Distribution of periphytic algae in wetlands (Palm swamps, *Cerrado*), Brazil

Dunck, B.[a]*, *Nogueira, IS.*[b] *and Felisberto, SA.*[b]

[a]Laboratório de Algas Perifíticas, Programa de Pós-graduação em Ecologia de Ambientes Aqüáticos Continentais – PEA, Universidade Estadual de Maringá – UEM, CEP 87020-900, Maringá, PR, Brazil

[b]Departamento de Botânica, Instituto de Ciências Biológicas – ICB, Universidade Federal de Goiás – UFG, sala 201, Campus II, CEP 74001-970, Goiânia, GO, Brazil

*e-mail: dunck.barbara@gmail.com

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(With 7 figures)

Abstract

The distribution of periphytic algae communities depends on various factors such as type of substrate, level of disturbance, nutrient availability and light. According to the prediction that impacts of anthropogenic activity provide changes in environmental characteristics, making impacted Palm swamps related to environmental changes such as deforestation and higher loads of nutrients via allochthonous, the hypothesis tested was: impacted Palm swamps have higher richness, density, biomass and biovolume of epiphytic algae. We evaluated the distribution and structure of epiphytic algae communities in 23 Palm swamps of Goiás State under different environmental impacts. The community structure attributes here analyzed were composition, richness, density, biomass and biovolume. This study revealed the importance of the environment on the distribution and structuration of algal communities, relating the higher values of richness, biomass and biovolume with impacted environments. Acidic waters and high concentration of silica were important factors in this study. Altogether 200 taxa were identified, and the zygnemaphycea was the group most representative in richness and biovolume, whereas the diatoms, in density of studied epiphyton. Impacted Palm swamps in agricultural area presented two indicator species, *Gomphonema lagenula* Kützing and *Oedogonium* sp, both related to mesotrophic to eutrophic conditions for total nitrogen concentrations of these environments.

Keywords: acidic water, anthropogenic activity, ecology, epiphyton.

Distribuição de algas perifíticas em áreas úmidas (Veredas, Cerrado), Brasil

Resumo

A distribuição de comunidades de algas perifíticas depende de vários fatores, como tipo de substrato, nível de distúrbio, disponibilidade de nutrientes e luz. De acordo com a predição de que impactos de ação antrópica proporcionam alterações nas características ambientais – tornando Veredas impactadas relacionadas a alterações ambientais, como desmatamentos e maiores cargas de nutrientes via alóctone –, a hipótese testada foi: Veredas impactadas apresentam maiores riqueza, densidade, biomassa e biovolume de algas epifíticas. Avaliaram-se a distribuição e a estruturação de comunidades de algas epifíticas em 23 Veredas do Estado de Goiás sob diferentes impactos ambientais. Os atributos da estrutura de comunidade avaliados foram composição, riqueza, densidade, biomassa e biovolume. Este estudo revelou a importância das características ambientais na distribuição e na estruturação das comunidades de algas, relacionando os maiores valores de riqueza, biomassa e biovolume dos organismos aos ambientes impactados. Águas ácidas e altas concentrações de sílica foram fatores importantes no estudo. Ao todo, foram identificados 200 táxons, sendo as zignemafíceas o grupo mais representativo em riqueza e biovolume, enquanto as diatomáceas, as mais representativas em densidade do epifíton estudado. Veredas impactadas em área de agropecuária apresentaram duas espécies indicadoras, *Gomphonema lagenula* e *Oedogonium* sp., ambas relacionadas com condições mesotróficas a eutróficas, para concentrações de nitrogênio total desses ambientes.

Palavras-chave: águas ácidas, ação antrópica, ecologia, epifíton.

1. Introduction

The Palm swamps are wetlands, marshy or wet environments of headwaters from the Brazilian Central Plateau, feeding the water courses for local and regional network, and form the three major Brazilian watersheds: Platina, São Francisco and Amazon (Ferreira, 2006). They are characterized by presenting "buritizais" (*Mauritia vinifera* L.

and *M. flexuosa* Mart.) as remarkable phanerogamic flora (Ribeiro and Walter, 1998). The importance of this subsystem of the *Cerrado* is in its contribution to continuity and regularity of its water courses, to protect the headwaters, supply of water, food and shelter for wildlife (Carvalho, 1991).

Deforestation for pasture and agricultural purposes (Allan, 2004) along with urbanization and sources of domestic and industrial pollution (Agostinho et al., 2005) influence the structure and functioning of aquatic ecosystems (Marcarelli et al., 2009) by changing hydrological and hydraulic patterns, modifying the geomorphology, interfering in water quality (Tundisi et al., 2004), besides initiating negative impacts on the integrity of these ecosystems. These changes may undermine the biodiversity of these environments and, in Palm swamps, may also undermine several watersheds whose headwaters are located in the *Cerrado* Biome.

Among the aquatic communities, periphytic algae are one of the major primary producers, affecting the growth, development, survival and reproduction of many organisms (Campeau et al., 1994). Establishing the structure of these communities depends on several factors, such as the type of substrate (Cattaneo et al., 1997), disturbance level (Biggs et al., 1998), hydrological regimes (Algarte et al., 2009), availability of nutrients (Elser et al., 2007; Ferragut and Bicudo, 2010; Larson et al., 2012), light (Hill, 1996; Tuji, 2000), trophy (Biggs, 1996), water quality and system hydrodynamics (Moschini-Carlos et al., 2000), temperature (Marcarelli and Wurtsbaugh, 2006) and biological control by grazing (Rosemond et al., 1993).

Biological indicators ('bioindicators') are readily measured components of the biota that are used to provide general information about the complex ecosystems in which they occur (Andersen, 1999). Due to the high abundance, cosmopolitanism, sensitivity to chemical changes, eutrophication and pollution, algae are considered excellent bioindicators (Larson et al., 2012).

