# Ecology of Peridinium gatunense and Peridinium umbonatum (Dinophyceae) in a shallow, tropical, oligotrophic reservoir (IAG Pond), São Paulo, southeast Brazil.

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**ABSTRACT: Ecology of Peridinium gatunense and Peridinium umbonatum (Dinophyceae) in a shallow, tropical, oligotrophic reservoir (IAG Pond), São Paulo, southeast Brazil.** Two dinoflagellate (Dinophyceae) species, Peridinium gatunense Nygaard and Peridinium umbonatum Stein were studied at the IAG Pond, a tropical, shallow, oligotrophic reservoir located at the Parque Estadual das Fontes do Ipiranga Biological Reserve (23° 38' 18,9" S and 46° 37' 16,3" W), southeast of the municipality of São Paulo, Brazil. Samples were gathered monthly from August 1998 to July 1999 at one fixed station of the reservoir (limnetic region, maximum depth ± 4.70 m), at five depths (subsurface (± 20 cm below surface), 1 m, 2 m, 3 m, and bottom (15-20 cm from the bottom)) to study temporal and vertical distribution of the two species. Both species showed very similar seasonal distribution, i.e. both were present during the mixing period (April-July 1999 and August-October 1998) distributed throughout the water column, although their greatest densities were detected in the reservoir superficial layers. During the same period, nutrient depletion was pronounced, except for high amounts of orthosilicate and DO. During the remaining months (rainy period, November 1998-March 1999), an increase of TN, $NO_2^{-1}$, $NO_3^{-1}$, $PO_4$, TDP, free $CO_2$, total $CO_2$, and $HCO_3^-$ and a significant increase in chlorophyll a concentration were registered, indicating that the phytoplankton community total density was highly due to nutrient availability. The two Peridinium species greatest development occurred during a period of evident limnological stress (nutrient depletion), with less intraspecific competition, suggesting their preference for oligotrophic conditions.
**Key-words:** autoecology, urban reservoir, indicating organisms, dinoflagellates, Brazil.

**RESUMO: Ecologia de Peridinium gatunense e Peridinium umbonatum (Dinophyceae) em reservatório tropical, raso, oligotrófico (Lago do IAG), São Paulo, Brasil sudeste.** Duas espécies de dinoflagelados (Dinophyceae), Peridinium gatunense Nygaard e Peridinium umbonatum Stein foram estudadas no reservatório do IAG, um sistema raso oligotrófico situado na Reserva Biológica do Parque Estadual das Fontes do Ipiranga (23° 38' 18,9" S, 46° 37' 16,3" W), região sudeste do município de São Paulo, Brasil. Coleta de material foi realizada mensalmente, de agosto/1998 a julho/1999, em uma estação fixa no reservatório (região limnética, profundidade máxima ± 4,70 m), em cinco profundidades (subsuperfície (± 20 cm superficiais), 1 m, 2 m, 3 m e fundo (15-20 cm do fundo). As duas espécies tiveram distribuição sazonal parecida, ou seja, ambas estiveram presentes durante o período de mistura (abril-julho/1999 e agosto-outubro/1998) e apresentaram distribuição vertical que contemplou toda a coluna d'água, embora as maiores densidades de cada uma tivessem sido registradas na superfície do sistema. No mesmo período, a carência de nutrientes foi pronunciada, excetuados ortossilicato e OD que apresentaram teores elevados. Nos meses remanescentes (período chuvoso, novembro/1998-março/1999) foram registrados aumentos dos valores de NT, $NO_2^{-1}$, $NO_3^{-1}$, $PO_4^{-3}$, PDT, $CO_2$ livre, $CO_2$ total e $HCO_3^-$ e acréscimo significante das concentrações de clorofila a, demonstrando que a densidade total da comunidade fitoplanctônica foi elevada devido à disponibilidade de nutrientes. As duas espécies alcançaram seu melhor desenvolvimento em período de evidente estresse limnológico (carência de nutrientes), com menor competição intra-específica, sugerindo sua preferência por condições de oligotrofia.
**Palavras-chave:** autecologia, reservatório urbano, organismos indicadores, dinoflagelados, Brasil.

## Introduction

Contributions to the understanding of autoecology of planktonic algae are scarce worldwide and probably less than 10% of the studies dealing with synecology. Furthermore, up to now nearly all autoecological papers published aimed at studying species of economic interest as water bloom producers (Burford, 2005; Canion & Ochs, 2005; Chinain et al., 1999; Cloern et al., 2005; Fauchot et al., 2005; Garces et al., 1999; Gordon et al., 2005; Hernandez-Becerril et al., 2000; Lassus et al., 1999; Raine et al., 2001; Ramírez-Camarena et al., 1999; Songhui & Hodgkiss (2004). Paolisso & Maloney (2000) reasoned for an integration of farmer environmentalism into ongoing programs and policies to control nutrient runoff and improve water quality in the Chesapeake Bay region of the United States. Lassus et al. (2000) focused on the importance of algae in shellfish poisoning. Stentiford et al. (2000a, 2000b) showed the changes, respectively, of taste, texture and marketability of infected meat and the swimming performance of the Norway lobster caused by parasitic dinoflagellates.

Nine of the ten papers published on the autoecology of freshwater phytoplankton in Brazil dealt with species with no economic interest. However, Nogueira (1997) studied the cyanobacteria Microcystis aeruginosa Kützing, an organism with economic potentials since it produces water blooms. Of the nine remaining papers, six dealt with the diatom Melosira italica (Ehrenberg) Kützing (today Aulacoseira italica (Ehrenberg) Simonsen), two with the desmids Croasdalea marthae (Grönblad) C. Bicudo & Mercante and Micrasterias arcuata Bailey, and one with the charophyte Nitella furcata (Roxburgh ex Bruzelius) C. Agardh emend. R.D. Wood subsp. mucronata (A. Braun) R.D. Wood var. mucronata f. oligospira (A. Braun) R.D. Wood.

Most of the morphological and ecophysiological characteristics of dinoflagellates do not favor these organisms during competition with nanoplankton species. Even though, dinoflagellates may be abundant and form blooms in some systems. This occurs because of their ecophysiological properties and reproductive strategies, which enable them to grow and survive under conditions unfavorable to the other algae. According to Pollingher (1988), most phytoplanktonic species need turbulence to survive and, in this sense, dinoflagellates are not an exception. They need turbulence during the period necessary for resuspension of their cysts, which are the inoculli for development of new populations. Nevertheless, dinoflagellates do not need turbulence to remain in the upper layers of the water column due to their motility. This ability facilitates their search for nutrients in the water column, but simultaneously diminishes their loss by sedimentation. Due to their capability of surviving with low P consumption, dinoflagellates may persist in the system even when that element is no longer available (van-den-Hoek et al., 1995). Features, such as low P consumption, vertical migration capability, and relatively great life span of their generations, give dinoflagellates great competitive advantage over other algae under extreme conditions of nutrient depletion. It should be added that, due to their relatively great size, dinoflagellates are less susceptible to zooplankton grazing, minimizing their losses. Finally, the possibility of forming cysts enables these algae to resist unfavorable environmental conditions.

