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Phytoplankton composition and functional groups in a tropical humic coastal lagoon, Brazil

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RESUMO – (Composição e grupos funcionais do fitoplâncton de uma lagoa costeira tropical húmica, Brasil). Este trabalho apresenta a composição e os grupos funcionais do fitoplâncton da lagoa Comprida, uma lagoa costeira tropical húmica localizada no sudeste brasileiro. Foi registrado um total de 28 táxons distribuídos em oito divisões taxonômicas: 26% Heterokontophyta, 21% Chlorophyta, 21% Cyanophyta, 14% Bacillariophyta, 14% Cryptophyta e 4% Prymnesiophyta. Vinte e três táxons foram identificados em nível específico e intraespecíficos, dos quais quatro constituem novos registros para o Brasil e dois para o estado do Rio de Janeiro. O fitoplâncton da lagoa Comprida esteve constituído por alguns flagelados, mas também por organismos picoplanctônicos eucariontes e procariontes, cianobactérias filamentosas e algumas diatomáceas. A biomassa foi menor que a comumente encontrada em outros sistemas lacustres e mostrou uma notável variabilidade temporal. Em relação aos grupos funcionais, as populações foram agrupadas em oito grupos: Q, Z, E, N, X_3, X_2, S_1 e Y, muitos dos quais típicos de sistemas oligo ou mesotróficos, tolerantes a baixas concentrações de nutrientes e sensíveis a baixos valores de pH.

Palavras-chave: fitoplâncton, trópicos, sistemas húmicos, lagoas costeiras, grupos funcionais, sudeste do Brasil

ABSTRACT – (Phytoplankton composition and functional groups in a tropical humic coastal lagoon, Brazil). This paper presents the composition and functional groups of the phytoplankton from Comprida lagoon, a tropical humic coastal Lagoon located in Southeast Brazil. A total of 28 taxa was found, distributed in eight taxonomic divisions as follows: 26% Heterokontophyta, 21% Chlorophyta, 21% Cyanophyta, 14% Bacillariophyta, 14% Cryptophyta, and 4% Prymnesiophyta. Twenty-three taxa were identified at the specific and infraspecific levels, from which four are new records for Brazil and two for Rio de Janeiro State. Phytoplankton of the Comprida lagoon was comprised of several flagellates, but also eukaryote and prokaryote picoplankton, filamentous cyanobacteria and several diatoms. The biomass was lower than that found in other lacustrine systems, and showed remarkable temporal variability. According to the functional-group approach, the populations formed eight groups: Q, Z, E, N, X_3, X_2, S_1 and Y, most typical of oligo- or mesotrophic systems, tolerant to nutrient deficiency and sensitive to increased pH.

Key words: phytoplankton, tropics, humic systems, coastal lagoons, functional groups, Southeast Brazil

Introduction

Traditionally, humic lakes are associated with low productivity, species richness and phytoplankton population densities (Luœciñska & Soska 1998). Dissolved humic substances can influence the physical characteristics of ecosystems (light attenuation, reduction of pH values and nutrient availability), as well as biological aspects in terms of biological enhancing effects and adaptations in the plankton food web (McKnight & Aiken 1998; Nürnberg & Shaw 1998). Therefore, lakes with high concentration of humic compounds are identified as a distinct class of systems, easily recognized by their dark-colored water (Hessen & Tranvik 1998). In regard to phytoplankton composition, they frequently show high contribution of chrysophytes and cryptomonads, both with mixotrophic taxa (Jones 1998; Drakare *et al*. 2002; M. Järvinen, unpublished data; Pålsson & Granéli 2004).

Most of the studies on phytoplankton of humic systems are restrict to stratified and deep temperate lakes. In tropical areas, there are very few studies on phytoplankton communities in this kind of system and in South America most of the studies are from black-water systems located in the Amazonian region (Marlier 1967; Schmidt & Uherkovich 1973; Schmidt 1970; 1976; Fisher 1979; Thomasson 1955; 1971; Uherkovich & Rai 1979; Uherkovich 1976; 1981). These studies

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indicate the presence of an algal flora with a high percentage of desmids and diatoms, with low phytoplankton productivity and population densities. Other studies from humic freshwater coastal lagoons at the Southern and Southeastern regions show, in general, the same properties and an important contribution of small chlorococcal green algae and picoplanktonic cyanobacteria to total phytoplankton biomass (Callegaro 1981; Huszar & Esteves 1988; Huszar *et al*. 1989; Dias & Barroso 1998; Melo & Suzuki 1998; Roland 1998; Pålsson & Granéli 2004). However, little importance is given to the phytoflagellates.