Despite such importance of the Palm swamps as a threatened neotropical ecosystem, studies linked to these environments related communities of algae, focusing on taxonomy, diversity and ecology are incipient, highlighting only Menezes (1986) for taxonomy of planktonic algae. Considering the high rate of degradation in Palm swamps caused by human activities and the importance of phycoperiphyton to aquatic ecosystems, the present study aimed to evaluate the distribution and structure of periphytic algal community in Palm swamps under different environmental impacts, in Goiás State. The following hypothesis was tested in this study: Palm swamps impacted present higher richness, density, biovolume and biomass of periphytic algae. We can predict that anthropogenic impacts change environmental characteristics, thus urban Palm swamps and in agriculture areas are related to various environment changes such as deforestation and higher allochthonous input of nutrients. Several studies have demonstrated that an increase in nutrients, in particular, increased productivity and periphytic chlorophyll (Dodds et al., 1997; Bourassa and Cattaneo, 2000), are therefore due to the density of periphytic algae of such environments.

2. Material and Methods

The Palm swamps examined in Goiás State are located in the municipalities of Caldas Novas, Catalão, Cidade de Goiás, Goiânia, Ipameri, Morrinhos and Piracanjuba (Figure 1). We sampled 23 Palm swamps: six in conserved areas – with native vegetation in the surroundings wider than 50 m – according to Law nº 7803 from July, 18 1983 (Brasil, 1992); nine in areas impacted by agriculture (under the influence of inputs such as fertilizers, herbicides and pesticides) and eight in urban areas (under the influence of domestic sewage and urban drainage). Nevertheless, all studied environments are within regions of low native vegetation cover of Goiás region (Bonnet et al., 2007). The characterizations regarding the presence of current flow, geomorphological position (Ferreira, 2006), location, date and sampling time, vegetation cover and type of impact of studied environments are listed in Table 1.

Samplings were undertaken in August and September 2008. Morphometrical analyses of Palm swamps (maximum width of the water body, depth of sampling points, marginal vegetation cover) were measured as suggested by Wetzel and Likens (1991). Limnological variables (pH, water temperature, electric conductivity and turbidity) were gauged concurrently to biotic data collection, and were taken using a multi-parameter water analyzer Horiba model U-22.

The nutrients (total nitrogen and total phosphorus expressed in $\mu g\ L^{-1}$) were measured according to standard methods (APHA, 2005), for which we collected 1L of raw water at each sampling point, fixed in situ with 0.5mL of acid sulfuric p.a., and then processed it. For silica, samples were collected of 250mL of water at each sampling point and analyses (expressed in $\mu g\ L^{-1}$ of SiO_2) were done according to APHA (2005).

In order to evaluate the trophic status of lentic and lotic palm swamps two indices were used: the proposed one by Lamparelli (2004) for a tropical environment using total phosphorus as a parameter and the one proposed by Dodds et al. (1997) for temperate environment using nitrogen and total phosphorus as parameters.

Each Palm swamp was sampled once in this study and periphytic material was obtained from grasses (Poaceae) which were partially submerged, predominant in the environments and randomly selected, as suggested by Rodrigues et al. (2004), according to criteria as collected from adult and uniform plants, without evident presence of predation. The periphytic material was obtained from replicates from two petioles of different plants at each Palm swamp, with a total of 46 quantitative samples. The part of the submerged petiole was cut and the epiphytic material was scraped with a steel blade wrapped in aluminum foil and jets of distilled water. The scraped areas of the petioles were then calculated.

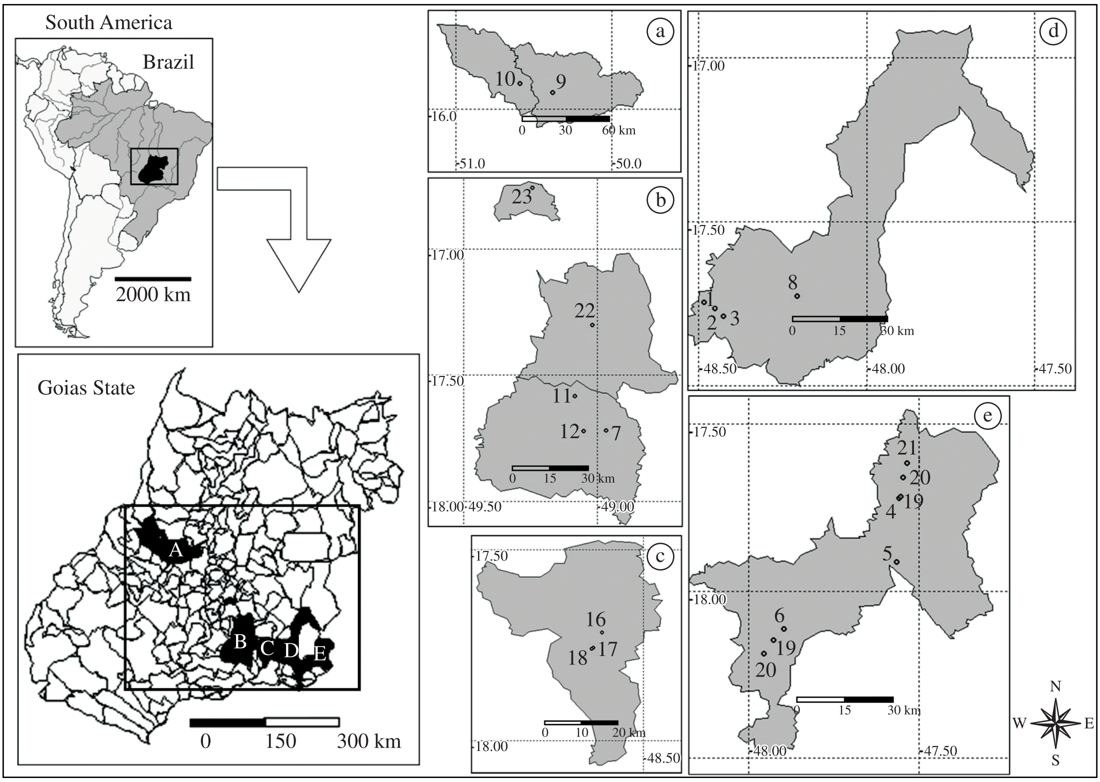

Figure 1. Location of the 23 Palm swamps sampled in Goiás State during the months of August and September 2008.

Chlorophyll-*a* samples were taken in replicate from two samples of different plants at each Palm swamp and the analyses performed with 90% acetone extraction (results of chlorophyll-*a* expressed in μg cm^{-2}) according to Golterman et al. (1978). For quantitative samples, the epiphytic material obtained in replicates was then fixed with acetic Lugol's solution 0.5% (Bicudo and Menezes, 2006).