The above characteristics were the reason for choosing the two dinoflagellate species, Peridinium gatunense Nygaard and Peridinium umbonatum Stein, the only two Dinophyceae occurring in the IAG Pond, as the subject of the present research, aiming at the possible utilization of phytoplankton species as water quality indicators and, in the present case, of an oligotrophic system.

### Study area

The Science and Technology Center (CIENTEC, Centro de Ciência e Tecnologia) reservoir, locally called IAG Pond, is a shallow, tropical, oligotrophic system located in the PEFI, Parque Estadual das Fontes do Ipiranga Biological Reserve, southeast region of the municipality of São Paulo, about 10.2 km south and 10.8 km east of the São Paulo zero mark, at 23° 38’ 18.9” S and 46° 37’ 16.3” W. It is, in fact, an urban reservoir built ca 1930 for landscaping in the CIENTEC area.

IAG reservoir (Fig. 1) is the only reservoir of the nine built in the PEFI area to have oligotrophic characteristics (Lopes, 1999). Consequently, it represents the pristine conditions and is considered a reference system for the area. In Table I, the morphological and metric features of the IAG reservoir are presented.

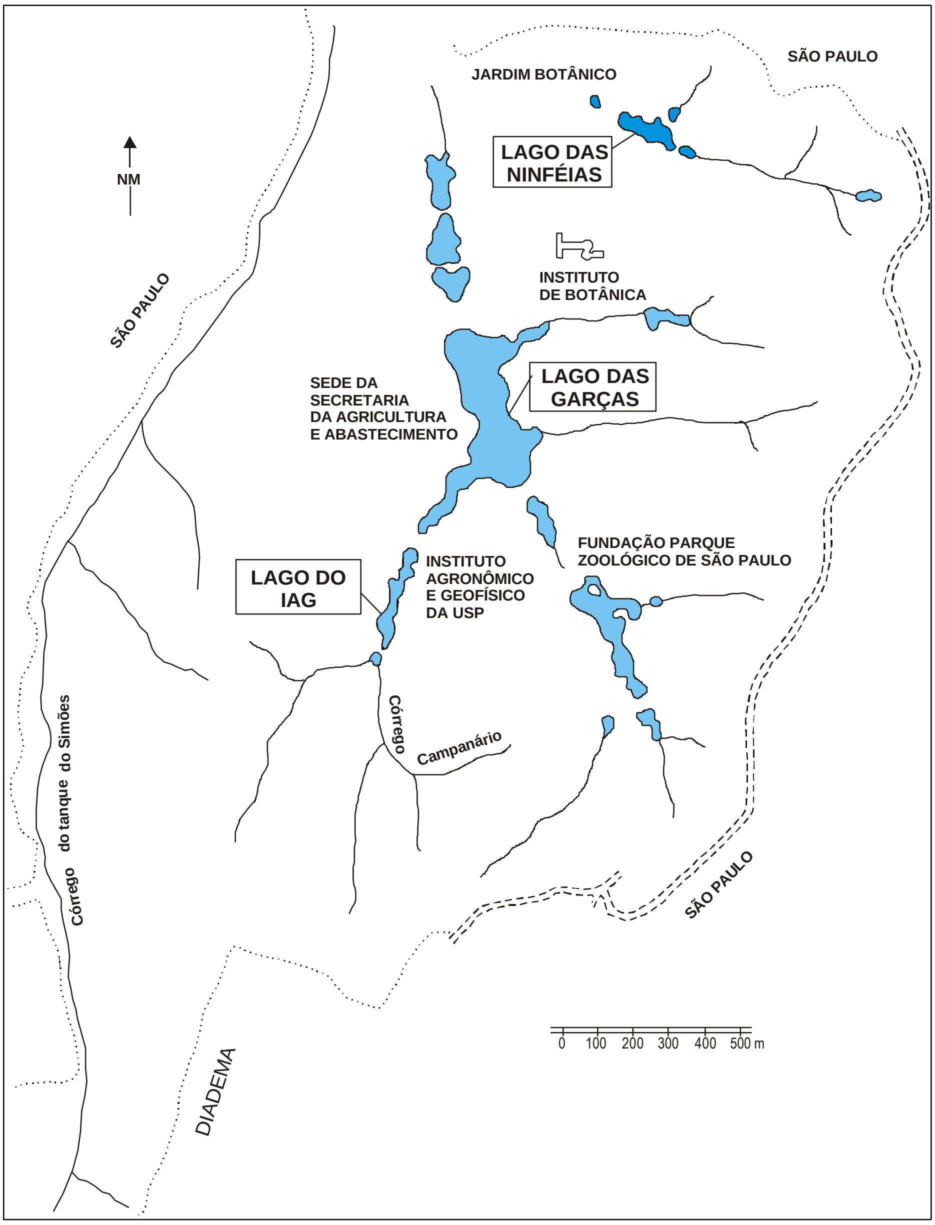


Figura 1: Map of the Parque Estadual das Fontes do Ipiranga showing IAG Pond.

Table I: Morphological and metric features of the IAG Reservoir (Bicudo et al., 2001).

| **Variable** | **Value** |
|---|---|
| Maximum length | 311.5 m |
| Maximum breadth | 45.5 m |
| Shoreline (L) | 782.8 m |
| Area (A) | 48,766.01 m$^2$ |
| Volume (V) | 76,652.64 m$^3$ |
| Maximum depth ($Z_{max.}$) | 4.70 m |
| Average depth (Z) | 1.57 m |
| Relative depth | 1.83% |
| Shoreline development (DL) | 1.00 |
| Volume development (DV) | 1.03 |

## Material and methods

The two species presently selected can be identified according to the descriptions below:

**Peridinium gatunense Nygaard 1925**

Cells spherical, 34-80 x 29-75 mm, 1.1-1.2 times wider than long, dorsiventrally flattened; epitheca and hypotheca bluntly conical, equal in size; cingulum wide, flanged, twisting to the left; sulcus widening slightly, reaching the antapex; plates reticulate, rarely rugose, irregularly distributed; chloroplasts numerous, parietal; bundles of trichocysts rarely present. Vegetative division following ecdysis, producing 2 naked cells. Sexual reproduction isogamic (Popovský & Pfiester, 1990).

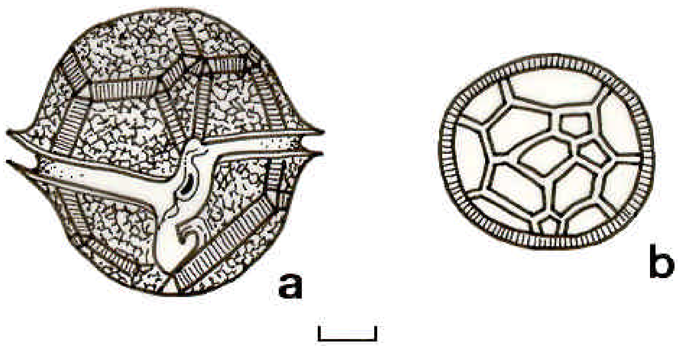

Figure 2: Frontal (a) and apical (b) view of Peridinium gatunense Nygaard. Bar = 10 mm.