Phytoplankton functional groups have been used to indicate environmental conditions and have proved to be more precise than phylogenetic groups (Huszar & Caraco 1988; Kruk *et al*. 2002). In the scheme proposed by Reynolds (1997) and updated by Reynolds *et al*. (2002), phytoplankton species are grouped into 33 functional groups, nominated by alphanumeric codes, based on their survival strategies, tolerances and sensitivities. Little is know about the phytoplankton of humic environments in regard to this approach. It is known, however, that some populations are more commonly found in these systems, such as chrysophytes, cryptomonads and raphidophytes, so that it is reasonable to expect that E, Y and Q groups could be dominant: E group includes chrysophytes able to live usually in small and oligotrophic pools; Y group is well adapted to a wide range of habitats and is tolerant of low light; and Q group is common in humic lakes at high latitudes.

This paper offers a more comprehensive account of the phytoplankton flora of a humic tropical coastal lagoon (Comprida Lagoon, Brazil) and analyses the changes in phytoplankton composition and biomass according to functional groups.

Material and methods

Comprida Lagoon (22°16'S; 41°39'W), located in the Municipality of Carapebus, is a shallow coastal system with a maximum depth of 3 m and a surface area of 0.13 km^2. It belongs to the Restinga de Jurubatiba National Park which is part of a large sandy coastal plain on the Northeastern coast of Rio de Janeiro State (Fig. 1). This lagoon has brown-colored, acidic freshwater (mean pH = 4.9) with a high concentration of dissolved organic carbon (DOC) (mean = 41-74 mg L^{-1}) due to high concentrations of humic compounds (Branco *et al*. 2000). High concentrations of DOC affect light penetration, leading to a high coefficient of light extinction, resulting in the heterotrophic metabolism observed during a diel cycle in this lagoon (Thomaz *et al*. 2001). Although the lagoon is separated from the sea by a 50 m-wide sand bar, it shows little marine influence, which is probably only caused by the entrance of seawater during storms or high tides (Branco *et al*. 2000).

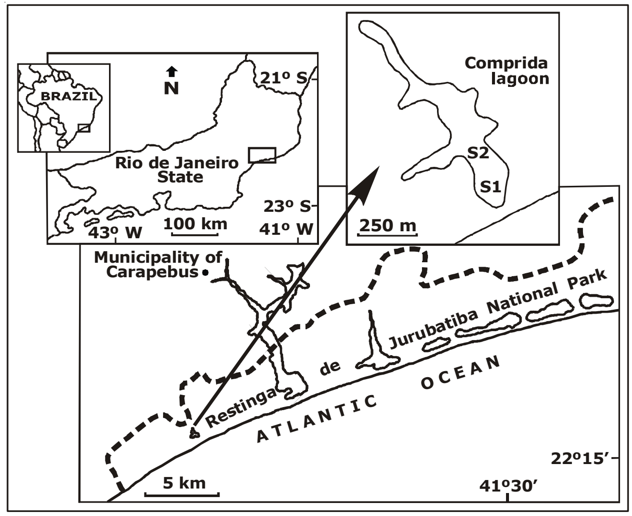

Figure 1. Location of Comprida Lagoon along the Brazilian coast and sampling stations (S1 = Station 1; S2 = Station). The dashed line indicates the limit of the National Park of "Restinga de Jurubatiba".

The surrounding lagoon area is occupied by sand dunes and shrubby vegetation, and macrophytes such as *Typha domingensis* Pers. are often found in the margins, forming extensive banks (Henriques *et al*. 1986). The local climate is sub-humid, with an annual mean relative humidity of 81%, maximum average temperature of 28 °C and minimum average temperature of 19.5 °C (Marinho *et al*. 2002). Annual rainfall reaches 1244 mm (Marinho *et al*. 2002) with monthly values reaching about 300 mm in the rainy period (CIDE 2003).

This study was based on 14 samples taken at two stations: Station 1 (S1), located closer to the sea, and Station 2 (S2), located near the banks of macrophytes (Fig. 1). Sampling was carried out in February, March, July, and October 1996 and April, August and November 1997. Samples were obtained by passing a flask along the subsurface water then fixing with acetic Lugol's solution. Water temperature was taken with an YSI temperature/conductivity meter (YSI-30), pH with a pH meter (DIGIMED), water transparence by Secchi disk and salinity was estimated based on the conductivity and temperature according to Fofonoff and Millard (1983).

