ECOLOGY

Taxonomy of common taxa of Chlorophyceae (Chlorophyta) and Zygnematophyceae (Streptophyta) from periphyton of a Neotropical floodplain

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ABSTRACT. Some orders of algal groups such as Chlorophyceae and Zygnematophyceae have been reported as frequent taxa in periphytic communities of wetlands. The present study aimed at submitting these algal members which occurred in high abundance and frequency in the periphyton of 30 environments of the Upper Paraná River floodplain to a taxonomic survey and to present some ecological data concerning their richness. Periphyton were collected from petioles by scraping of *Eichhornia azurea* (Sw.) Kunth and preserved with Lugol acetic solution in the Upper Paraná River, Brazil, during high water period in March 2010. Taxa were counted in inverted microscope and those higher than 2,500 individuals in density with frequency of occurrence less than 50% simultaneously in the 30 environments sampled were subjected to a detailed taxonomical treatment under optical microscope coupled to a light camera and ocular micrometer under 1000x. Identifications and descriptions were made according to the algal literature. Some abiotic data were shown. Fifteen taxa belonging to the classes Chlorophyceae and Zygnematophyceae were abundant representing 64.6% of the total density. A Procruste analysis within a Detrended Correspondence Analysis showed that distribution pattern of richness of clorophyceans and zygnematophyceans was represented by common species of these communities, highlighting the importance of knowing about these algae taxonomy.

Keywords: chlorophyceans; desmids; periphytic community; richness; Upper Paraná River.

Introduction

Periphyton community displays high algal species richness and diversity (França, Lopes, & Ferragut, 2011). The morphological structure and the taxonomical diversity of the periphytic communities are strongly related to abiotic factors e.g., physical and chemical variables (Villeneuve, Montuelle, & Bouchez, 2010). In most cases this community can be regulated by a few species with high abundance and wide frequency of occurrence, thus playing an important ecological role (Gaston, 2011). Common species, unlike rare species, present a broad environmental range (i.g., generalists) and evaluation of parameters governing distribution of these common species may help the knowledge of the general patterns influencing the spatial variation of biodiversity (Tonial et al., 2012).

Although periphyton algal community of the Upper Paraná River floodplain has been studied in various aspects (Murakami, Bicudo, & Rodrigues, 2009; Biolo & Rodrigues, 2011b; Neif, Behrend, & Rodrigues, 2013; Carapunarla, Baumgartner, & Rodrigues, 2014; Dunck, Rodrigues, & Bicudo, 2015; Bichoff, Osório, Dunck, & Rodrigues, 2016; Algarte, Siqueira, Ruwer, Osorio, & Rodrigues, 2017a; Zanon, Marco, & Rodrigues, 2018; Adame, Dunck, & Rodrigues, 2018), knowledge about green microalgae mainly ecology as *chlorococcaleans* and desmids from this ecosystem is still incipient. Members of algal orders such as Chlorococcales and Desmidiales have been reported as frequent taxa in the periphytic communities of that floodplain (Murakami et al., 2009; Biolo & Rodrigues, 2013). These groups may contribute to characterizing the periphyton community from the Upper Paraná River floodplain exhibiting high species richness (Algarte, Rodrigues, Landeiro, Siqueira, & Bini, 2013; Bichoff et al., 2016) and abundance (Biolo & Rodrigues, 2013; Neif et al., 2013), mainly during high water periods. Furthermore, studies have been concentrated on evaluating linear relations between the taxonomic variable and environmental factors, which could not accurately represent the biological conditions (DeNicola & Kelly, 2014).

The Upper Paraná River floodplain is an important center of biological diversity in Brazil, where preservation and conservation are priorities for this wetland (Algarte, Siqueira, Murakami, & Rodrigues, 2009). In this context, taxonomic surveys of periphytic algal communities can provide valuable information and it is indispensable. Taxonomic data concerning description of periphytic taxa for the Upper Paraná River floodplain are only presented for Cyanobacteria (Fonseca & Rodrigues, 2005), for xanthophyceans and euglenoids (Biolo & Rodrigues, 2011a), for dominant algal species in an open lake (Biolo & Rodrigues, 2011b) and for a diatom genus, *Gomphonema* Ehrenberg (Osório, Tremarin, Ludwig, & Rodrigues, 2017).