The periphytic algae were quantified by the method of Utermöhl (1958) in random fields up to 100 individuals of the most common species (Bicudo, 1990), using a Zeiss Axiovert 25 inverted microscope with an objective to 400-fold increase. In order to identify the diatom species, the quantitative material was oxidized and cleaned using the technique of Simonsen (1974) modified by Moreira-Filho and Valente-Moreira (1981), and permanent slides were prepared using Naphrax resin as embedding medium for diatom frustules. Taxa analysis was performed using a Zeiss Axioscop 40 optical microscope equipped with an image capture system, and was identified based on morphological characteristics, size and shape of stalk organization, using recent and updated literature. The classification system adopted was that proposed by Round (1971).

Species density was estimated according to Ros (1979) and the results were shown in the number of individuals per unit area (ind cm^{-2}). The biovolume estimate followed Hillebrand et al. (1999) from the multiplication of the densities of each individual by the average biovolume of organisms of the species, according to the size of analyzed populations, and the final result was given in mm^3cm^{-2}. We determined the dominance and abundance of species as proposed by Lobo and Leighton (1986), where dominant species are those with densities higher than 50% of total density of the community, and abundant were those species whose densities exceed the mean density of populations of each sample.

The principal component analysis (PCA) was used to verify the spatial variation of the environments in relation to limnological variables. The criteria used to retain the axes for interpretation was the Broken-Stick. For this analysis, the matrix of limnological data was previously standardized [(Xij-Xi)/Si] (Legendre and Legendre, 1998). Analysis of variance (One way ANOVA) was applied to the scores generated by PCA for the axes retained to test the differences between the environments and the limnological variables, and the impact of Palm swamps was used as a factor to analyse.

Detrended correspondence analysis (DCA, Hill and Gauch, 1980) was applied to verify the similarity between the species composition summarized by classes among the environments studied. A non-metric multidimensional scaling (NMDS) was used to investigate the distribution of the algae group with the highest density among environments. This ordination was used with transformed data matrix by log x + 1 (Legendre and Legendre, 1998). The Bray-Curtis index was used for calculating the distances and checking

Table 1. Location, date and sampling time, vegetation cover, impact, current flow and geomorphological position of the 23 Palm swamps studied in Goiás State during the months of August and September 2008.

Palm swamps	Coordinates	Location	Date	Sampling Time	Vegetation cover	Impact	Current flow	Geomorphological position
1	17° 44,589' S - 48° 28,489' W	Fazenda Lageado, GO-213	08/31/2008	15:29- 15:45	>50m of riparian vegetation	conserved areas	lentic	Enclave
2	17° 46,112' S - 48° 26,880' W	Fazenda Buritis, GO- 213 Ipameri	08/31/2008	16:30- 17:00	>50m of riparian vegetation	conserved areas	lotic	Enclave
3	17° 47,525' S - 48° 25,356' W	Fazenda Providência de Deus, Córrego Fundo	09/01/2008	15:15- 16:15	>50m of riparian vegetation	conserved areas	lotic	Terraço
4	17° 43,428' S - 47° 33,336' W	Fazenda Tomasini, GO-301- Catalão	09/26/2008	08:50- 9:20	>50m of riparian vegetation	conserved areas	lentic	Patamar
5	17° 54,995' S - 47° 33,742' W	GO- 506	09/26/2008	13:10- 13:30	>50m of riparian vegetation	conserved areas	lotic	Enclave
6	18° 06,956' S - 47° 53,564' W	Fazenda Hortaliças do Baiano, BR-050	09/26/2008	14:45- 15:00	>50m of riparian vegetation	conserved areas	lotic	Enclave
7	17° 43,412' S - 48° 57,802' W	GO-213, próximo a Caldas Novas	08/30/2008	16:30-17:00	<50m of riparian vegetation	impacted by agriculture	lotic	Enclave
8	17° 43,771' S - 48° 12,283' W	GO-330, próximo Catalão	09/01/2008	14:00- 14:45	<50m of riparian vegetation	impacted by agriculture	lotic	Enclave
9	15° 53,685' S - 50° 22,430' W	GO-070 Km 160	09/15/2008	14:50- 15:03	<50m of riparian vegetation	impacted by agriculture	lentic	Anfiteatro
10	15° 50,037' S- 50° 34,930' W	GO-070, próximo Cidade de Goiás	09/15/2008	16:01- 16:29	<50m of riparian vegetation	impacted by agriculture	lotic	Enclave
11	17° 35,202' S - 49° 04,841' W	GO-147, Km 70	09/24/2008	11:05- 11:35	<50m of riparian vegetation	impacted by agriculture	lentic	Anfiteatro
12	17° 43,468' S - 49° 02,888' W	Fazenda Vivaldo Machado GO-247	09/24/2008	13:15- 13:35	<50m of riparian vegetation	impacted by agriculture	lentic	Patamar
13	17° 43,200' S - 47° 33,016' W	Águas emendadas, vertente direita,GO-301	09/26/2008	9:30- 9:50	<50m of riparian vegetation	impacted by agriculture	lentic	Anfiteatro
14	17° 39,803' S - 47° 32,673' W	Fazenda Grande Buriti, GO-247	09/26/2008	10:30-10:55	<50m of riparian vegetation	impacted by agriculture	lentic	Anfiteatro
15	17° 37,240' S - 47° 31,847' W	Fazenda Cafezal,GO-247	09/26/2008	11:40- 11:55	<50m of riparian vegetation	impacted by agriculture	lentic	Anfiteatro

Table 1. Continued...