Identification of taxa was based on light microscope observations of live and preserved material. The classification system followed Round *et al*. (1990) for diatoms and Hoek *et al*. (1997) for other algal divisions. Taxa names preceded by one or two asterisks represent new records for Brazil or for Rio de Janeiro State, respectively.

Phytoplankton densities were estimated by the settling technique with an inverted microscope (Utermöhl 1958). Units (cell, colonies and filaments) were quantified in random fields of view (Uhelinger 1964), and at least 100 specimens of the most frequent taxa ($p < 0.05$) were enumerated (Lund *et al*. 1958). Specific biomass was estimated from the product of population densities and mean unit volume (Edler 1979), assuming a specific density of phytoplankton cells of 1 g cm^{-3}. Phytoplankton assemblages were classified in terms of morpho-functional categories following Reynolds *et al*. (2002).

Results

A total of 28 taxa was found, distributed in eight taxonomic divisions as follow: 26% Heterokontophyta, 21% Chlorophyta, 21% Cyanophyta, 14% Bacillariophyta, 14% Cryptophyta, and 4% Prymnesiophyta. Twenty-three taxa were identified at the specific and infraspecific levels, from which four are new records for Brazil and two for Rio de Janeiro State. Table 1 presents the taxa recorded from Comprida Lagoon.

Phytoplankton shows important biomass values of flagellates (*Dinobryon sertularia*, *Gonyostomum semen*, *Heterosigma* cf. *akashiwo*, aff. *Teleaulax* sp. and *Cryptomonas brasiliensis*), eukaryote and prokaryote picoplankton (*Chlorella minutissima*, *Choricystis minor* and *Synechococcus nidulans*), filamentous cyanobacteria (*Planktolyngbya limnetica*) and diatoms (*Synedra nana* and *Eunotia incisa*).

According to changes in phytoplankton biomass and composition, we recognized three periods during this study: Period I (Feb-Mar-Jul/1996), characterized by relatively low biomass and dominated by heterokontophytes and chlorophytes; Period II (Oct/1996 and Apr/1997) also with relatively low biomass but with dominance of cyanobacterias, heterokontophytes and diatoms; and Period III (Aug and Nov/1997), with the highest biomass and dominance of cryptomonads and chlorophytes (Fig. 2).

Water temperature varied from 22 to 31.5 °C, and July/1996 and August/1997 were the coldest months

Table 1. Phytoplankton species recorded from Comprida lagoon during the study period. Species indicated with * and ** are new records to Brazil and Rio de Janeiro State, respectively.

CYANOPHYTA
- Cyanophyceae
  - *Chroococcus microscopicus* Komárková et Cronberg
  - ***Eucapsis densa* Azevedo, Sant'Anna, Senna, Komárek & Komárková
  - *Jaaginema subtilissimum* (Kützing ex De Toni) Anagnostidis et Komárek
  - *Planktolyngbya limnetica* (Lemmermann) Komárková & Cronberg
  - *Rabdoderma lineare* Schmidle & Lauterborn
  - **Synechococcus nidulans* (Pringsheim) Komárek

BACILLARIOPHYTA
- Coscinodiscophyceae
  - *Cyclotella meneghiniana* Kützing
- Fragilariophyceae
  - ***Synedra nana* Meister
- Bacillariophyceae
  - *Eunotia incisa* W. Smith ex Gregory
  - *Nitzschia palea* (Kützing) W. Smith

HETEROKONTOPHYTA
- Chrysophyceae
  - *Dinobryon sertularia* Ehrenberg
  - *Epipyxis* sp.
  - **Monochrysis parva* Skuja
  - *Ochromonas* sp.
- Raphydophyceae
  - *Gonyostomum semen* (Ehrenberg) Diesing
  - *Heterosigma* cf. *akashiwo* (Hada) Hada ex Hara & Chihara
  - *Merotrichia bacillata* Mereschkowsky

PRYMNESIOPHYTA
- Prymnesiophyceae
  - **Diachronema vlkianum* Pranser

CRYPTOPHYTA
- Cryptophyceae
  - *Chroomonas acuta* Utermöhl
  - *Chroomonas nordstedtii* Hansgirg
  - *Cryptomonas brasiliensis* Castro, C. Bicudo & D. Bicudo
  - aff. *Teleaulax* sp.