Therefore, in the present study we aimed at carrying out a taxonomy treatment of chlorophyceans and desmids which occurred in high abundance and frequency in 30 environments of the Upper Paraná River floodplain. We also have shown some ecological data concerning how richness of those groups behaved in the periphytic community.

Material and methods

The Upper Paraná River floodplain in Brazil is located between Mato Grosso do Sul and Paraná States (22º40'-22º50'S and 53º10'-53º24'W). The study was conducted including 30 different environments of this floodplain: 12 areas belonging to the Ivinhema River subsystem; 12 areas of the Baía River subsystem; and six of the Paraná River subsystem (Figure 1).
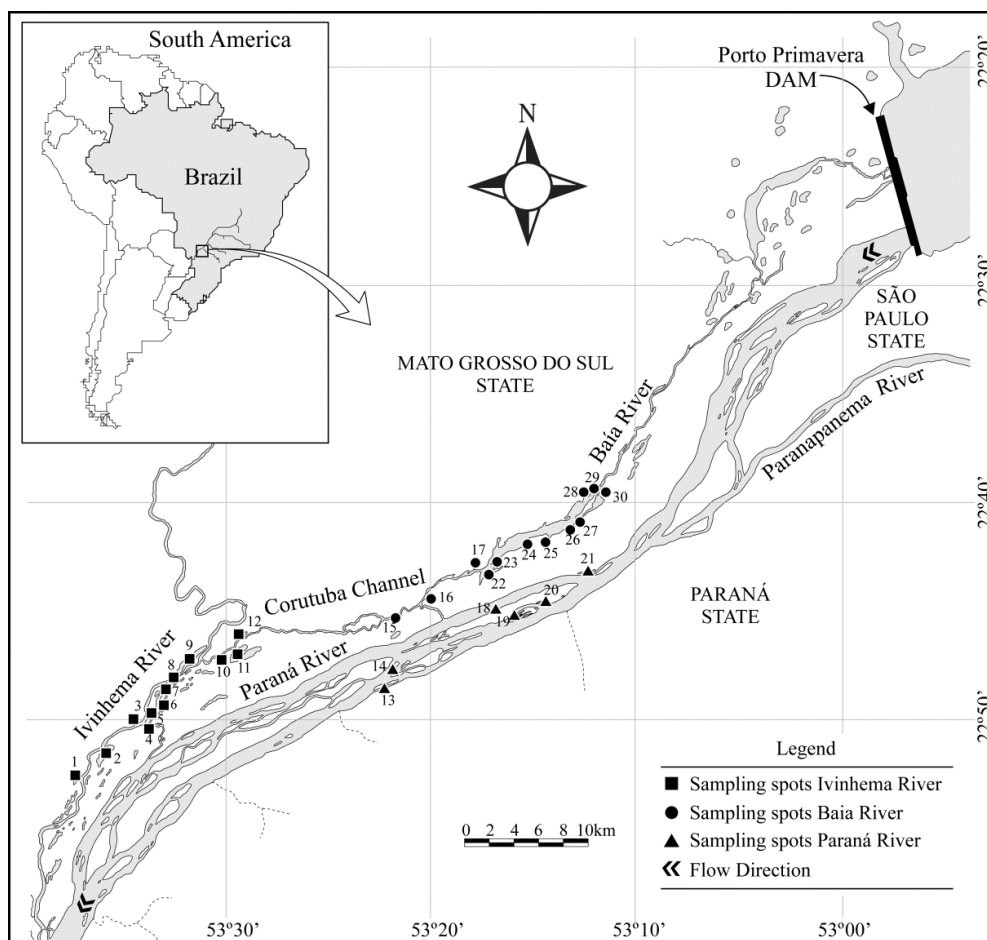

Figure 1. Upper Paraná River floodplain and location of the sampled environments.

Periphyton samples were collected at each sampling site during high water period in March 2010, the period of study which was chosen for sampling by the highest species richness of periphytic community according to earlier studies (Algarte et al., 2017b). Periphyton was removed from two petioles of the macrophyte *Eichhornia azurea* (Sw.) Kunth by scraping with a stainless-steel blade and jets of distilled water. Substrate is an abundant and persistent aquatic macrophyte in the studied environment and thus was chosen as the standard substrate for sampling. Periphytic material collected was placed in Wheaton flasks (150 mL) preserved with Lugol acetic solution (Bicudo & Menezes, 2017) and were deposited in the

Herbarium at the *Universidade Estadual de Maringá* (HUM) under the numbering registers 28702-28726.