**Peridinium umbonatum**

Cell ellipsoid, egg-shaped to 5-angular in front view, 15-45 x 12-32 mm, dorsiventrally flattened; epitheca conical or bell-shaped, wider than the hypotheca, hypotheca hemispherical; cingulum wide, twisting to the left; sulcus extending slightly into the epitheca, widening along the hypotheca, reaching the antapex; theca relatively thin, dorsal part may be ornamented with fine teeth-like or large spine-like processes; plates convex or concave, with rows of papillae; chloroplasts numerous, parietal, radially arranged, usually discoid, rare clavate, sometimes may be lacking. Vegetative division within the theca. Sexual reproduction isogamic, 2 thecate isogametes fusioning to form a spherical zygote, which is completed outside the fusioned thecae; repeated ecdysis of the growing zygote occurs several times so that it becomes peanut-shaped (Popovský & Pfiester, 1990).

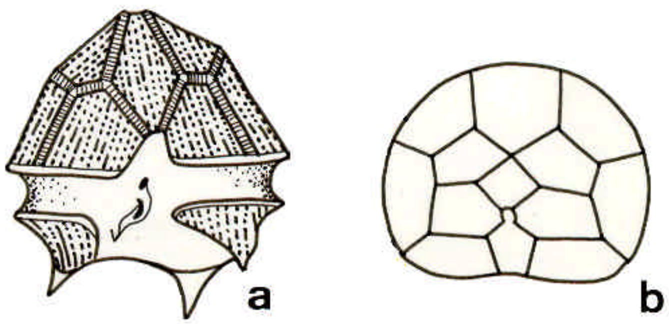

Figure 3: Frontal (a) and apical (b) view of Peridinium umbonatum Stein. Bar = 10 mm.

**Sampling stations and methods**

Samplings were performed in a single station located in the limnetic region of the reservoir (»4.70 m deep), in five fixed depths (subsurface (± 20 cm superficial), 1 m, 2 m, 3 m, and bottom (15-20 cm from the bottom)), during 12 consecutive months (August 1998 to July 1999), covering a full seasonal cycle.

Environmental variables measured and respective analytical methods used are summarized in Table II.

Statistical treatment of data was conducted by using average as the central tendency measurement. Standard deviation (s) was calculated as a measure of the absolute dispersion of data, and Pearson variation coefficient (CV) of their relative dispersion. Principal Components Analysis (PCA) was used to ordinate the sampling units on the basis of their climatic and limnological characteristics. The PC-ORD Program, version 3.0 for Windows (McCune & Mefford, 1997) was used for the analyses above, matrices being transformed by ranging with the aid of the FITOPAC Program (Shepherd, 1996). Aiming at having a simultaneous analysis of the environmental variables and of the species distribution in the reservoir, Canonical Correspondence Analysis (CCA) was performed according to Ter-Braak (1986).

Table II: Environmental variables values measured at the IAG reservoir from August/1998 to July/1999.

| Variable | Unit | Method |
|---|---|---|
| Rain precipitation | mm | Meteorological Station located at the PEFI |
| Air temperature | $^oC$ | Meteorological Station located at the PEFI |
| Wind speed | $m.s^{-1}$ | Meteorological Station located at the PEFI |
| Water temperature | $^oC$ | Termistor |
| Water turbity | NTU | Turbidimeter |
| Electric conductivity | $mS.cm^{-1}$ | Conductivimeter |
| Dissolved oxygen | $mg.L^{-1}$ | Golterman et al. (1978) |
| pH | pH | pHmeter |
| Chlorophyll-a | $mg.L^{-1}$ | Golterman & Clymo (1969); Wetzel & Likens (2000) |
| $CO_2$ (free and total) | $mg.L^{-1}$ | Mackereth et al. (1978) |
| Ammonium ($NH_4^{+1}$) | $mg.L^{-1}$ | Solorzano (1969) |
| Nitrate ($NO_3^{-1}$) | $mg.L^{-1}$ | Mackereth et al. (1978) |
| Nitrite ($NO_2^{-1}$) | $mg.L^{-1}$ | Golterman et al. (1978) |
| Orthophosphate ($PO_4^{-3}$) | $mg.L^{-1}$ | Golterman et al. (1978) |
| Total nitrogen (TN) | $mg.L^{-1}$ | Valderrama (1981) |
| Total phosphorus (TP) | $mg.L^{-1}$ | Valderrama (1981) |

# Results and discussion

## Local climate

Maximum and minimum values of precipitation, air temperature, winds, and solar radiation registered for the area during the study period are shown in Table III.

Based on a 30-year data set, mean annual precipitation is 1,368 mm, mean air temperature of the coldest month (July) is 15°C, and mean temperature of the hottest months (January-February) is 21.4-21.6°C (Marques-dos-Santos & Funari, 2002). The climate of the area is tropical of altitude (Conti & Furlan, 2003).

Two very distinct climatic periods can be defined for the PEFI area, a hot and humid period from October to March and a cold and dry period from April to September. During the present research, however, November was atypical due to the low precipitation (44.1 mm) that month.

Table III: Maximum and minimum values of precipitation, air temperature, winds, and solar radiation registered for the area during the study period.

| Variable | Maximum value | Minimum value |
|---|---|---|
| Precipitation (daily total) | 292.7 mm | 41.0 mm |
| Air temperature | 32.5 $^oC$ | 11.5 $^oC$ |
| Wind speed (daily average) | 2.39 $m.s^{1}$ | 0.61 $m.s^{1}$ |
| Solar radiation | 31.17 $MJ.m^{2}$ | 0.33 $MJ.m^{2}$ |

According to Reynolds (1992), only winds over 3 $m.s^{-1}$ will interfere in the stratification process of a lake. Wetzel (2001) stated that it is also important to consider the topography and the vegetation in lakes with small surface areas, mainly those protected from wind action. Wind speed varied during the study period from a whiff (min. 0.3 to max. 1.5 $m.s^{-1}$) to a very weak breeze (min. 1.6 to max. 3.3 $m.s^{-1}$) according to Beaufort's anemometric scale (Watanabe, 1997) (Fig. 4), i.e. were not strong enough as they did not surpass an average of 1.56 $m.s^{-1}$ (whiff to very weak breeze) and highest wind speed (2.39 $m.s^{-1}$) in November 1998 was much lower than that indicated by Reynolds (1992). Winds of such intensity are not able to interfere in the stratification/mixing pattern of the reservoir. It should also be considered that the topographic location of the reservoir does not favor the wind work, since it is located in a depression of the ground and it is surrounded by dense arboreal vegetation that makes the wind action on the water dynamics even more difficult.

Wind direction in the IAG reservoir area varied significantly, but the registered East-Northeast direction dominated during three months of the present study (October and December 1998 and March 1999), followed by Northeast direction in two months (August 1998 and May 1999). All other directions (South-East, East, North-West, South-Southeast, East-Southeast, and North-Northeast) were registered just once during the study period.

In Table IV, maximum and minimum values of water temperature, transparency, euphotic zone, and light vertical attenuation coefficient registered in the PEFI area during the present study period are shown.