CHLOROPHYTA
- Prasinophyceae
  - *Scourfieldia cordiformis* Takeda
  - Chlorophyceae
  - *Chlamydomonas* sp.
  - *Chlorella minutissima* Fott & Nováková
  - *Choricystis minor* (Skuja) Fott
  - **Klebsormidium pseudostichococcus* (Heering) Ettl & Gärtner
  - *Tetraedrum caudatum* (Corda) Hansgirg

during the study period (22 and 23 °C, respectively). Low pH values were observed, with an average, by period, varying from 5.0 to 5.8. Little marine influence (0.36-1.24‰) was found during the study period, the highest salinity values observed during Period III (Tab. 2). Although a difference was observed in phytoplankton composition and biomass values between the three periods, among the abiotic variables only salinity followed this difference.

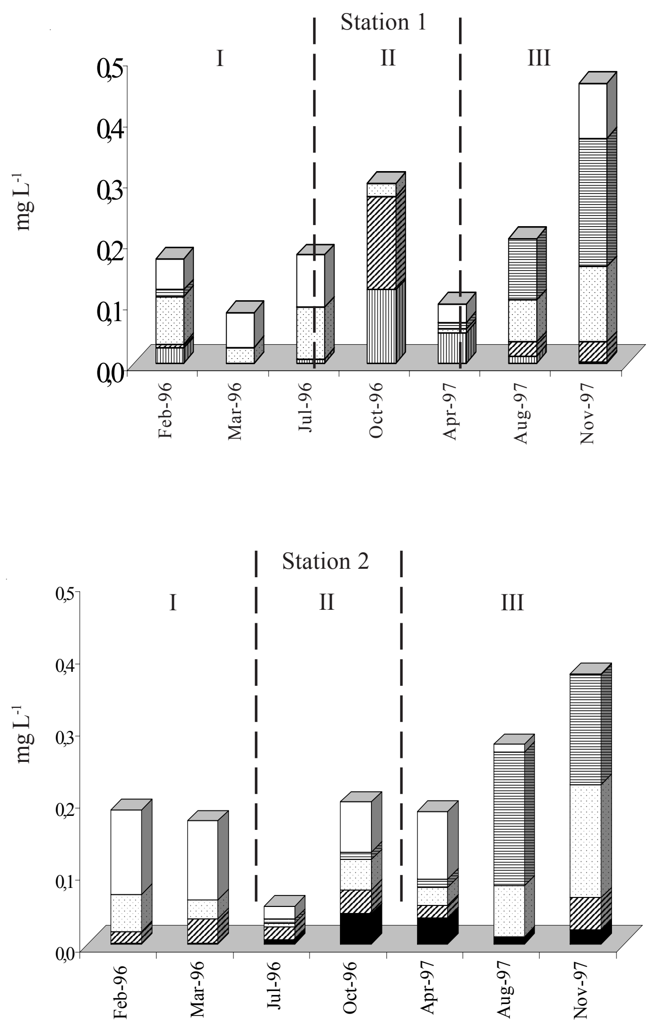

Figure 2. Contribution of phytoplankton biomass (mg L^{-1}) by taxonomic divisions to the total phytoplankton of Comprida lagoon by period (I = Period I; II = Period II; III = Period III) in surface of Stations 1 and 2 (S1 and S2). ▥ = Cyanobacteria; ▧ = Diatoms; ⬚ = Chlorophytes; ▤ = Cryptophytes; □ = Heterokontophytes.

Phytoplankton biomass was low and showed remarkable variability between the three periods. Period I was characterized by the lowest mean biomass (0.14 mg L^{-1}), dominated by *Chlorella minutissima* and *Dinobryon sertularia* in Station 1, and by *Gonyostomum semen* and cysts of *Heterosigma* cf. *akashiwo* in Station 2. Period II, with mean phytoplankton biomass of 0.18 mg L^{-1}, was characterized by the dominance of *Eunotia incisa*, *Planktolyngbya limnetica* and *Synechococcus nidulans* in Station 1, and *Gonyostomum semen*, *Synedra nana* and *Synechococcus nidulans* in Station 2. Period III showed the highest mean biomass values during the study period (0.33 mg L^{-1}), with dominance of aff. *Teleaulax* sp., vegetative cells of *Heterosigma* cf. *akashiwo* and *Cryptomonas brasiliensis* in Station 1, and aff. *Teleualax* sp., *Chlorella minutissima*, *Choricystis minor* and *Cryptomonas brasiliensis* in Station 2. These populations were classified into eight functional groups (Q, Z, E, N, X_3, X_2, S_1 and Y) as specified in Table 3.

