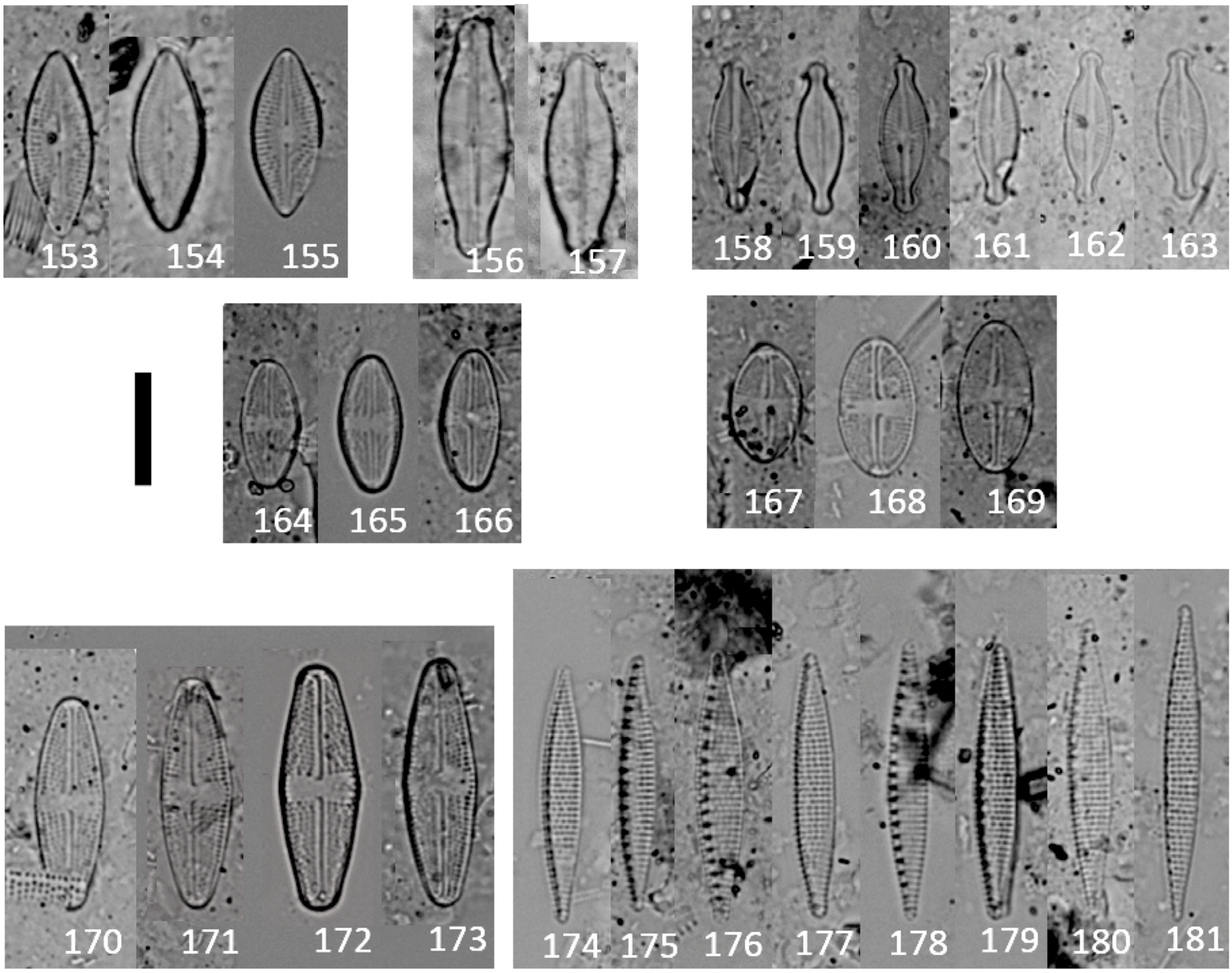

Figure 153-181. Sediment diatoms from subtropical floodplain lakes (LM). **153-155**. *Diadesmis confervaceae*; **156-157**. *Sellaphora paenepupula*; **158-163**. *Sellaphora sassiana*; **164-166**. *Luticola mutica*; **167-169**. *Luticola muticoides*; **170-173**. *Luticola simplex*; **174-181**. *Nitzschia amphibia*. (Scale bar: 10 µm).