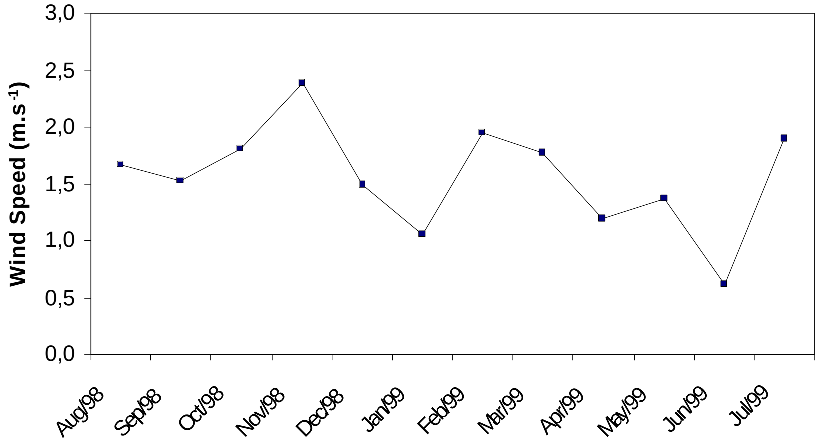


Figure 4: Wind speed (m.s$^{-1}$) temporal variation (daily average) during the period August/1998-July/1999 in the IAG reservoir area.

Table IV: Maximum and minimum values of water temperature, transparency, euphotic zone and light vertical attenuation coefficient registered in the PEFI area during the study period.

| Variable | Maximum value | Minimum value |
|---|---|---|
| Water temperature | 24.2 °C | 15.1 °C |
| Transparency | 2.4 m | 1.2 m |
| Euphotic zone | 4.7 m | 3.6 m |
| Light attenuation coefficient | 0.47 | 0.24 |

## Thermal structure of reservoir and dissolved oxygen

Development of a thermal structure, but mainly its duration, is of the utmost importance for lacustrine system's metabolism (Marinho, 1994).

Lewis (1996) stated that, despite the lack of long duration studies in tropical systems, there seems to exist some seasonal repetition of the mixing period if a specific lake or reservoir is considered. The same author also mentioned that the water density response is high under temperatures around 24 °C, and that this fact leads to great water column stability even if very small differences of temperature are detected. Consequently, tropical medium to deep lakes very frequently show stratification during a full season of the year (Lewis, 1996).

IAG reservoir is located very close to the tropical region southern limit and, despite its low depth ($Z_{max.}$ = 4.7 m), it was possible to identify thermal stratification during the present study period. Such stratification was established by thermal gradients with values ³0.5°C.m$^{-1}$ according to that established by Payne (1986). Lewis (1983) considered, however, that temperature differences of 0.1-0.2°C might generate great density gradient values in the water column of warm lakes (»24°C). Present thermal gradients (Fig. 5) during the period January 1999 to April 1999 were very much pronounced (20-24°C), and generated great relative thermal resistance (RTR) values that resulted in a stratification period, i.e. a period of great water column stability during the summer. Relatively great differences between the water temperature at the surface and bottom of reservoir were measured during the above period, with values close to 3°C in January 1999. Depth of the mixing zone ($Z_{mix}$) was shallow during the latter period, restricted to the system surface (0.5-1 m). In May 1999, reservoir thermal structure showed a reverse tendency to stratification and since then and up to July 1999 the reservoir water column presented complete mixing, i.e. a complete circulation of the reservoir took place during the winter. Towards the end of the winter (August 1998), low RTR and high $Z_{mix}$ values defined another mixing period. Spring stratification started in September 1998 and was maintained in October 1998. It is very probable that, with the end of the winter, increasing water temperature and decreasing precipitation governed the beginning of the reservoir thermal stability change. In November 1998, the reservoir presented again great values of $Z_{mix}$ (»3 m) that gradually decreased in December 1998 and January 1999.

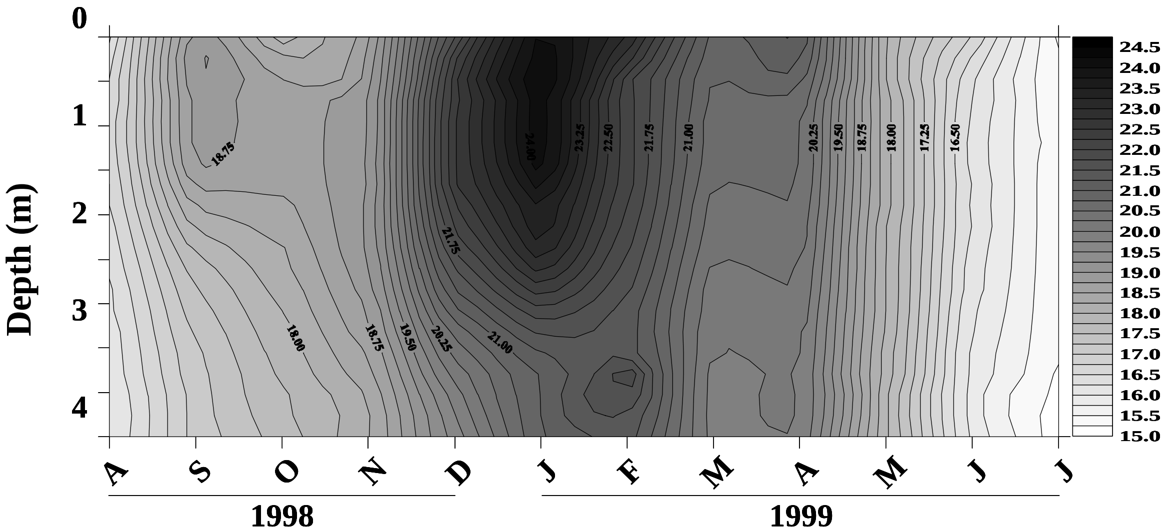


Figure 5: Depth and time isolines diagram of temperature (°C) in the IAG reservoir during the period August/1998-July/1999.

Lopes (1999) studied the IAG reservoir at short time intervals (seven consecutive days in August 1996 and another seven consecutive days in January 1997) three times a day (07:00 hr, 13:00 hr, and 19:00 hr) and observed low RTR values during the early morning hours, thus indicating daily mixing of the water column during the dry period (winter) and stratification during the day. During the rainy period (summer), stratification lasted longer. The reservoir was identified as warm polymitic discontinuous during the summer (Lopes, 1999) and atelomitic during the winter (Lopes et al., 2005).

During the present study, the IAG reservoir presented thermal stratification during the summer and part of the spring and mixings during the fall and winter. According to Lewis' (1983) classification, IAG reservoir is considered warm polymitic discontinuous, stratification lasting for days or weeks, however, with more than one mixing period during the year. Despite the presently observed stratification pattern, well-defined thermocline was never observed during the present study. Lopes (1999) also did not depict a typical hypolimnion (a thick layer with homogeneous temperature and density) during the two climatic periods (rainy and dry) of her study. During the dry period (great RTR values), daily temporary stratification at 13:00 hr and 19:00 hr. was noticed, while during the rainy period, well-defined thermocline was detected at the reservoir superficial layer. In the rainy period, water column thermal stability was followed by stratification of physical and chemical characteristics of the reservoir.