Palm swamps	Coordinates	Location	Date	Sampling Time	Vegetation cover	Impact	Current flow	Geomorphological position
16	17° 43,067' S - 48° 36,310' W	Aeroporto-Caldas Novas	08/31/2008	9:18- 9:40	<50m of riparian vegetation	urban area	lentic	Anfiteatro
17	17° 45,501' S - 48° 37,668' W	Rodoviária-Caldas Novas	08/31/2008	11:49- 12:00	<50m of riparian vegetation	urban area	lentic	Enclave
18	17° 45,654' S - 48° 37,894' W	centro-Caldas Novas	08/31/2008	12:39- 12:56	<50m of riparian vegetation	urban area	lentic	Enclave
19	18° 08,942' S - 47° 55,429' W	Lagoa Paquetá, sede Ibama-Catalão	09/01/2008	9:27- 9:53	<50m of riparian vegetation	urban area	lentic	Anfiteatro
20	18° 11,392' S - 47° 57,116' W	Córrego do Almoço, Catalão	09/01/2008	10:50- 11:20	<50m of riparian vegetation	urban area	lentic	Terraço
21	17° 17,636' S - 49° 01,657' W	Córrego Zé Rato, fórum-Piracanjuba	09/24/2008	10:00- 10:30	<50m of riparian vegetation	urban area	lentic	Anfiteatro
22	17° 18,285' S - 49° 00,898' W	Chácara São Lucas-Piracanjuba	09/27/2008	10:55- 11:15	<50m of riparian vegetation	urban area	lotic	Anfiteatro
23	16° 45,656' S - 49° 14,345' W	Alameda dos Buritis Chácara 1 Qd. 2- Goânia	09/27/2008	13:00- 13:25	<50m of riparian vegetation	urban area	lotic	Enclave

the stress level of adjustment of the newly created axes and the ordering of the dissimilarity matrix (Kruskal and Wish, 1978). Usually stress values below 20 are acceptable for this analysis (Zheng and Stevenson, 2006).

The indicator species analysis (Indval, Dufrêne and Legendre, 1997) was performed to evaluate possible species indicators of the studied environments, applied to density of all the dominant and abundant taxa (species matrix log transformed, log x + 1). This method is based on the comparison of relative abundance (specificity) and frequency of occurrences (fidelity) of taxa in different set of environments. The indicator value (IV) ranges from 0 to 100, and is maximum when the individuals of a species show high specificity and high fidelity to all environments of a particular group specified a priori. This analysis was tested by Monte Carlo with 999 randomizations with $p < 0.05$.

The hypothesis of the present study was tested by an ANOVA (One-Way), using the type of impact on the Palm swamps as factor, assessing if there is difference in the attributes richness, density, biovolume and biomass of epiphytic algae among the Palm swamps examined. All multivariate analysis was conducted using the program PC-ORD version 4.01 (McCune and Mefford, 1999) and ANOVA for the program STATISTICA version 7.1 (Statsoft, 2005).

3. Results

3.1. Limnological characterization

All the studied Palm swamps presented high values of silica (28.675×10^3 to 727.415×10^3 µg.L^{-1}) and acidic pH (4.6 to 6.9). Low values of electric conductivity were observed in Palm swamps located in areas impacted by agriculture (9, 10, 11, 12), while 7, 8, 13, 14, 15 and 16 had higher conductivity. The Palm swamps situated in urban areas (21, 22 and 23) were resembled by presenting pH values closer to 6 and the higher values of total phosphorus in the present study. The maximum concentration of chlorophyll-*a* registered was 193.24 µg cm^{-2} (palm swamp 22), whereas in the palm swamps 8, 11 and 21 this parameter was not detected. Limnological variables values are listed in Table 2.

For total phosphorus concentrations, 95.6% of environments were classified as oligotrophic according to both indices used (Table 2). For total nitrogen concentrations, 30.4% were classified as hipereutrophic environments, and among conserved palm swamps, only one was oligotrophic (Table 2).

PCA results represented 63.2% of total data variability in the first two axes. The first axis was most influenced by electric conductivity and turbidity (Figure 2). The second axis was related with total phosphorus (Figure 2). This analysis showed a gradient between the environment, with preserved Palm swamps and that in urban areas at the extremes and Palm swamps in areas of agriculture as intermediaries. The conserved Palm swamps were highlighted since they presented the lowest values of total nitrogen (except palm swamp 3) (Table 2).

The results of ANOVA show differences between Palm swamps with different impacts only to scores for

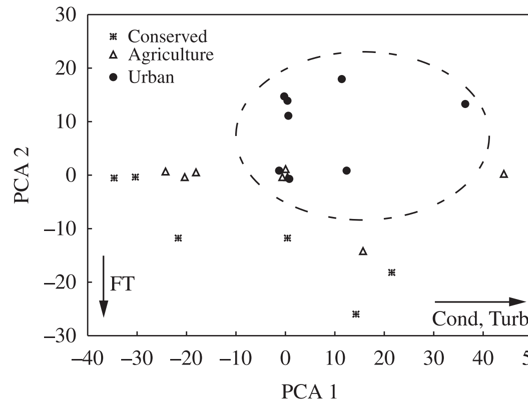

Figure 2. Principal component analysis biplot with ordination of the studied environments in relation to limnological variables.

PCA 2 ($F = 13.49$ $p < 0.001$), and the differences were significant between all impacts (Tukey, $p < 0.05$). The variables reached the assumptions for analysis.

3.2. Epiphytic algal community

The community was represented by 200 taxa, distributed into 66 genera and 10 classes (Bacillariophyceae – 43 taxa, Chlorophyceae – 26, Cyanophyceae – 25, Chrysophyceae – 5, Dinophyceae – 4, Euglenophyceae – 8, Oedogoniophyceae – 6, Rhodophyceae – 1, Xanthophyceae – 3 and Zygnemaphyceae – 79). The genera with the highest number of taxa for the classes Zygnemaphyceae and Bacillariophyceae were respectively *Cosmarium* Corda (21 taxa) and *Eunotia* Ehrenberg (nine taxa).

Conserved Palm swamps presented lower richness of taxa, mainly represented by Bacillariophyceae and Cyanophyceae (Figure 3). On the other hand, impacted Palm swamps, with a greater number of taxa, presented Zygnemaphyceae as the most expressive class (Figure 3). The Palm swamps with greater richness were the impacted 19 (33 taxa) and 12 (31 taxa) (Figure 3).

For density of taxa, the Bacillariophyceae class was the most relevant, followed by Zygnemaphyceae and Cyanophyceae (Figure 4). Among the examined environments, the highest density values were observed in impacted Palm swamps (palm swamp 19, with the highest density 158.734×10^3 ind cm^{-2}); and the lowest in the conserved Palm swamp 5 (634.54 ind.cm^{-2}) (Figure 4).