Qualitative analysis of taxa was made under optical microscope coupled to a light camera and ocular micrometer under 1000x and identifications were made as possible at the lowest taxonomic level, according to the classical and regional literature (e.g., Croasdale & Flint, 1986, 1988; Prescott, Croasdale, Vinyard, & Bicudo, 1980; Komárek & Fott, 1983; González, 1996; Domingues & Torgan, 2012; and others). Taxa higher than 2,500 individuals in density simultaneously with frequency of occurrence higher than 50% in the 30 environments were subjected to the taxonomical treatment.

Daily water-level data were obtained from Porto São José (22°43'00''S and 53°10'00''W), from February to March 2010 and are available at http://www.peld.uem.br/. Following variables were measured in the field: water temperature (° C; YSI thermistor coupled to an oximeter), electrical conductivity (μS cm^{-1}), total suspended matter (μg L^{-1}). Water samples were filtered through Whatman GF/F filters, under low pressure (<0.5 atm) and stored at -20° C for later determination of the concentrations (μg L^{-1}) of dissolved fractions of phosphorus (Mackereth, Heron, & Talling, 1978) and nitrogen (Koroleff, 1976; Giné, Bergamin, Zagatto, & Reis, 1980). Abiotic data were transferred by the Laboratory of Limnology at the NUPELIA (*Núcleo de Pesquisa em Limnologia e Aquicultura*).

To assess the level of whether the community of clorophyceans and zygnematophyceans can be represented by common species, it was verified the congruence between ordinations which were carried out with common taxa and total using the Procruste (Jackson, 1993; Peres-Neto & Jackson, 2001). We used the randomization procedure of Monte Carlo (9999 with randomization) to assess their validity. Results of the Procruste analysis (m2) were subjected to square root of their complements (r = $\sqrt{(1-m2)}$ (Oksanen et al., 2011) and transformed in a correlation coefficient (r). Thereby values close to 1 indicate greater similarity between the patterns of order and values close to zero greater dissimilarity between these standards. A Detrended Correspondence Analysis (DCA) was applied to show how those results behaved in our study.

Results and discussion

It was recorded a total of 208 taxa belonging to Chlorophyceae and Zygnematophyceae in the 30 sampled environments at the Upper Paraná River floodplain. Fifteen taxa of this total were abundant and occurred widespread. These taxa represented 64.6% of the total density and were submitted to a taxonomical treatment, classified and described in the present study as follows:

CHLOROPHYTA
Class Chlorophyceae
Order Chlorococcales
Family Chlorellaceae
Ankistrodesmus falcatus (Corda) Ralfs, Brit. Desm., 180, pl. 34, figures a-c. 1848. (Figure 2A)

Colonies composed of 1-2 fascicles with 5 cells irregularly arranged, cells 2 times longer than wide, 13.9-17.8 μm long, 0.8-1 μm wide; long, fusiform, falcate cells, slightly arched, cells joined by contact of the convex middle region; single, parietal chloroplast without pyrenoid.

Notes: Our specimens presented cellular dimensions lower than those described by González (1996), but description of cell morphology agrees with that presented by Komárek and Fott (1983). Present taxon is common in calm waters with low concentration of nutrients, in phytoplankton and periphyton (Ramos, Bicudo, Góes Neto, & Moura, 2012).

Ankistrodesmus fusiformis Corda ex Korsikov, Protococcinae: 300, fig. 263. 1953. (Figure 2B)

Colonies composed of 2-4 cells, cells radially or crucially arranged, 27-30 times longer than wide, 36.4-48.6 μm long, 1.2-1.8 μm wide; elongated-fusiform cells, straight or slightly arched, gradually tapered towards the apex; single, parietal chloroplast without pyrenoid.

Notes: *A. fusiformis* is related to *A. spiralis* which the first differs by its crossed disposition of cells instead of twisted cells in the second. Our populations agree with that presented by Komárek and Fott (1983). It is considered a cosmopolitan taxon in phytoplankton and periphyton (Ramos et al., 2012).

