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Phytoplankton diel variation and vertical distribution in two Amazonian floodplain lakes (Batata Lake and Mussurá Lake, Pará-Brasil) with different mixing regimes

by

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Abstract

Both phytoplankton diel variation and vertical distribution were studied in two clear water Amazonian floodplain lakes (Batata and Mussurá) during the high water hydrological period. Small chlorococales, especially *Chlorella homosphaera* SKUJA in both Batata and Mussurá lakes, *Cryptomonas marsonii* SKUJA, *Cryptomonas pyrenoidifera* GEITLER and *Mougeotia delicata* BECK, in Batata Lake, and *C. marsonii*, *Cryptomonas curvata* EHRENBERG and *Chromulina gyrans* STEIN in Mussurá Lake were the most representative algal populations. Reduced phytoplankton densities were found in Batata Lake, with a stratified vertical distribution during the day and tendency to a more even distribution from the end of night time to sunrise. On the other hand, the highest phytoplankton densities were observed in Mussurá Lake, being concentrated mainly in superficial layers (0-3 meters) during a 24-hour cycle. In both lakes, higher concentrations were found during the middle of the day. Hydrological and hydrographical conditions may be the reason for such different behaviour between Batata Lake and Mussurá Lake.
Keyword: **Phytoplankton, diel variation, floodplain lakes, Amazonian ecosystems**.

Resumo

Variação nictemeral e distribuição vertical da comunidade fitoplanctônica foram estudadas em dois lagos de inundação amazônicos de águas claras (Lagos Batata e Mussurá) no período de águas altas. Pequenas clorococales, especialmente *Chlorella homosphaera* SKUJA, em ambos os lagos, e *Cryptomonas marsonii* SKUJA, *Cryptomonas pyrenoidifera* GEITLER, no lago Batata, e *C. marsonii*, *Cryptomonas curvata* EHRENBERG, *Chromulina gyrans* STEIN no Lago Mussurá, foram as espécies mais representativas.

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Reduzidas densidades populacionais fitoplanctônicas foram constatadas no Lago Batata, as quais apresentaram distribuição vertical estratificada na coluna d'água durante o dia e tendência à homogeneização do final da noite ao amanhecer. O Lago Mussurá, por outro lado, apresentou maiores densidades das populações fitoplanctônicas do que o Lago Batata, as quais concentraram-se principalmente nas camadas mais superficiais (0-3 m) ao longo do ciclo de 24-horas. Durante o ciclo nictemeral, maiores densidades populacionais no meio do dia em ambos os lagos foram observadas. Diferenças hidrográficas e hidrológicas são sugeridas como principais determinantes das diferenças no comportamento nictemeral entre as comunidades fitoplanctônicas dos Lagos Batata e Mussurá.

Introduction

Diel variation and vertical distribution of tropical and subtropical phytoplankton communities have been documented for different ecosystems (TALLING 1957; GANF 1974; GARCÍA DE EMILIANI 1990; TORGAN et al. 1981; HUSZAR et al. 1994; PATTERSON & WILSON 1995; REYNOLDS 1996; MELO & HUSZAR 2000). Most of these papers reported phytoplankton diel variation and vertical distribution as dependent on i) mixing properties; ii) occurrence of self-regulating populations by active movement via flagella or passive movement throughout aerotopes; and iii) occurrence of fast-growing species, which are able to change in abundance during a single diel cycle. Another general pattern is the occurrence of higher phytoplankton population densities during the second part of the day.

Mixing behaviour in Amazonian floodplain lakes is generally related to hydrological and hydrographical properties. Several studies have shown the total mixing of the water column, at least once a day, when the lakes are shallow (<4-5 m), and persistent stratification, at least for a few days, when they are deep (>4-5 m) (TUNDISI et al. 1984; MACINTYRE & MELACK 1988; MELO & HUSZAR 2000). Previous studies on the vertical distribution of phytoplankton in Batata Lake showed a close relationship between mixing patterns and phytoplankton vertical distribution, during a 24-hour cycle in different phases of the hydrological annual cycle (MELO & HUSZAR 2000).

Recent studies on phytoplankton periodicity in floodplain lakes in South America were carried out by GARCÍA DE EMILIANI (1997), IZAGUIRRE et al. (2001), TRAIN & RODRIGUES (1998) for the Paraná basin, and by HUSZAR & REYNOLDS (1997), IBAÑEZ (1998) and HUSZAR (2000) for the Amazonian floodplain lakes. Seasonal fluctuations of water levels are pointed out to be the major factor regulating phytoplankton periodicity. On the other hand, little is known on phytoplankton diel variation dynamics in Amazonian lakes.

Diel variation of temperature, pH, electrical conductivity, dissolved oxygen and chlorophyll *a* were investigated in the Batata Lake and Mussurá Lake by ESTEVES et al. (1994), during the high water level. Different patterns of water column mixing were found. Batata Lake was completely mixed at night and Mussurá Lake developed a well-established temperature gradient, which persisted all through the diel cycle. Now, we aim to complement the above study by comparing the diel variation and vertical distribution of phytoplankton densities in both Batata and Mussurá lakes in the same high water level as studied by ESTEVES et al. (1994).