Depletion of dissolved oxygen and nutrient accumulation at the deepest layers of reservoir have been used as an indication of a long lasting thermal stratification (Froehlich et al., 1978; Tundisi et al., 1984; Arcifa et al., 1990). DO is essential to the metabolism of most aquatic organisms. Oxygen distribution dynamics in a reservoir is controlled by the equilibrium between the input of gases from the atmosphere and photosynthesis production, and the losses from chemical and biological oxidation (Wetzel, 2001).

Research carried out in Brazilian lakes indicated that two main factors would interfere with the magnitude of DO deficits in the water column: (1) extension of the thermal stratification period, and (2) organic matter concentration (dissolved and particulate) in the water (Esteves, 1998).

Oxygen was always largely present along the whole water column during the study period. However, its distribution pattern was very distinct depending on the time of year. According to Silva (1995), DO distribution is, more than any other factor, rapidly affected by the establishment of thermal stratification. DO vertical profile followed the thermal stratification pattern of the system. In August 1998, the greatest value of DO (7.91 $mg.L^{-1}$) was registered at the surface and in October 1998 the smallest value (1.70 $mg.L^{-1}$) at the bottom of the reservoir. During the months of greatest thermal stability of the system (May to July 1999), DO profile was very homogeneous and showed its greatest values in the entire water column. Such a homogeneous condition was also observed by Henry (1981) in the Pardo river reservoir, in the state of São Paulo, and by Lopes (1999) in the present reservoir, due to intense photosynthetic activity. During the great thermal stability period, DO vertical profile indicated the presence of a stratification gradient with very low values at the reservoir bottom that would very possibly result from the increase of the respiration and the decomposition rates measured in that compartment of the system. During the rainy period, DO values also were smaller than in the dry period, which is to be expected due to the higher water temperatures measured in that period. Highest DO values obtained at the surface as well as the lowest values at the bottom of the reservoir defined a clinograd profile. A similar situation was detected by Lopes (1999) in the same reservoir, but in a different period (20 to 26 August 1996 and 22 to 28 January 1997). Considering that the IAG reservoir has low chlorophyll a and nutrient concentrations (Tab. V), i.e. a typical oligotrophic condition, OD orthograd profiles would be expected. However, Esteves et al. (1985) mentioned that temperature is always higher at the lower layers of tropical lacustrine ecosystems than at those of temperate regions, which implies high oxygen consumption by the community. During the present study, temperature was always higher than 19°C and clinograd profiles were observed in the IAG reservoir. Lopes (1999) also associated the presence of OD profiles with thermal stability of the water column observing a definite pattern for the rainy period (greater stability) and an indefinite pattern for the dry period (greater instability). Esteves (1998) stated that OD distribution pattern in aquatic ecosystems is, as a rule, the opposite of that of $CO_2$, as observed in Fig. 6. In the Garças reservoir, Ramírez (1996) concluded that DO values variations detected were closely related to the daily thermal structure variations of both the water and the air temperature, duration of thermocline, organic matter concentration in the water, and wind speed.

Table V: Annual variation of chlorophyll a ($mg.L^{-1}$) of the water column in the IAG reservoir.

| Depth | Aug/ 98 | Sep/ 98 | Oct/ 98 | Nov/ 98 | Dec/ 98 | Jan/ 99 | Feb/ 99 | Mar/ 99 | Apr/ 99 | May/ 99 | Jun/ 99 | Jul/ 99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Surface** | 4.19 | 4.19 | 3.49 | 2.39 | 3.72 | 3.91 | 17.22 | 2.79 | 9.57 | 11.17 | 9.17 | 6.38 |
| **1 m** | 3.84 | 2.79 | 2.09 | 1.99 | 3.72 | 2.58 | 16.75 | 6.73 | 7.98 | 9.57 | 3.19 | 5.98 |
| **2 m** | 4.19 | 2.44 | 4.39 | 1.99 | 3.26 | 1.98 | 20.74 | 6.51 | 7.91 | 9.57 | 4.39 | 4.19 |
| **3 m** | 2.79 | 1.60 | 2.79 | 5.19 | 2.79 | 3.19 | 14.96 | 5.58 | 7.45 | 6.78 | 2.79 | 5.19 |
| **Bottom** | 6.28 | 0.93 | 2.23 | 2.13 | 2.05 | 4.19 | 13.50 | 4.47 | 8.84 | 7.45 | 6.38 | 3.99 |

Electric conductivity pattern generally followed fluctuation tendencies of DO (Tab. VI). Its greatest values were measured at the bottom of reservoir during the greatest thermal stability and oxygen depletion period. According to Esteves (1998), vertical distribution of electric conductivity values is related, in most cases, to the water column thermal stratification pattern. DO and electric conductivity values at the IAG reservoir presented spatial and seasonal variation tendencies that indicated that the thermal stability during the summer and part of the spring lasted long enough to determine chemical stratification (Tab. VII).

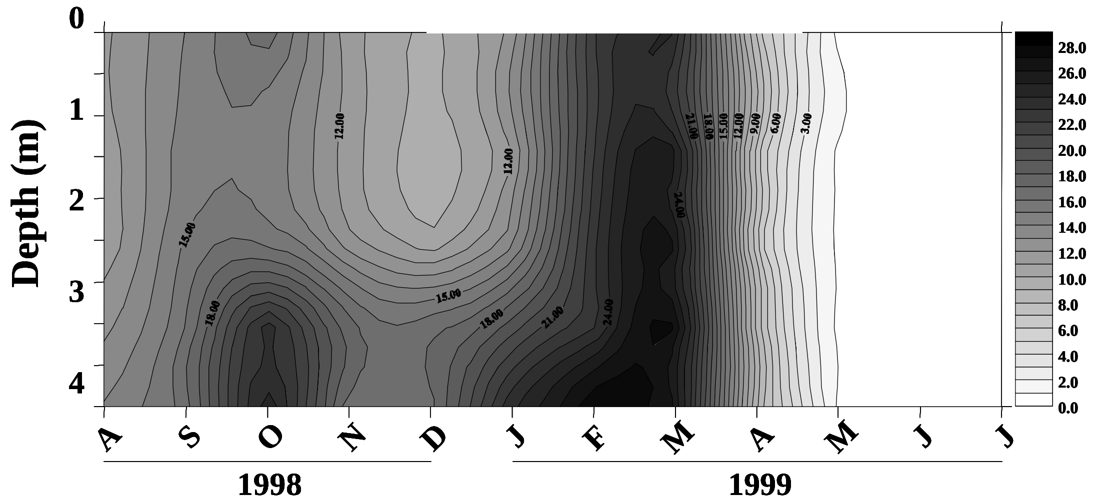


Figure 6: Depth and time isolines diagram of total $CO_2$ (mg.L$^{-1}$) concentration in the IAG reservoir during the period August/1998-July/1999.