Zygnemaphyceae was the most significant class regarding biovolume, mainly by the occurrence of filamentous taxa. Similarly to density values, the highest biovolume values were also verified in impacted Palm swamps, mainly for the lentic and urban Palm swamps 20 (*Spirogyra*) and U18 (*Mougeotia*) (Figure 5).

According to criteria of dominance and abundance adopted, six taxa were dominant (*Aphanothece chlatrata* West & West; *Chlorella vulgaris* Beyerinck; *Eunotia bilunaris* (Ehrenberg) Mills; *Eunotia mucophil*a Lange-Bertalot; *Spirogyra* sp.6; *Tapinothrix bornetii* Sauvageau) and 54

Table 2. Morphometric, limnological variables and trophic state index of the 23 Palm swamps in Goiás State, during the study period (PROF-depth, LARG-width, COND-electric conductivity, pH, TEMP-water temperature, TURB- turbidity, PT- total phosphorus, NT- total nitrogen, SIL- silica, CLO-chlorophyll-*a*, TSI- trophic state index, OLIGO-oligotrophic, MESO- mesotrophic, EUT- eutrophic, HIPER-hipereutrophic).

Palm swamps	PROF (m)	LARG (m)	COND (μm.S-1)	pH	TEMP (°C)	TURB (NTU)	PT (μg.L^{-1})	NT (μg.L^{-1})	SIL (10^3 μg.L^{-1})	CLO (μg.cm^{-2})	TSI (following Dodds- NT)	TSI (following Dodds- PT)	TSI (following Lamparelli- PT)
1	0.35	3.00	24.00	6.07	29.80	4.70	1.00	1000.00	169.6	2.40	EUT	OLIGO	OLIGO
2	0.30	2.00	20.60	5.77	25.80	3.81	1.00	10.00	234.84	7.88	MESO	OLIGO	OLIGO
3	0.30	3.00	16.29	5.21	30.40	2.71	1.00	1000.00	66.85	43.88	MESO	OLIGO	OLIGO
4	1.35	21.00	2.00	4.95	23.40	5.00	1.00	10.00	74.49	50.08	MESO	OLIGO	OLIGO
5	0.15	1.50	1.00	4.96	20.00	1.00	1.00	10.00	28.65	192.88	HIPER	OLIGO	OLIGO
6	0.20	1.00	1.00	4.9	21.00	14.00	1.00	10.00	166.13	7.60	OLIGO	OLIGO	OLIGO
7	0.34	3.93	8.82	6.11	22.20	4.44	1.00	4000.00	78.31	10.63	HIPER	OLIGO	OLIGO
8	0.15	1.50	9.91	5.77	26.00	1.71	1.00	1000.00	120.31	0.00	MESO	OLIGO	OLIGO
9	2.00	8.00	115.60	6.89	30.50	54.40	32.00	1000.00	601.41	20.86	EUT	OLIGO	OLIGO
10	0.06	3.00	24.20	5.16	30.30	12.83	1.00	10.00	727.41	121.72	EUT	OLIGO	OLIGO
11	0.5	60.00	2.00	5.47	25.90	14.00	1.00	1000.00	82.13	0.00	EUT	OLIGO	OLIGO
12	3.00	8.00	1.00	5.26	21.40	11.00	1.00	10.00	40.29	89.94	OLIGO	OLIGO	OLIGO
13	0.50	30.00	1.00	5.34	22.40	7.00	11.00	2000.00	295.95	73.47	MESO	OLIGO	OLIGO
14	0.50	5.00	1.00	4.75	22.30	130.00	1.00	10.00	93.58	50.08	HIPER	OLIGO	OLIGO
15	0.15	100.00	1.00	4.60	23.10	6.00	1.00	1000.00	135.58	29.20	MESO	OLIGO	OLIGO
16	0.15	85.96	6.32	5.40	22.70	2.79	1.00	10.00	94.40	6.78	MESO	OLIGO	OLIGO
17	0.72	2.30	27.4	5.59	22.50	6.03	1.00	10.00	150.50	2.73	HIPER	OLIGO	OLIGO
18	0.98	10.00	13.6	5.24	28.60	0.82	1.00	10.00	120.31	29.06	MESO	OLIGO	OLIGO
19	0.40	208.00	42.5	6.06	22.22	3.16	1.00	2000.00	181.40	137.20	HIPER	OLIGO	OLIGO
20	0.80	6.00	30.8	5.9	23.90	3.31	1.00	10.00	154.67	146.34	OLIGO	OLIGO	OLIGO
21	4.00	94.40	5.00	5.98	23.80	24.00	23.00	10.00	349.40	0.00	OLIGO	OLIGO	OLIGO
22	0.10	1.00	9.00	6.06	26.20	12.00	1.00	2000.00	85.94	193.24	HIPER	OLIGO	OLIGO
23	2.00	6.00	37.00	6.9	28.60	89.00	800.00	4000.00	582.32	18.33	HIPER	MESO	HIPER
Average	0.82	28.89	17.43	5.58	24.91	17.98	38.47	874.78	201.47	53.66			
Minimum	0.10	1.00	1.00	4.60	20.00	0.82	1.00	10.00	28.65	0.00	OLIGO	OLIGO	0
Maximum	3.00	208.00	115.60	6.90	30.50	130.00	800.00	4000.00	582.32	193.24	HIPER	MESO	HIPER

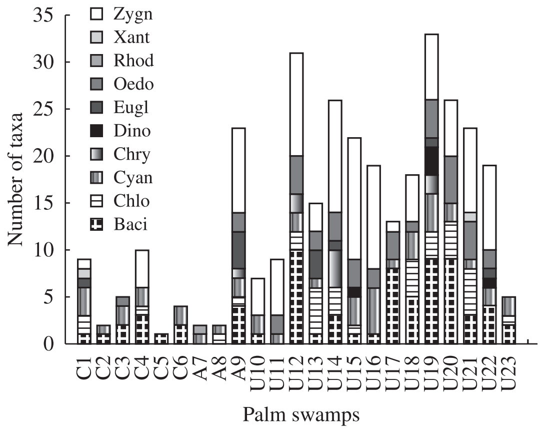

Figure 3. Richness of the epiphytic algae classes in each studied Palm swamp (Zygn - Zygnemaphyceae, Xant - Xanthophyceae, Rhod - Rhodophyceae, Oedo - Oedogoniophyceae, Eugl- Euglenophyceae, Dino - Dinophyceae, Chry - Chrysophyceae, Cyan - Cyanophyceae, Chlo - Chlorophyceae, Baci - Bacillariophyceae).