Kahlert & Gottschalk 2014, Soininen & Weckström 2009). The relationship of the floodplain aquatic environments with hydrological periods and the dynamics created by flood pulse promote a great complexity of aquatic habitats providing a differentiated diversity in each environment (Agostinho & Zalewski 1996, Thomaz *et al.* 2007). This may explain the difference in the diatom taxa present in the core sediment in each lake. Among the 47 taxa addressed, 19 were exclusive for Patos Lake, and 20 were exclusive for Garças Lake. Only eight taxa were found in both lakes: *Aulacoseira ambigua*, *A. distans*, *A. granulata*, *Eunotia longicamelus*, *E. pseudosudetica, Pseudostaurosira cf. brevistriata, Achnanthidium minutissimum,* and *Luticola mutica*.

Patos Lake is inserted in the conservation area of the Várzeas do Rio Ivinhema State Park, between two main rivers of the Upper Paraná River floodplain (Agostinho & Zalewski 1996). Among the taxa with more than 2% relative abundance, the genera with the largest number of taxa in Patos Lake was *Eunotia* (13 taxa), *Aulacoseira* (six taxa) and *Luticola* (four taxa). The presence of *Aulacoseira* and *Luticola* species suggests possible periods of low waters, with moist or hydrological changes in Patos Lakes (Devercelli 2006, Fontana & Bicudo 2009, Rodrigues *et al.* 2009, Ruwer *et al.* 2018). Whereas, the greater occurrence of *Eunotia* (13 taxa) taxa in the Patos Lake sediment suggest conditions of low values of pH, conductivity, and nutrients (Moro & Fürstenberger 1997, Round *et al.* 1990, Vélez *et al.* 2005, Bicca & Torgan 2009, Burliga *et al.* 2013).

Gaças Lake presented a greater amount of abundant diatom species genera (Figure 182). Fragilaroids taxa (*Staurosira*, *Pseudostaurosira*, and *Staurosirella*) were the most represented taxonomic groups in Garças Lake, among the most abundant species. The presence of fragilaroids species suggests possible periods with unstable conditions with continual changes in the environment, linked to anthropogenic impacts, hydrological and limnological changes (Fayó *et al.* 2018, Gell *et al.* 2002, Reid *et al.* 2017). Algarte *et al.* (2016) observed the predominance of species in this same taxonomic family after changes in limnological conditions in a lake after the impact of a dam near the Upper Paraná River floodplain. Thus, both lakes have species that indicate hydrological changes, a dynamic that often occurs in floodplains.

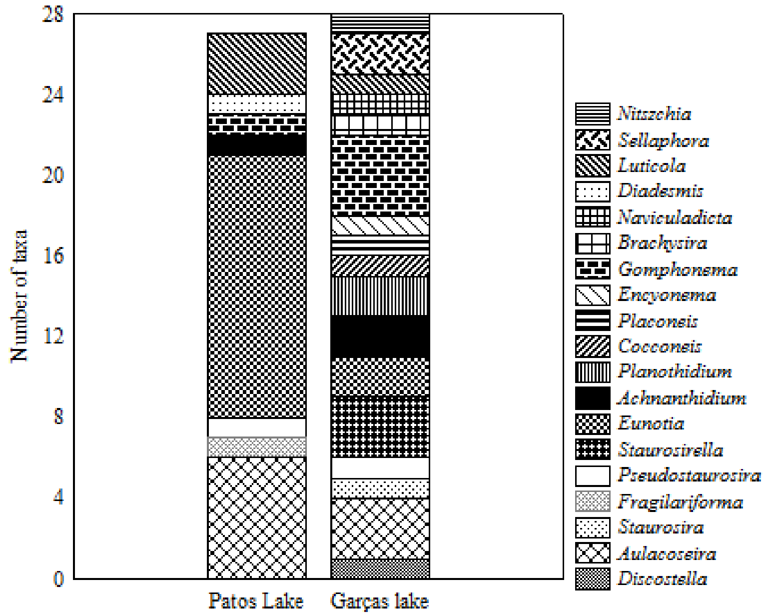

Figure 182. Taxa number per genera in Garças and Patos lakes from species with >2% of relative abundance.

This study provided new information about the distribution and biodiversity of tropical diatoms. From a total of 47 taxa recorded in floodplain lakes sediments, our study added 12 new citations of diatom species to the Upper Paraná River floodplain. Furthermore, were registered the other seven possible new taxa. The present study emphasizes the importance of use of sediment samples to access the diatom biodiversity of continental aquatic environments. Highlighting the need for surveying diatom assemblages in environments that present great biodiversity and that comes suffering the influence of anthropic impacts, to assist in the conservation of these environments.

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