Table VI: Annual variation of average electric conductivity (mS.cm$^{-1}$) of the water column in the IAG reservoir.

| Depth | Aug/ 98 | Sep/ 98 | Oct/ 98 | Nov/ 98 | Dec/ 98 | Jan/ 99 | Feb/ 99 | Mar/ 99 | Apr/ 99 | May/ 99 | Jun/ 99 | Jul/ 99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface | 31.5 | 33.5 | 41.8 | 35.8 | 30.1 | 35.5 | 39.6 | 48.6 | 40.4 | 38.0 | 29.8 | 37.4 |
| 1 m | 32.4 | 34.3 | 26.4 | 35.7 | 32.2 | 36.4 | 39.0 | 46.4 | 39.7 | 37.2 | 29.1 | 37.8 |
| 2 m | 32.5 | 34.3 | 38.9 | 35.6 | 33.0 | 38.0 | 40.2 | 46.7 | 39.0 | 37.5 | 28.6 | 37.7 |
| 3m | 31.8 | 35.1 | 41.8 | 36.3 | 30.7 | 41.4 | 40.2 | 47.3 | 39.0 | 36.9 | 29.5 | 38.1 |
| Bottom | 33.5 | 35.8 | 43.2 | 36.1 | 30.4 | 43.4 | 44.5 | 46.9 | 39.1 | 38.0 | 29.5 | 38.0 |

Table VII: Annual variation of dissolved oxygen average concentration (mg$O_2$.L$^{-1}$) of the water column in the IAG reservoir.

| Depth | Aug/ 98 | Sep/ 98 | Oct/ 98 | Nov/ 98 | Dec/ 98 | Jan/ 99 | Feb/ 99 | Mar/ 99 | Apr/ 99 | May/ 99 | Jun/ 99 | Jul/ 99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface | 7.91 | 7.03 | 6.89 | 7.33 | 7.54 | 6.32 | 5.23 | 5.51 | 7.14 | 7.43 | 7.31 | 7.58 |
| 1 m | 7.85 | 7.21 | 6.91 | 7.17 | 7.44 | 6.54 | 5.18 | 5.77 | 7.35 | 7.65 | 7.39 | 7.78 |
| 2 m | 7.47 | 6.77 | 6.16 | 7.28 | 7.67 | 6.15 | 4.41 | 5.93 | 7.12 | 7.53 | 7.54 | 7.52 |
| 3 m | 7.25 | 6.19 | 4.49 | 6.87 | 6.77 | 3.93 | 4.58 | 5.63 | 6.71 | 7.59 | 7.53 | 7.43 |
| Bottom | 6.63 | 4.10 | 1.70 | 5.90 | 6.29 | 3.76 | 4.16 | 5.88 | 6.79 | 7.24 | 7.47 | 7.55 |

## Nitrogen and phosphorus

At the IAG reservoir, $NO_2^{-1}$ concentration values were below 5 mg.L$^{-1}$ throughout the study period. Only in October 1998, values up to 21.08 mg.L$^{-1}$ were recorded at the bottom. Similar results were observed by Lopes (1999) at short time intervals in two climatic periods (dry and rainy).

During the present study, $NO_3^{-1}$ values remained low, confirming oligotrophic conditions (Fig. 7). Only during the period February to April 1999 did $NO_3^{-1}$ values increase significantly to reach their greatest value (1,798 mg.L$^{-1}$) at the bottom of the reservoir in March 1999. The input of allochthonous material into the system contributed to this situation, since the above value was recorded immediately after the wettest month of the rainy period (February 1999).

During the present study, $NH_4^{+1}$ values were low (Fig. 8); greatest values were detected at the bottom of reservoir during greatest water column stability, when oxygen deficits were recorded.

Total nitrogen concentration values were homogeneous in the IAG reservoir throughout the study period. There was a slight TN stratification during the greatest thermal stratification of the water column (January 1999) with the greatest values detected at the bottom. Lopes (1999) observed a similar situation at short time intervals during the two main climatic seasons in the area (rainy and dry).

Throughout the study period, phosphorus values ($PO_4^{-3}$ and total phosphorus) were below 10 mg.L$^{-1}$, and no vertical distribution pattern was observed (Tab. VIII). Lopes (1999) found an identical situation after studying the present IAG reservoir during both dry (20-26 August 1996) and rainy (22-28 January 1997) periods.

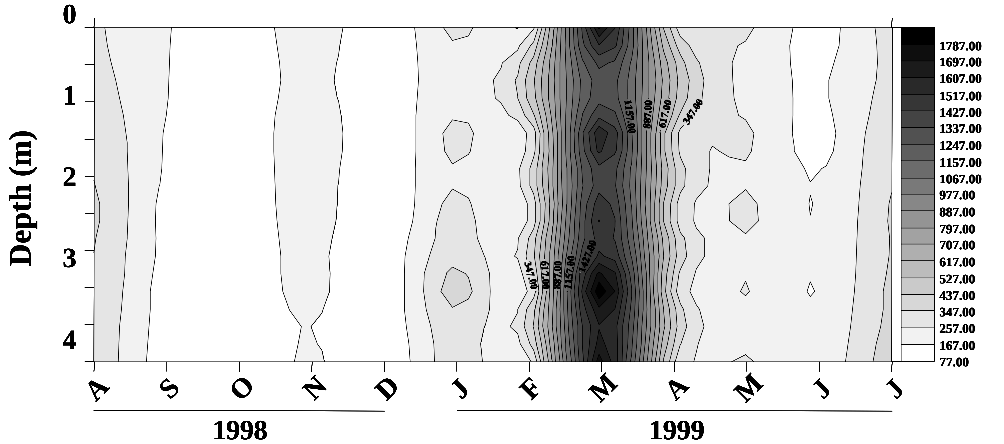


Figure 7: Depth and time isolines diagram of ion nitrate (mgN-$NO_3^{-1}$.L$^{-1}$) concentration in the IAG reservoir during the period August/1998-July/1999.

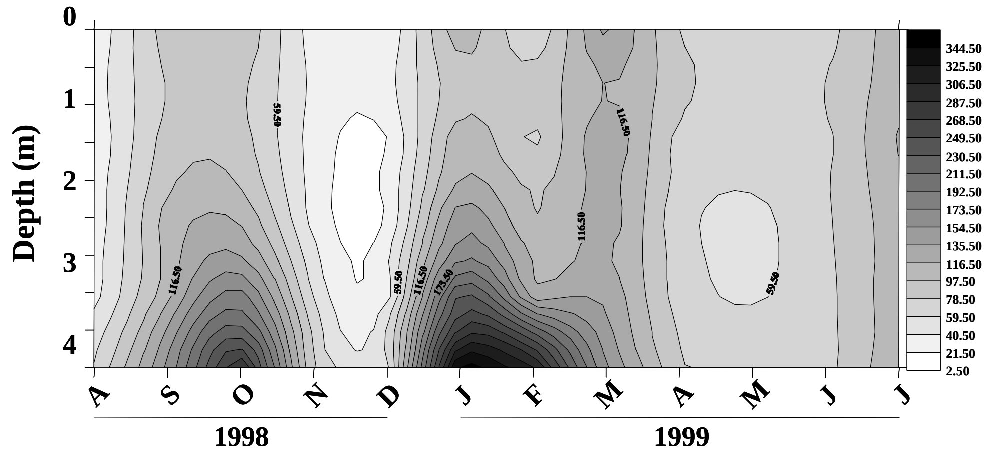


Figure 8: Depth and time isolines diagram of ion ammonium (mgN-$NH_4^{+1}$.L$^{-1}$) concentration in the IAG reservoir during the period August/1998-July/1999.