Monoraphidium arcuatum (Korsikov) Hindák, Alg. Stud. 1: 25. 1970. (Figure 2C)

Cells solitary, 7 times longer than wide, 32-33 μm long, 4.5-5 μm wide; fusiform cells, arched, sometimes sigmoid, gradually tapered towards the apex; single, parietal chloroplast without pyrenoid.

Notes: *M. arcuatum* resembles *M. indicum* Hindák which the last is smaller and less rounded and curved

than the first (Ramos et al., 2012). It is easily identified by the arcuated cells. Komárek and Fott (1983) and González (1996) stated the cosmopolitan distribution of this taxon in high nutrients concentration waters, from phytoplankton, metaphyton and periphyton (Ramos et al., 2012).

Monoraphidium contortum (Thuret) Komárek-Legnerová, Stud. Phycol. 104. 1969. (Figure 2D)

Cells solitary, 5 times longer than wide, 9-11 μm long, 1-2 μm wide; fusiform cells, spiraled, with 1-1.5 spirals, gradually tapered towards the apex, acuminate poles; single, parietal chloroplast without pyrenoid.

Notes: *M. contortum* is morphologically similar to *M. irregulare* (G.M. Smith) Komárková-Legnerová, but the first presented more sigmoid cells and larger cell dimensions. It is a cosmopolitan taxon, very common in waters with different trophic conditions (Ramos et al., 2012).

Closteriopsis acicularis (Chodat) Belcher & Swale, Brit. Phycol. Bull., 2(3): 132. 1962. (Figure 2E)

Cells solitary, 43.5-53 μm long, 4.7-7.3 μm wide; very long, spiniform cells, straight or slightly arched, tapering to sharp points at both ends; single, parietal chloroplast, with an axial row of 2-4 pyrenoids and an indentation in the middle region of cell.

Notes: Cosmopolitan. Associated with plants and in the phytoplankton (John & Tsarenko, 2002), as in the present study in the periphyton.

Family Oocystaceae

Oocystis lacustris R. Chodat, Bull. Herb. Boissier 5. 119, pl. 10, fig 1-7. 1897. (Figure 2F)

Colonies composed of 2-4-8 cells irregularly disposed in an hyaline, conspicuous mucilage; cells 1.4-1.6 times longer than wide, 17-25.5 μm long, 10-16 μm wide; ellipsoid cells, with rounded poles, polar thickening absent; 1-2 parietal chloroplasts, with 1 pyrenoid.

Notes: Present taxon is morphologically similar to *O. parva* West & G.S.West, which differs by the larger dimensions and the presence of the mucilaginous sheath in the first (Komárek & Fott, 1983).

STREPTOPHYTA

Class Zygnematophyceae

Order Desmidiales

Family Closteriaceae

Closterium incurvum Brébisson, Mém. Soc. Imp. Sci. Nat. Cherbourg, 4: 150, pl. 2, fig. 47. 1856. (Figure 2G)

Cells solitary, small to large, 5-7 times longer than wide, 38.8-97.2 μm long, 7.2-10.2 μm wide, strong curvature (140-160º of arc); convex dorsal margin, concave ventral margin, rounded-acuminate poles; cell wall hyaline to brown, with or without polar thickening, single, axial chloroplast, with 4-5 pyrenoids arranged in a line.

Notes: Differs from *C. venus* Kützing *ex* Ralfs by having more pronounced curvature of cell and acuminated poles (Oliveira, Bicudo, & Moura, 2013).

Family Desmidiaceae

Cosmarium abbreviatum Raciborski var. *minus* (West & G.S.West) W.Krieger & Gerloff, Gattung *Cosmarium* 3-4: 242. 1965. (Figure 2H)

Small cells, about as long as broad, 10-10.5 μm long, 9-9.5 μm wide, deeply constricted at the middle, sinus narrow, linear and closed; transverse angular-oval semicells, lateral margin divergent, straight, to a rounded median angle, sometimes slightly pronounced, the upper margin almost straight, apex relatively broad, truncate; smooth cell wall, hyaline, axial, single chloroplast, with a single pyrenoid.

Notes: Present variety differs from the typical of species by its smaller dimensions, lateral angles less rounded and not pronounced (Felisberto & Rodrigues, 2010).