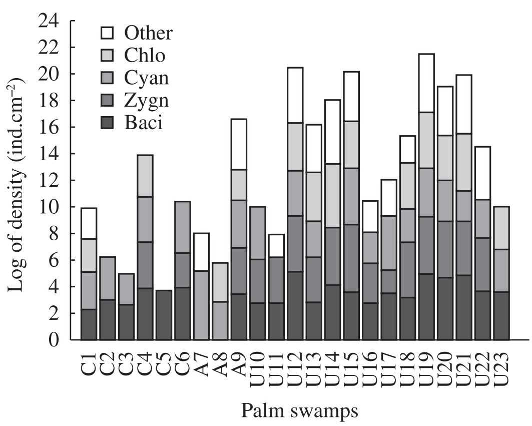

Figure 4. Logarithm of the density of the main classes of epiphytic algae registered in the 23 Palm swamps studied in Goiás State (Baci - Bacillariophyceae, Zygn - Zygnemaphyceae, Cyan - Cyanophyceae, Chlo - Chlorophyceae, Other - others classes).

were abundant (25.9% belonging to class Bacillariophyceae, and 24% to Zygnemaphyceae (Table 3). Among dominant and abundant organisms occurred the predominance of filamentous algae; 83% of Cyanophyceae and 54% of Zygnemaphyceae presented this morphology (Table 3).

Detrended correspondence analysis (DCA) showed 65% of the variability of the data represented in the first two axes, with eigenvalues 0.51 (first axe) and 0.14 (second axe) (Figure 6). The difference in epiphytic algae composition classes between the Palm swamp showed Zygnemaphyceae and Bacillariophyceae with higher richness of taxa, and together with Oedogoniophyceae and Chrysophyceae were related to impacted environments (Figure 6), both in urban and agricultural area.

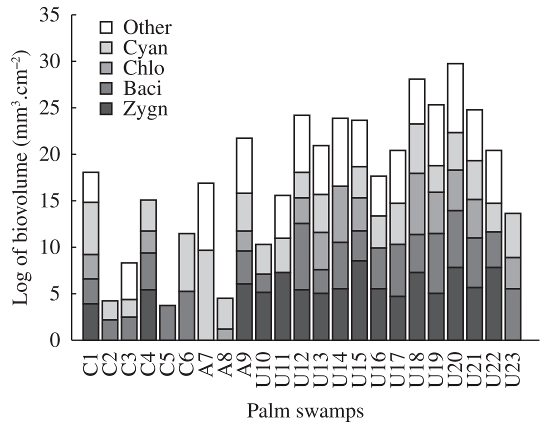

Figure 5. Logarithm of the biovolume of the main classes registered in the studied environments in Goiás State, between August and September 2008 (Baci - Bacillariophyceae).

The ordination of the environments in terms of density of diatoms (NMDS) showed that conserved Palm swamps were more distant from others concerning this distribution, while the impacted Palm swamps had higher similarity according the density of diatoms (Figure 7). The stress value for this analysis for the first three axes was 14.8. Thus, there was differences in the distribution of diatoms in environments under different impacts. In general, preserved Palm swamps were related only to the genera *Eunotia, Gyrosigma, Navicula* and *Pinnularia*. In impacted Palm swamps, in addition to thementioned above, *Encyonema, Fragilaria, Frustulia, Gomphonema, Nitzschia, Stenopterobia, Surirella* and *Ulnaria* were recorded.

The indicator species analysis revealed that the taxa *Gomphonema lagenula* Kützing (IV- 37.5; $p < 0.05$) and *Oedogonium* sp.4 (IV- 42.2; $p < 0.05$) had relative abundance and relative frequency statistically associated with Palm swamps impacted by agriculture, defining them as asymmetric indicator species. *Gomphonema lagenula* presented low indicator values, however presented high specificity (relative abundance of 100%) for this group of Palm swamps, and fidelity (relative frequency) of 38%. *Oedogonium* sp.4 also showed low indicator values, but with high specificity (84%) and fidelity of 50% for these environments.

The results of One-Way ANOVA showed evidence of differences in the attributes of the epiphytic algal community among the studied Palm swamps to richness ($F = 5,19$; $p = 0,01$), with Palm swamps in urban areas different from others; for biomass ($F = 5,19$; $p = 0,01$) with Palm swamps in urban area different from others (Tukey, $p = 0,01$); for biovolume ($F = 3,85$; $p = 0,03$) with Palm swamps in agriculture area different from others (Tukey $p = 0,04$), but for densities the environments did not differ significantly ($F = 3,36$; $p = 0,05$). The log-transformed data reached the assumptions of normality and homoscedasticity for the analysis. Thus, the results support the hypothesis of the study for the parameters richness, biomass and biovolume of epiphytic algae communities.

Table 3. List of dominant and abundant taxa recorded in the 23 Palm swamps studied in Goiás State between August and September 2008 (Legend: A- abundant taxa; D- dominant taxa).

Taxa	Palm swamps																						
BACILLARIOHYCEAE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Encyonema silesiacum (Bleisch) Mann																			A				
Encyonema sp.1																			A				
Eunotia bilunaris(Ehrenberg) Mills					D																A		
Eunotia cf. *mucophila* Lange-Bertalot												D											
Eunotia cf. *veneris* (Kutzing) De toni				A		A																	
Eunotia paludosa Grunow				A																			
Gomphonema cf. *lagenula* Kützing																			A				
Gomphonema gracile Ehrenberg																							A
Gomphonema parvulum Kützing									A														
Gomphonema sp.1																			A				
Gomphonema sp.2																					A	A	
Navicula sp.1																			A				
Navicula sp.2																A							
Navicula sp.4																				A			
Nupela sp.1																				A			
Stenopterobia delicatissima (Lewis) Brebisson & Van Heurck			A																				
CHLOROPHYCEAE																							
Chlorella vulgaris Beyerinck								D															
Dicloster acuatus Jao, Wei & Hu																							A
Monoraphidium longiusculum Hindak																			A		A		
Monoraphidium griffithi (Berkeley) Kormarková-Legnerová	A																						
Monoraphidium komarkovae Nygaard																					A		
Scenedesmus acunae Comas													A										

Table 3. Continued...