Table VIII: Annual variation of orthophosphate average concentration (mg.P-$PO_4$.L$^{-1}$) of the water column in the IAG reservoir.

| Depth | Aug/ 98 | Sep/ 98 | Oct/ 98 | Nov/ 98 | Dec/ 98 | Jan/ 99 | Feb/ 99 | Mar/ 99 | Apr/ 99 | May/ 99 | Jun/ 99 | Jul/ 99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Surface** | 2.19 | 2.26 | 0.11 | 0.11 | 1.01 | 1.62 | 0.01 | 0.67 | 0.22 | 0.52 | 0.60 | 0.30 |
| **1 m** | 2.63 | 2.04 | 0.11 | 0.11 | 1.16 | 2.43 | 0.01 | 1.33 | 0.37 | 0.37 | 0.45 | 0.30 |
| **2 m** | 1.75 | 2.26 | 0.11 | 0.11 | 1.16 | 2.87 | 0.01 | 2.79 | 0.82 | 0.45 | 0.45 | 0.30 |
| **3 m** | 1.97 | 2.34 | 0.11 | 0.11 | 1.16 | 2.35 | 0.01 | 1.91 | 0.75 | 0.45 | 0.30 | 0.30 |
| **Bottom** | 1.90 | 2.34 | 0.11 | 0.11 | 1.68 | 2.13 | 0.01 | 1.69 | 2.02 | 0.52 | 0.30 | 0.30 |

According to Esteves (1998), $PO_4^{-3}$ in the water depends on the organism's density and activity, mainly those of the phytoplankton and the aquatic macrophytes. Another relevant factor that affects the metabolism of these organisms in tropical lakes is the high temperature, which increases assimilation of $PO_4^{-3}$ and incorporation into biomass. $PO_4^{-3}$ concentrations are quite variable due to its rapid incorporation by the aquatic communities, and together with TN it is the best indicator of the nutrient content in any ecosystem (Payne, 1986). According to Wetzel (2001), P concentrations must be considered in terms of TP during the algal productivity increase. TP values during the present study were seasonally distributed somewhat uniformly (Fig. 9). Some vertical variation of TP values was observed during January and February 1999 with the greatest values of the nutrient measured at the bottom of reservoir. During the entire remaining period, PT values did not vary among depths, similar to Lopes' (1999) results.

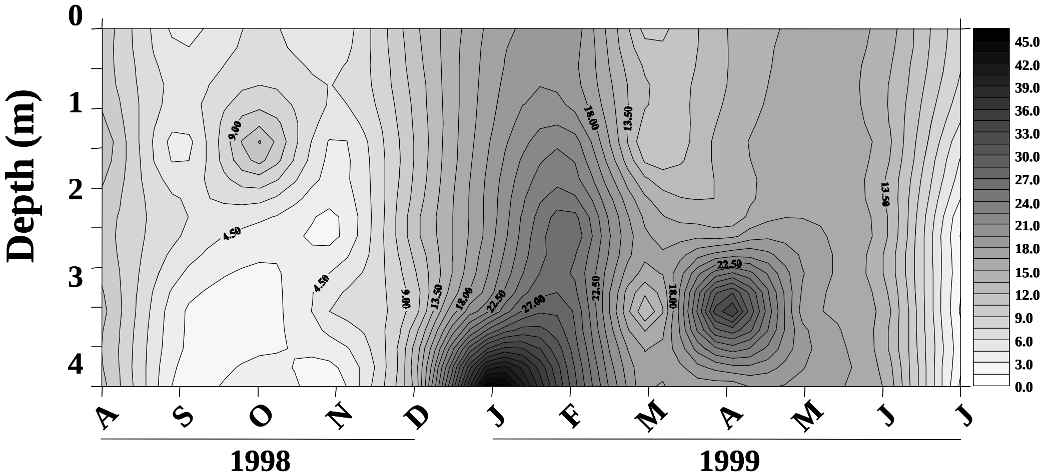


Figure 9: Depth and time isolines diagram of total phosphorus (mg.P-TP.L$^{-1}$) concentration in the IAG reservoir during the period August/1998-July/1999.

## Peridinium gatunense and P. umbonatum in the reservoir

Dinoflagellates are free-living organisms that alternately inhabit the plankton as active vegetative motile cells and the benthos as non-motile resistance cysts (Pollingher, 1988), and may form water blooms in certain aquatic systems. This happens due to some ecophysiological characteristics and to reproductive strategies that enable them to survive and grow under conditions that are unfavorable for the remaining algal species.

During this research, both Peridinium gatunense and P. umbonatum showed similar seasonal distribution patterns. During the period of greater water column thermal stratification (January to March 1999) both species were scantly found (Fig. 11-12). However, during the greater thermal instability (April to July 1999 and August to October 1998) both species were present in almost the entire water column, but greater densities were detected at the surface of the reservoir.

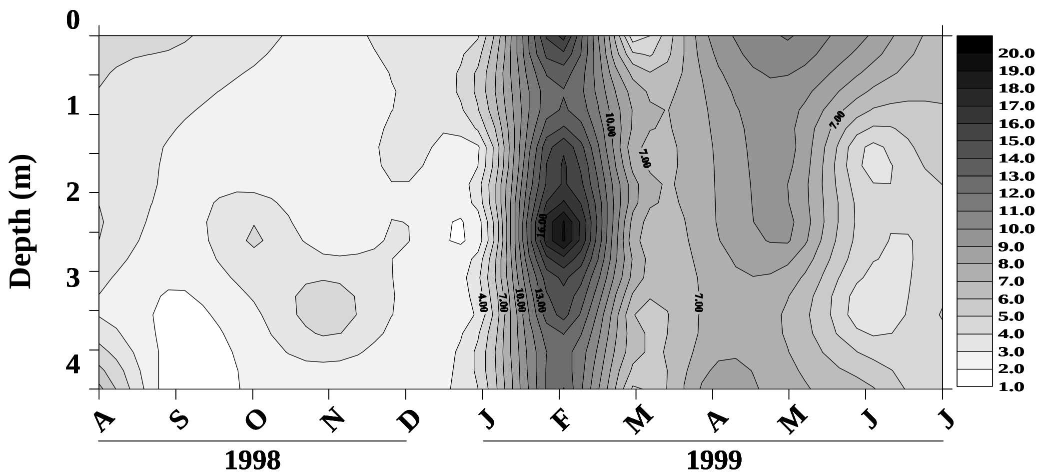


Figure 10: Depth and time isolines diagram of chlorophyll a (mg.Chlor-a.L$^{-1}$) concentration in the IAG reservoir during the period August/1998-July/1999.

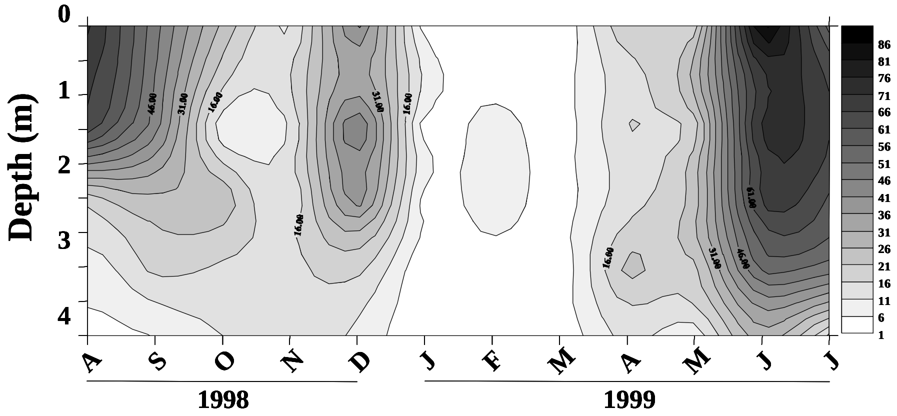


Figure 11: Depth and time isolines diagram of Peridinium gatunense (ind.ml$^{-1}$) density in the IAG reservoir during the period August/1998-July/1999.