Cosmarium blyttii Wille, Christiania Vidensk.-Selsk. Förhandl.1880 (11): 25, pl. 1, fig. 7. 1880. (Figure 2I)

Small cells, about as long as wide, 12-13 μm long, 12-13 μm wide, deeply constricted at the middle, linear, closed median sinus; trapezoid-semicircular semicells, subretangular basal angles, rounded, 4-crenate lateral margin, often with a retuse, emarginated basal crenulation, apical margin retuse, 4-crenate, face of semicells with 1-2 sets of granules bellow crenulations, a single, central granule, cell wall granulated, hyaline, single, axial chloroplast, with a single, central pyrenoid.

Notes: *C. blyttii* may exhibit polymorphism in semicells, especially with regard to the number of crenulations in lateral and apical margins and number of granules on the face of each semicell (Oliveira, Bicudo, & Moura, 2010).

Cosmarium laeve Rabenhorst, Öfv. Kongl. Vet.-Akad. Förhandl., 6: 29, pl. 12, fig. 4. 1876. (Figure 2J)

Cells 1.3 times longer than wide, 15-16 μm long, 11-12 μm wide, deeply constricted at the middle, linear

median sinus, closed, dilated at the apex; semicircular to subpyramidal semicells, slightly angular, convex lateral margin, narrow apical margin, truncate; finely punctuated cell wall, hyaline, 1 chloroplast, axial, 1 pyrenoid, central.

Notes: Cells with larger sizes can be confused with *C. granatum* Brébisson *ex* Ralfs, although the first taxon has a less rounded cell and smaller cell width (Felisberto & Rodrigues, 2010).
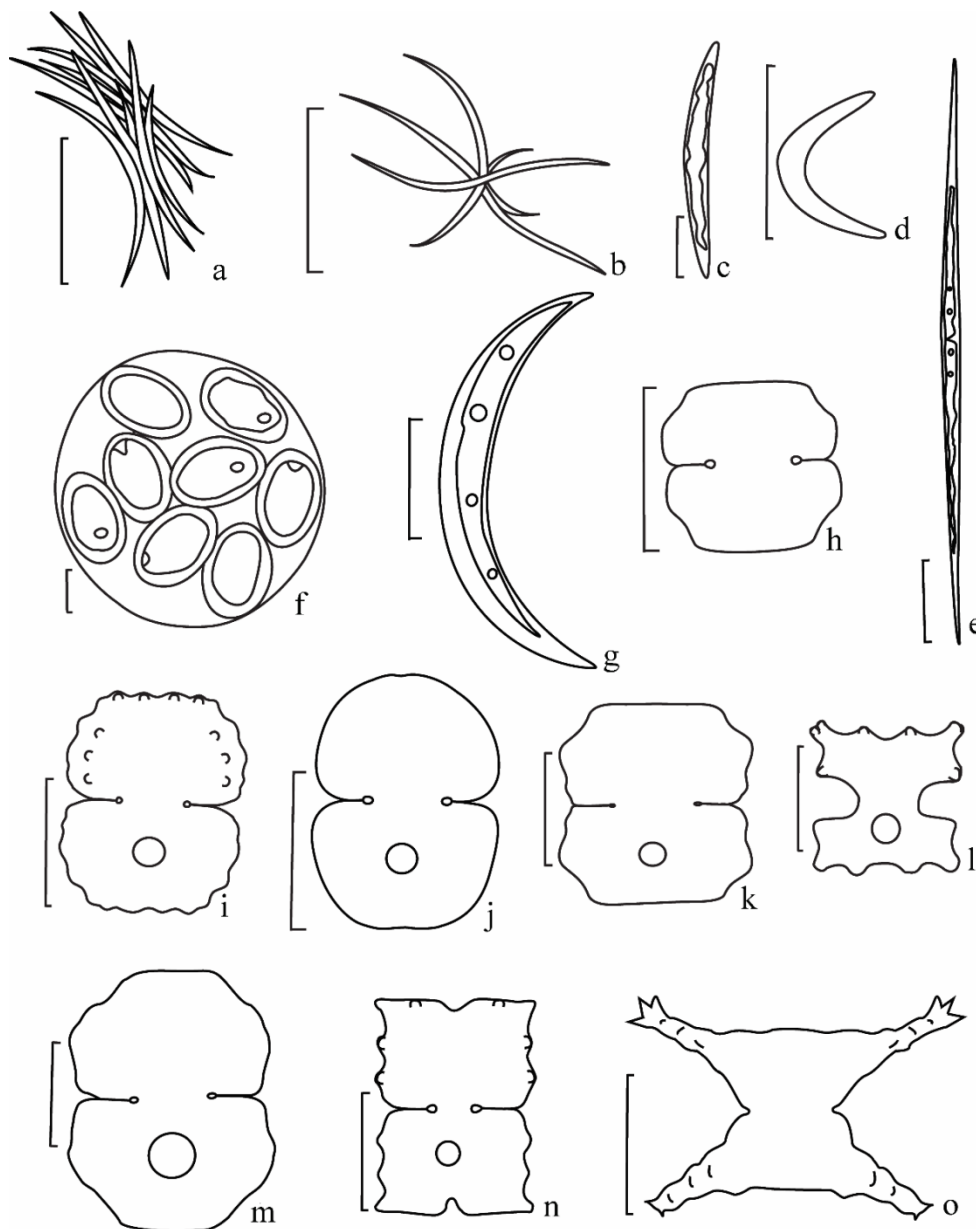