Taxa	Palm swamps																					
Scenedesmus obliquus (Turpin) Kützing var. *dimorphus* (Turpin) Kützing																		A					
Scenedesmus sp.6														A									
Stigeoclonium sp.2														A									
CHRYSOPHYCEAE																							
Chromulina sp.1									A														
Lagynium delicatulum Skuja														A									
CYANOPHYCEAE																							
Aphanothece chlatrata West & West	A	D								D							D						
CYANOPHYCEAE																							
Chroococcus minimus (Keissler) Lemmermann	A																						
Leiblenia sp.1																							A
Leptolyngbya angustissima (West & West) Anagnostidis & Komárek									A														
Leptolyngbya sp.1						A																	
Planktothrix clathrata (Skuja) Anagnostidis & Komarek											A												
Pseudanabaena skujae Claus																		A					
Pseudoanabaena cf. *voronichinii* Anagnostidis																					A		
Pseudoanabaena limnetica (Lemmermann) Komárek																		A					
Schizothrix sp.1				A																			
Synechocystis minuscula Voronichin															A								
Tapinotrhix bornetii Sauvageau							D																
DINOPHYCEAE																							
Peridinium sp.1									A														
OEDOGONIOPHYCEAE																							
Bulbochaete sp.1													A	A					A				

Table 3. Continued...

Taxa	Palm swamps																		
OEDOGONIOPHYCEAE																			
Oedogonium sp.2																			A
Oedogonium sp.4													A					A	
XANTOPHYCEAE																			
Characiopsis sp.2																		A	
ZYGNEMAPHYCEAE																			
Actinotaenium cf. *cruciferum* (De Bary) Teiling								A											
Actinotaenium curcubita (Brébisson)Teiling & Ruzicka													A		A				
Cosmarium cf. *hammeri* var. *schmidlei* Groenblad & Scott						A													
Gonatozygon monotaenium De Bary										A			A						
Groenbladia undulata Nordstedt Förster																	A		
Mesotaenium endlicherianum Nägeli															A				
Mougeotia sp.1											A		A						
Mougeotia sp.2													A						
Spirogyra sp.1																	A		
Spirogyra sp.2								A											
Spirogyra sp.3								A											A
Spirogyra sp.6	A										D								A
Staurastrum margaritaceum (Elvesberg) Ralfs																A			

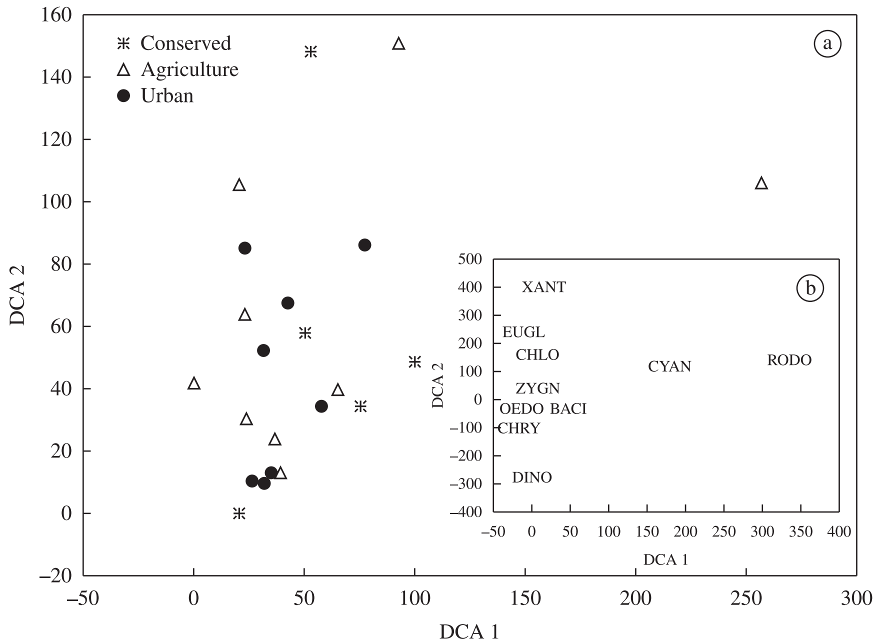

Figure 6. Similarity of the studied environments in relation of epiphytic algae classes summarized by DCA. a) Palm swamps, b) epiphytic algae classes (Bacillariophyceae (Baci), Chrysophyceae (Chry), Cyanophyceae (Cyan), Dinophyceae (Dino), Oedogoniophyceae (Oedo), Rodophyceae (Rodo), Xantophyceae (Xant), Zygnemaphyceae (Zygn).

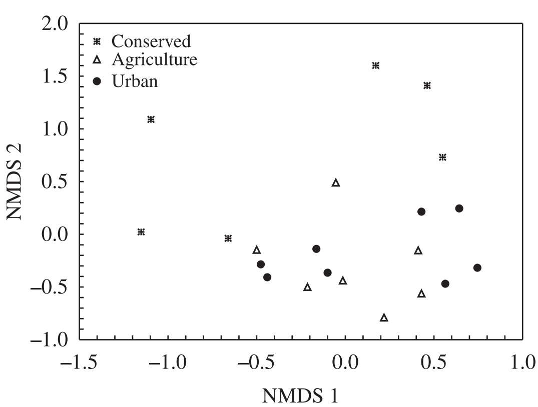

Figure 7. Distances of studied environments according densities of diatoms by non-metric multidimensional scaling (NMDS).

4. Discussion

The soils of the Palm swamps are hapludult type, rich in clay, iron oxide, silica and aluminum, and present a reddish color (Embrapa, 1999, Lima et al., 2008). Such features may explain the low values of pH and the high values of silica recorded in the present study.