Discussion

Based on nutrient data (Branco *et al*. 2000), Comprida Lagoon could be classified as having distinct trophic states, depending on the criteria used either for warm lakes (Salas & Martino 1991) or for temperate lakes (Nürnberg 1996). It is important to mention that the proportion of organic nitrogen (N) in Comprida Lagoon is higher when compared with dissolved inorganic levels, which indicates N deficiency for phytoplankton growth (Reynolds 1997). Considering the limiting concentrations of soluble reactive phosphorus (mean = 2.29 µg l^{-1}) and the low levels of chlorophyll (mean = 2.72 µg L^{-1}) mentioned in Branco

Table 2. Average and minimum and maximum values of some abiotic variables, in the surface of the Comprida lagoon, by periods.

	Period I (Feb, Mar and Jul/96)		Period II (Oct/96 and Apr/97)		Period III (Aug and Nov/97)	
	Average	Min-Max	Average	Min-Max	Average	Min-Max
Transparency (m)	0.3	0.3-0.5	0.3	0.3-0.5	0.3	0.3-0.5
Water temperature (°C)	26.6	22-31	25.5	25-26	25.6	23-32
pH	5.45	4.4-6.8	5.1	4.6-5.4	5.1	5.1-6.2
Salinity (‰)	0.35	0.2-0.4	0.35	0.3-0.4	1.1	0.8-1.4

Table 3. Relative contribution (%) based on biomass of the main phytoplankton functional groups (FG.) by period, of surface samples taken at Stations 1 and 2 (S1 and S2) of Comprida lagoon.

	Period I (Feb, Mar and Jul/96)			Period II (Oct/96 and Apr/97)			Period III (Aug and Nov/97)		
		%	FG		%	FG		%	FG
S1	*C. minutissima*	40	X_3	*E. incisa*	39	N	aff. *Teleaulax* sp.	27	Y
	D. sertularia	21	E	*P. limnetica*	29	S_1	*C. brasiliensis*	14	Y
	H. cf. *akashiwo* (cysts)	13	Q	*S. nidulans*	14	Z	*H.* cf. *Akashiwo* (vegetative cells and cysts)	14	Q
				C. minutissima	7	X_3			
	G. semen	7	Q	*H.* cf. *akashiwo*	7	Q	*C. minor*	13	X_3
	S. nidulans	7	Z	(cysts)			*C. minutissima*	10	X_3
							S. nana	8	N
							S. cordiformis	6	X_2
S2	*G. semen*	31	Q	*G. semen*	26	Q	aff. *Teleaulax* sp.	34	Y
	H. cf. *akashiwo*(cysts)	15	Q	*S. nana*	13	N	*C. minutissima*	18	X_3
		14	X_3	*S. nidulans*	12	Z	*C. minor*	16	X_3
	C. minutissima	12	N	*C. minutissima*	8	X_3	*C. brasiliensis*	13	Y
	E. incisa	8	E	*P. limnetica*	8	S			
	D. sertularia			aff. *Teleaulax* sp.	6	Y			

et al. (2000), Comprida Lagoon can be classified as an oligotrophic system using both warm lake and temperate lake criteria. However, at least for tropical systems, phytoplankton species composition may be more informative for the classification of lake trophic state than other trophic indicators such as nutrients, transparence or chlorophyll (Huszar *et al*. 1998). Indeed, the dominant functional groups of Comprida Lagoon were indicative of an oligo-mesotrophic system.

Most of the knowledge on phytoplankton of humic systems is restricted to stratified and deep temperate lakes. In these environments, phytoplankton communities include, in general, few species of phytoflagellates, which can optimise their access to light and nutrients by vertical migration (Bowling & Tyler 1988). Phytoplankton of the Comprida Lagoon was composed of some flagellates, but also contained eukaryote and prokaryote picoplankton, filamentous cyanobacterias and some metaphytic diatoms. Although turbulent humic lakes exhibit a strong contribution of phytoflagellates, they also show a more diverse phytoplankton community, including a higher proportion of diatoms (Jones 1998).

Mixotrophy has been thought to be a particularly successful strategy in humic systems (Drakare *et al*. 2002; M. Järvinen, unpublished data), where low light and low dissolved inorganic nutrients are limiting to phytoplankton growth, and high concentration of dissolved organic matter leads to high bacterial density (Jones 2000). However, there is very little information on the importance of mixotrophic phytoflagellates in tropical humic systems. Pålsson & Granéli (2004) compared the phytoplankton of three temperate humic lakes with three tropical humic lagoons (among them Comprida Lagoon) and recorded that the mixotrophic biomass was low in the tropical systems and constituted only 1-7% of the total biomass. These data are in disagreement with our results to Comprida Lagoon, when the species indicated by these authors as mixotrophic constituted 5-50% of total biomass at some sampling dates. This discordance may be explained because the results of Pålsson & Granéli (2004) were based on only in one sample collected in the summer of 1998 and a higher number of samples at different times of the year might be necessary to characterize the presence mixotrophic flagellates in tropical humic systems.