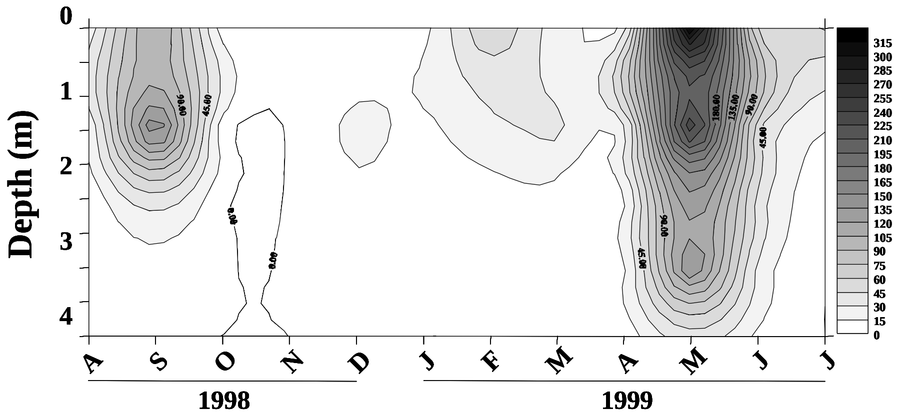


Figure 12: Depth and time isolines diagram of Peridinium umbonatum (ind.ml$^{-1}$) density in the IAG reservoir during the period August/1998-July/1999.

Periods in which the greatest densities of cells of the two Peridinium species were measured corresponded to those of greatest nutrients deficiency (except for silicates) in the reservoir, i.e. from May to July 1999. However, there was an increase of $NO_2^{-1}$, $NH_4^{+1}$, TN, $PO_4^{-3}$, and TP during the previous months. During the same period, a significant increase of chlorophyll a was also registered in the system, indicating an increase in the total density of phytoplankton related to the great nutrient availability in the reservoir (Fig. 10). The increase of competition among species consequently took place, and may have turned the environment adverse to the Peridinium species.

According to Lopes (1999), the rainy period at the IAG reservoir was different from the dry period by its greater species richness, and greater nutrient availability due to the greatest input of allochthonous material. Lopes (1999) emphasized that P. gatunense was one of the most abundant species during the dry season, a fact also presently observed.

According to Pollingher (1988), thecate dinoflagellates are relatively large organisms, with a small surface to volume ratio. Consequently, these organisms cannot effectively compete with small-sized algae, mainly those present in the first stages of seasonal succession (Pollingher, 1981). Thus, with an increase of the interspecific competition both presently studied Peridinium species would very probably be encysted, one of their strategies to overcome adverse conditions of the system.

Dinoflagellate blooms usually start with the suspension of cysts from the sediments (Polingher, 1988). Heaney et al. (1983) pointed out the importance of benthic cysts as inoculli for triggering the Ceratium hirundinella bloom. At the Kinneret Lake in Israel, Peridinium sp. bloom is an annual event (Pollingher, 1988) directly connected with the extension of the mixing period. With water circulation, cysts are suspended and the species is back to the plankton.

The same situation as above was documented for the IAG reservoir. During the thermal instability period (mixing period), the two Peridinium species reached their greatest development in the reservoir, i.e. during the period of lesser nutrient availability. Pollingher (1988) mentioned that dinoflagellate blooms in subtropical lakes are more frequent during the spring and winter. The two presently studied species once more behaved in a very similar way since their greatest densities were detected from August to September 1998 (spring) and from May to July 1999 (winter).

Despite being mostly planktonic organisms, dinoflagellates may also occur physiologically active in the periphyton (Stevenson, 1996). In a N and P enrichment experiment, Ferragut (1999) observed exponential dinoflagellates growth only in the mesocosms filled with water from the IAG reservoir. According to Rosen (1981), dinoflagellates prefer to inhabit oligotrophic environments, although they are found in all kinds of lakes.

A similar situation to that documented by Rosen (1981) was presently observed, as the greatest densities of P. gatunense and P. umbonatum occurred in periods where nutrient availability was lower than that usually registered for the IAG reservoir. Probably, the two Peridinium species waited for the limnological stress moment (nutrient scarcity) to affect the other species in the system to reach their greatest development in the reservoir.

## Conclusions

During the rainy period (October-March), the greatest values for water temperature, conductivity, turbidity, TN, TP, $NH_4^{+1}$, and carbon forms were measured as well the smallest DO values. Conversely, during the dry period (April-September) the above water abiotic variables presented small values, except for DO and orthosilicate. Wind speed was extremely low during the entire study period and could not be considered a disturbance factor for the IAG reservoir, at least during the present study period.

Thermal structure pattern of the reservoir was characterized by a thermal stability period of the water column (stratification) during the summer and part of the spring, and a period of thermal instability (mixing) during the fall/winter. Consequently, the reservoir was classified as warm discontinuous polymitic according to Lewis' 1983 scheme. Despite the observed stratification pattern, well-defined thermoclines were never detected. DO and conductivity vertical and seasonal distribution patterns indicated that the thermal stability during the summer and part of the spring lasted long enough to define a chemical stratification in the system. Greatest concentrations of some nutrients (free $CO_2$, total $CO_2$, $HCO_3$, TP, TN, $NO_3^{-1}$, and $NH_4^{+1}$) in the deepest layers of reservoir were detected simultaneously to the greatest thermal stability periods.

Both species - Peridinium gatunense and P. umbonatum - were present in the reservoir during the period of greater thermal instability (April to July 1999 and August to October 1998). In addition, vertical distribution included the entire water column, despite the fact that the greatest densities of both species occurred at the reservoir surface. Periods in which the greatest densities of both species were detected corresponded to those of lowest nutrient concentrations (except for silicates and DO), i.e. during May to July 1999. However, in the previous months the system showed an increase of some chemical variables ($NO_2^{-1}$, $NH_4^{+1}$, TN, $PO_4^{-3}$, and TP), as well as a significant increase in the chlorophyll a, thus indicating that the increase in the total phytoplankton community density was due to the reservoir nutrient availability.

With the reservoir greater nutrient depletion in the next period, both P. gatunense and P. umbonatum presented relative high densities. This is most probably due to the germination of the cysts and the alga consequent return to the water column. Since this situation was documented immediately after the system's thermal instability period (mixing), this period of lower nutrient availability represents a definite state of oligotrophy. This situation shows that the two Peridinium species took advantage of the limnological stress (depletion of nutrients) affecting the other species in the system and allowed the two Peridinium species to reach their full development. If such is true, the two species could well be used as indicators of oligotrophic water.

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