Figure 2. Chlorophyceae and Zygnematophyceae frequently found in the periphytic community of the Upper Paraná River Floodplain: a) *Ankistrodesmus falcatus*; b) *A. fusiformis*; c) *Monoraphidium arcuatum*; d) *M. contortum*; e) *Closteriopsis acicularis*; f) *Oocystis lacustris*; g) *Closterium incurvum*; h) *Cosmarium abbreviatum*; i) *C. blyttii*; j) *C. laeve*; k) *C. regnellii* var. *pseudoregnellii*; l) *C. regnesi*; m) *C. trilobulatum*; n) *Euastrum rectangulare*; o) *Staurastrum micron*. Scale bar = 10 μm.

Cosmarium regnellii Wille var. *pseudoregnellii* (Messikommer) W. Krieger & Gerloff, Die Gattung *Cosmarium* 3-4: 247, pl. 43, fig. 6. 1969. (Figure 2K)

Cells 1.03 times longer than wide, 17.39 μm long, 16.73 μm wide, deeply constricted at the middle, linear median sinus, closed, dilated at the apex; subtrapezoid semicells, parallel lower side edge or slightly divergent, almost rectangular lower angles, sometimes slightly oblique, rounded, rounded upper corners, truncated apical margin straight to slightly concave; smooth cell wall, hyaline, 1 chloroplast, axial, 1 pyrenoid, central.

Notes: This variety differs from typical to present the lateral margins of semicell never straight in the middle and apical margin relatively wide (Felisberto & Rodrigues, 2010).

Cosmarium regnesi Reinsch, Brit. Desm., 68: 19. 1908. (Figure 2L)

Cells about as long as wide, 12-12.5 μm long, 12-12.5 μm wide, deeply constricted at the middle, wide open median sinus, excavated; transversely oblong-rectangular semicells, lateral and apical margins toothed, 6-8 marginal teeth, very small, usually 2 apical and 2 lateral approximately equidistant, widely retuse apical margin (between the teeth); finely punctuated cell wall, hyaline, single, axial chloroplast, with a single, central pyrenoid.

Notes: Prescott et al. (1980) affirmed that Brazilian material of this taxon have considerable polymorphism, with cells presenting the lobes reduced and variation in shape of the lateral and apical margins. We also observed this polymorphism in our specimens in agreement with those authors.

Cosmarium trilobulatum Reinsch, Acta Soc. Senckenb. 6: 118, pl. 22 AII, fig. 1-6. 1867. (Figure 2M)

Cells slightly wider than long to 1.3 times longer than wide, 12.2-24.4 μm long, 10.9-18.8 μm wide, deeply constricted at the middle, close median sinus; subtrapeziform semicells, trilobed, truncated basal lobes, with a concavity between the apex, basal and apical angles slightly rounded; smooth or finely punctuated cell wall, hyaline, single, axial chloroplast, with a single, central pyrenoid.

Notes: This taxon is similar to *C. pseudoretusum* Ducellier, in which the last one has less flattened apex and tumid ventral view (Aquino, Bueno, Servat, & Bortolini, 2016).