High loads of nutrients in aquatic environments, mainly nitrogen and total phosphorus, may be associated to inappropriate farming practices, urban discharges or effluents from waste treatment plants (EPA, 2006). These environments with low levels of human interference may present concentrations of total phosphorus around 10 μg L^{-1} (Stevenson et al., 2008; Roberts and Bilby, 2009). These characteristics were observed in this study, in which low concentrations of these nutrients were observed in conserved Palm swamps, as opposed to those found in impacted Palm swamps in urban and agricultural areas.

On the other hand, for total nitrogen concentrations, only five palm swamps were classified as oligotrophic environments, confirming the impact caused by human activity in increasing concentrations of nutrients. Moreover, only one conserved palm swamps was assorted as oligotrophic for this nutrient. These results indicate that possibly even in environments with riparian vegetation above 50 m, surrounded with activities the monocultures and large pasture areas lead to changes in nutrient concentration (Ribeiro Filho et al., 2011).

Chemical changes in the water along with urbanization process influence the establishment of periphytic algal communities (Baker et al., 2009; Wu et al., 2009). This study observed differences in the distribution and structure of epiphytic algae among the studied Palm swamps under different impacts. Urban impacted Palms swamps presented higher richness and biomass of epiphytic algae and Palm swamps in agriculture areas presented a higher biovolume. These results may be assigned to several factors, such as changes in nutrient input and light availability, which may have a strong impact on algal communities (Miller et al., 1992).

Direct rates of sunlight in the water body (Tuji, 2000) and greater nutrient loading via allochthonous in water body both caused by the low proportion of riparian forest may favor the high algal development (Bourassa and Cattaneo, 2000). This possibly explains the more significant epiphyton in the impacted Palm swamps with low riparian vegetation cover, which is located in areas under agricultural and urban impacts, with greater nutrient loading.

Among the epiphytic algae registered, the high taxa richness and biovolume of Zygnemaphyceae is mainly due to the relationship with acidic waters present in all studied Palm swamps. They are species colonizing substrates, at least for reproduction (Coesel, 1996), mainly found in acidic water, poor in nutrients, with low electric conductivity, and high transparence (Felisberto and Rodrigues, 2005). In the meantime, in this study, a greater richness of this class was verified in impacted Palm swamps, with higher turbidity values.

Regarding the biovolume, Zygnemaphyceae was also significant, mainly by the high occurrence of filamentous organisms (*Spirogyra* (Link) Endlicher and *Mougeotia* Agardh). The filaments are excellent adaptive forms that grow rapidly in length and may remain with a constant area/volume ratio (Margalef, 1983), maintaining high biovolumes. The taxa of *Spirogyra* prefer freshwater with meso to eutrophic conditions (Margalef, 1983; Simons, 1994) and environments with absence or low current velocity (Biggs et al., 1998), as registered, mainly under higher nutrient concentrations and in lentic waters. The taxa of *Mougeotia* are always registered in acidic waters in Europe and North America, but can have wide distribution in waters with high light incidence and under conditions eutrophic to oligotrophic (Graham et al., 1996).

High silica concentrations are relevant aspects for the expressivity of Bacillariophyceae in density and composition, and are an essential nutrient for the formation of frustules. Morphological and physiological characteristics may also influence the development of this group in the epiphyton, as they have the ability to secrete mucilage to form stalks or mucilaginous matrices, allowing the attachment to substrates (Round, 1991). The high richness of the genus *Eunotia* Ehrenberg is probably due to the fact that they are acid-tolerant organisms (Planas, 1996; De Nicola, 2000; Wunsam et al., 2002; Andrén and Jarlman, 2008), which can develop in environments with acidic waters, such as the Palm swamps.

In this study, two asymmetric indicator species were revealed for Palm swamps impacted by agriculture due to the high specificity (relative abundance) to these environments (*Gomphonema lagenula* Kützing – Bacillariophyceae and *Oedogonium* sp.4 – Oedogoniophyceae). Asymmetric indicator species are those, whose presence (frequency) was not detected in all environments of the group in which there were indicators. Nevertheless, they contributed to the habitat specificity of this group, with significant relative abundance in these environments (Dufrêne and Legendre, 1997).

Indicator species have a strong relationship with environmental characteristics (Kitching et al., 2000), thus providing information about the complexity of the ecosystem where they occur, and may respond to ecological changes associated to human intervention (McGeoch, 1998), making them important for conservation and management plans (Andersen, 1999). In this study, among the main environmental characteristics related to these indicator species, there are mesotrophic to eutropic environments to total nitrogen concentrations, high values of turbidity, conductivity, silica and acidic waters.

Gomphonema lagenula, as well as all species of *Gomphonema,* have the ability to release mucilage by apical pore field and form long mucilaginous stalks (Round, 1991), presenting great advantages representative of other genera in environments where the competition for light is high (Tuji, 2000), as in the case of environments with high turbidity. Studies point out that this species can be found in environments with high to moderate nutrient loads (Blanco et al., 2004; Leelahakriengkrai and Peerapornpisal, 2010), as reported by Reichardt (1999), which states that this species is tolerant to high nutrient concentrations, proven in this study.

Oedogonium species can be found attached to several types of substrate (Lee, 2008), they are dominant in environments with a good availability of nutrients and there is a presence of currents with slow or inexistent velocity (Simons, 1994; Biggs, 1996). 66.6% of the environments impacted by agriculture were lentic and mesotrophic to eutrophic for total nitrogen concentrations and high concentrations of silica.

5. Conclusion

The present study revealed the importance of the environmental characteristics and limnological variables concerning the distribution and structuration of epiphytic algal communities in Palm swamps of Goiás State, relating the higher values of richness, biomass and biovolume to impacted environments. These findings are mainly due to the high light rate in the water body, caused by the low proportion of riparian vegetation and to the availability of nutrients in these environments, unlike conserved Palm swamps. We observed the importance of pH mainly for composition of Zygnemaphyceae species and of silica for diatoms density.

We found that few conserved environments had oligotrophic characteristics for total nitrogen, probably because they were surrounded by large pasture areas, leading to changes in nutrient concentration. Still, here we identified *Gomphonema lagenula* and *Oedogonium* sp as bioindicators of impacted areas by agriculture, mostly mesotrophic to eutrophic conditions for total nitrogen.

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