As observed in temperate humic systems, the potential mixotrophics (heterokontophytes and cryptophytes) played an important role in the phytoplankton community of Comprida Lagoon. *Dinobryon sertularia* is known to be potentially mixotrophic, showing facultative bacterial feeding (Jones & Rees 1994; Pugnetti & Bettinetti 1999) and *Gonyostomum semen* has the facultative capacity of heterotrophy by osmotrophy (Eloranta & Järvinen 1989). Indeed, many phytoplankton species, like *Cryptomonas* spp., can take up dissolved organic carbon or, under inorganic nutrient deficiency, can use dissolved amino acids or other organic sources of nitrogen (Schoonhoven 2000).

Despite the fact that planktonic flora of Comprida Lagoon was typically limnobiont euryhaline, one marine euryhaline taxa, *Heterosigma* cf. *akashiwo*, was observed. A very small marine influence was observed, however, during Period III when salinity values were slightly higher (Tab. 2). This difference in salinity values was reflected in the floristic composition throughout the study period: although cysts of *H*. cf. *akashiwo* were commonly observed during the entire study, some vegetative cells were present only in Period III. Indeed, some individuals of *Prorocentrum minimum* (Pavillard) Schiller, a marine euryhaline species, were recorded in net samples and also only in Period III (Alves-de-Souza *et al.* unpublished data).

According to the functional group approach, the populations were classified in eight groups (Tab. 3). Thus, *Gonyostomum semen*, dominant in Comprida Lagoon during Period I, can be recognized as a representative species of group Q, which is common in humic lakes of high latitudes (Cronberg *et al*. 1988), usually having low calcium contents and acidic waters (Reynolds *et al*. 2002). This species was also found forming bloom in a shallow, humic artificial pond in a Brazilian tropical region (M. Menezes, unpublished data). In this same group we are now also including another raphidophyte, *Heterosigma* cf. *akashiwo*, which was co-dominant during Period III.

Dinobryon sertularia, a representative of group E, is sensitive to CO_2 deficiency and usually able to live in small, oligotrophic or heterotrophic ponds. Mixotrophy may be an advantageous strategy in these particular conditions. Some diatoms, such as *Synedra nana* and *Eunotia incisa*, although typical metaphytic species, conbtributed somewhat to the phytoplankton biomass of Comprida Lagoon. Despite the functional group approach having been developed for pelagic vegetation, both species can be thought of as N-functional group. We are now including them in group N, which is characterized by strong dependence of physical mixing and could be present in acidic shallow lakes with low values of nutrients (Reynolds *et al*. 2002).

Small size representatives of non-motile nanoplankton (X_3 - *Choricystis minor* and *Chlorella minutissima*) and also prokaryote picoplankton (Z - *Synechococcus nidulans*) had an important contribution to the phytoplankton biomass in this study. X_3 and Z groups are expected to live in shallow, clear and mixed layers, being sensitive to light deficiency and grazing (Reynolds *et al*. 2002). Although these groups are not expected to occur in dark water systems, non-motile nanoplankton (Dias & Barroso 1998) and prokariotic picoplankton (Roland 1998; Melo & Suzuki 1998) could also be co-dominant in humic systems. The dominance of *C. minor* was also recorded from a temperate partially polymictic humic lake and could be a result of the capacity of this small alga to respond rapidly to nutritional conditions (Hechmann *et al*. 2001).

Group Y is well adapted to live in a wide range of habitats and is tolerant of low light and sensitive to grazing, being commonly observed in humic lakes (Jones 1998). *Cryptomonas brasiliensis* and an aff. *Teleaulax* sp. were also important to phytoplankton of Comprida Lagoon.

In synthesis, our data show that in tropical systems, besides the phytoflagellates, the chlorophytes, cyanobacterias and diatoms may be important components of phytoplankton and, due to the high proportion of potential mixotrophics, the mixotrophy may also be considered a successful strategy, as observed in temperate humic systems. Finally, the functional group approach constitutes a useful tool understanding the phytoplankton community in tropical humic systems, despite having been originally formulated for temperate systems.

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