Euastrum rectangulare Fritsch & Rich, Trans. Roy. Soc. S. Afr. 25(2): 174. 1937. (Figure 2N)

Cell 1.4 times longer than wide, 16-16.5 μm long, 12-12.5 μm wide, deeply constricted at the middle, median sinus closed; apical incision shallow, open, V-shaped, rectangular semicells, basal lobes as wide as the apical lobe, 2-undulated lateral margins, a single granule in each undulation, apical margin truncated, slightly undulating, a single granule on each side of the apical incision; smooth cell wall, hyaline, single, axial chloroplast, a single axial, central pyrenoid.

Notes: *E. rectangulare* resembles *E. denticulatum* (Kirchner) Gay var. *rectangulare*, however, it differs by having the V-shaped apical medium incision (the latter U-shaped), lower cell dimensions and basal angles without ornamentations as spines (Oliveira, Bicudo, & Moura, 2011).

Staurastrum micron W. West & G.S. West, Brit. Desm. 5: 123. 1923. (Figure 2O)

Cell 2 times wider than long, 9.4 μm long, 18.8 μm wide (with processes), shallow median constriction, median sinus opened; subpyramidal semicells, sharp angles forming short processes, upwardly directed, with marginal spines, 3 spines at the apex of the processes, apical margin truncated, with marginal spines; smooth cell wall, hyaline, chloroplast and pyrenoid not observed.

Notes: The present report of *S. micron* consists in the first citation of this taxon for the state of Mato Grosso do Sul.

Abiotic data were demonstrated in Table 1 and the water level in Figure 3. More information related to the limnological and ecological characteristics of environment and periphyton communities were discussed by Algarte et al. (2009, 2017a, b).

Table 1. Abiotic data of 30 environments sampled during the study period.

Abiotic data	Min.	Max.	Mean	CV(%)
Water temperature (° C)	27.4	31.3	28.75	2.68
Condutivity (μS.cm^{-1})	24	70.2	46.5	31.33
Total Suspended Matter (mg.L^{-1})	0.22	7.25	1.14	125.86
Inorganic nitrogen (μg.L^{-1})	0.05	360.4	68.9	150.38
Total phosphorus (μg.L^{-1})	13.9	68.43	35.48	35.09

Although periphyton community displays high algal species richness and diversity (Biolo & Rodrigues, 2013; Algarte et al., 2017a), identifying the spatial (and also temporal) pattern in composition of periphytic algae is fundamental to the knowledge of its biodiversity (Svoboda, Kulichová, & St'astny, 2013). It is known that periphyton dynamics is related to climatic, hydrodynamic and abiotic variables (Larned, 2010). In our study, *Cosmarium leave* and *C. abbreviatum* were characteristic in environments with high conductivity and inorganic nitrogen contents related to the Paraná subsystem. *Cosmarium regnesii, Staurastrum micron, Euastrum rectangulare, Ankistrodesmus fusiformis* and *Monoraphidium arcuatum* occurred in deeper environments with higher temperatures and with higher levels of orthophosphate related subsystem Ivinhema. *Closterium incurvum, Ankistrodemus falcatus* and *Monoraphidium contortum* preferentially occurred in more transparent waters related to Baía subsystem. Other taxa occurred under wide environmental conditions.
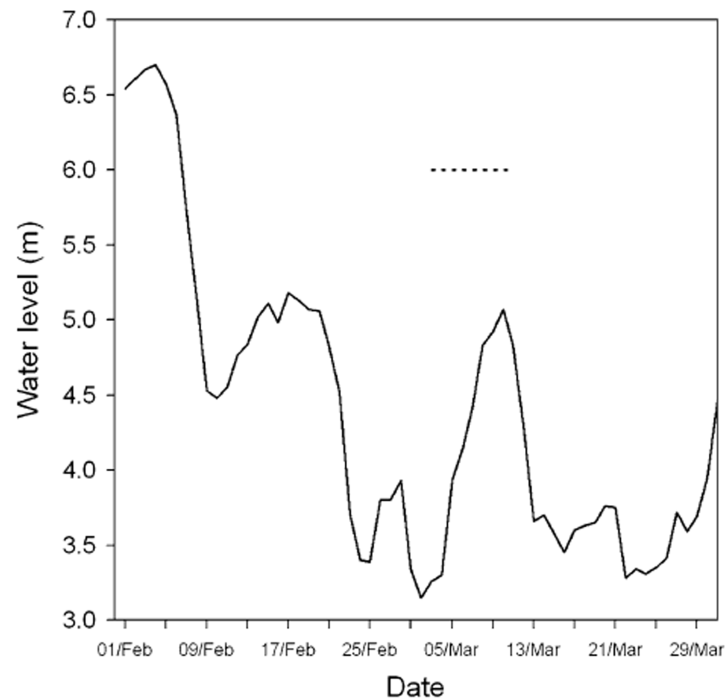
Figure 3. Water level in the Upper Paraná River floodplain in February and March 2010. The dashed line indicates the sampling period.

It was performed a DCA (Figure 4) with the frequent taxa of desmids and chlorococcaleans found in our study, to preview how data could behave, according to tendencies in current studies about investigations on partitioned richness. According to the result obtained by Procruste ordination based on data from common species, a high congruence with the ranking based on all taxa was shown (r = 0.71; p < 0.001). This indicates that the distribution pattern of clorophyceans and zygnematophyceans is represented by common species of these communities. Our results meet those reported by Lennon, Koleff, Greenwood, and Gaston (2004) with birds. According to them, low richness is better explained by common species than high richness by a group of rare species with the same size.
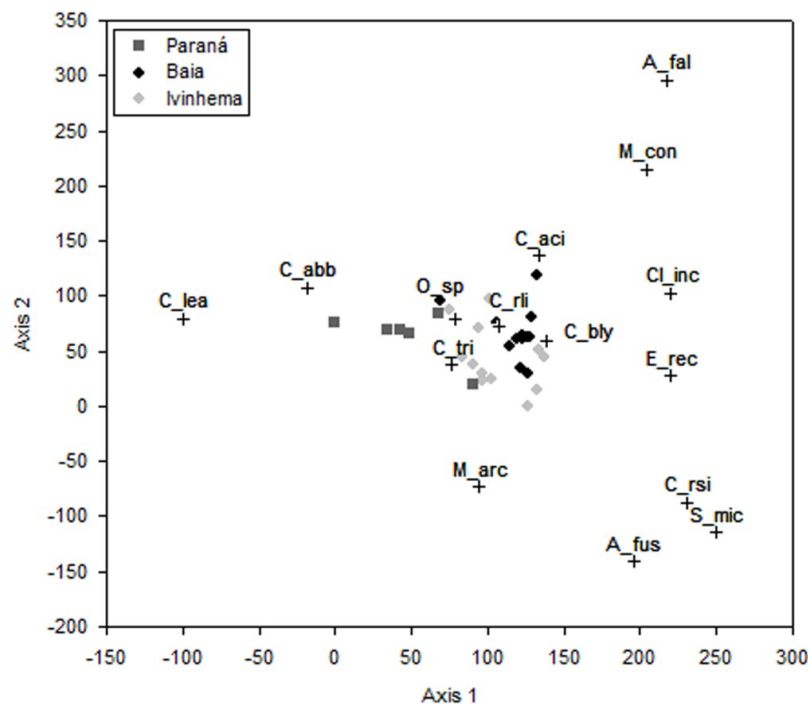

Figure 4. Detrended Correspondence Analysis (DCA) ordination diagram of the species/subsystems scores. (Legends: A_fal = *Ankistrodesmus falcatus*; A_fus = *A. fusiformis*; M_arc = *Monoraphidium arcuatum*; M_con = *M. contortum*; C_aci = *Closteriopsis acicularis*; O_sp = *Oocystis lacustris*; Cl_inc = *Closterium incurvum*; C_abb = *Cosmarium abbreviatum*; C_bly = *C. blyttii*; C_lea = *C. laeve*; C_rli = *C. regnellii* var. *pseudoregnellii*; C_rsi = *C. regnesi*; C_tri = *C. trilobulatum*; E_rec = *Euastrum rectangulare*; S_mic = *Staurastrum micron*).

By comparing the two algal groups - zygnematophyceans and chlorophyceans - worldwide, it was observed that desmids are better known in its distribution or occurrence than other green algae, mainly because of the difficulty to identify coccoid forms of chlorococcaleans (Coesel & Krienitz, 2008). In this way, we focused on the taxonomical recording of these two frequent groups in the Paraná River floodplain in the present study.

Conclusion

We encourage taxonomic researches for the knowledge of biodiversity of the neotropical areas and tendency of more studies concerning how the richness of individual groups combine to produce the overall variation that could be observed in nature, creating diversity patterns, using data about common species.

Acknowledgements

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