Study area

Batata Lake (56°00 to 56°14''W; 1°28' to 1°33'S) and Mussurá Lake (56°18' to 56°19'W; 1°26' to 1°29'S) are located, respectively, on the right-bank and on the left-bank of the Trombetas River (Fig. 1), a clear water system according to SIOLI's classification (SIOLI 1984). The total area and depth of both lakes change considerably during a single annual cycle on account of fluctuations in the water level of the Trombetas River, which can vary by about seven meters (PANOSSO et al. 1995). During the low water period, Batata Lake and Mussurá Lake each have a single point of communication with the Trombetas River. During the high water period, Mussurá Lake maintain a single communication with the river, while Batata Lake is linked to the Trombetas over a large flooded area. Both lakes are slightly acidic and poor in nutrients (ESTEVES et al. 1994). Batata Lake, in special, is a warm polimyctic discontinuous lake with oligo-mesotrophic state (HUSZAR et al. 1998).

Materials and methods

Sampling stations (Fig. 1) were established in the main body of each lake. Samples were taken in Batata Lake (22-23 June) and Mussurá Lake (26-27 June), during the period of the highest water levels of 1991 (Fig. 2). Collections were made at 4-h intervals at the surface, at 1.5, 3.0, 4.5, 6.0 and 7.5 meters with a VAN DORN bottle. Temperature was measured with a FAC 400 electronic thermometer (resolution of 0.1 °C), every 10 cm down to 2.5 m and every 50 cm between 2.5 m and the lake bottom. The mixing zone was defined as the depth where the strongest temperature gradient was observed during the sunrise. The euphotic zone (Z_{eu}) was calculated as 3 times the SECCHI disk extinction depth (COLE 1994).

The phytoplankton samples were fixed with LUGOL's iodine solution and the phytoplankton populations were numbered following the sedimentation and inverted-microscope method of UTERMÖHL (1958). The units (cells, colonies and filaments) were numbered in random fields (UHELINGER 1964), at least to 100 specimens of the most frequent species ($p < 0.05$; LUND et al. 1958).

Results

During the study, Batata Lake and Mussurá Lake were 8.0 meters in depth (Z_{max}) with a euphotic zone (Z_{eu}) confined to about 40 % of water column in both lakes (Fig. 3). Mixing regimes were different: mixing zone (Z_{mix}) extended from the surface to the bottom in Batata Lake during the night and was restricted to water upper layers (ca. 3.0 m) during a 24-hour cycle in Mussurá Lake (Fig. 4).

A total of 108 algal taxa were noted during the present study. 67 % of this total were common in both Batata and Mussurá lake. These lakes were dominated by non-motile green algae, specially by *Chlorella homosphaera* SKUJA and flagellates, particularly *Cryptomonas marsonii* SKUJA and *Komma caudata* (GEITLER) HILL. In spite of some similarity, other dominant species provide some differences between the both lakes (Table 1). For instance, *Mougeotia delicata* BECK and *Cryptomonas pirenoidifera* GEITLER were dominant in Batata Lake while *Cryptomonas curvata* EHRENBERG, *Chromulina gyrans* STEIN and *Chrysococcus punctiformis* PASCHER, were more representative at Mussurá Lake.

Very different total phytoplankton densities were recorded in both lakes. Batata Lake showed a very sparse community (67-985 ind ml^{-1}) whereas Mussurá Lake displayed higher population densities (1119-4317 ind ml^{-1}). Phytoplankton communities in the two lakes showed highest values from the end-morning to the afternoon, especially in the upper layers (Fig. 5). During the night, throughout early morning, phytoplankton concentrations were lower and trended to homogeneous vertical distribution in Batata Lake, but it was persistently stratified during a 24-hour cycle in Mussurá Lake. Phytoplankton integrated data by area (Fig. 6) confirmed the highest population densities at end-morning to early afternoon and the tendency to decrease at the beginning of the night. Phytoflagellates was the group with highest population densities during this study in both lakes. Considering that they are expected to show an interesting diel variation profile in water column, analysing only flagellates diel variation, both lakes showed a more even vertical distribution during the night (Fig. 7).

Discussion

Physical properties of water, such as mixing and light availability, are among the most relevant determinant driving forces for vertical distribution of phytoplankton (REYNOLDS 1994). In floodplain lakes, these properties are closely related to seasonal flood pulse variations (JUNK et al. 1989). Stratified patterns of phytoplankton in the water column in Mussurá Lake, during 24-hour period, and stratification during the day with homogeneous vertical distribution at the end of night in Batata Lake suggested a strong link between mixing patterns and phytoplankton distribution (see also ESTEVES et al. 1994).

Another difference between both lakes was the lower phytoplankton densities in Batata Lake, showing a greater fluvial influence, if compared to Mussurá Lake. The parallel localization of Batata Lake in relation to the Trombetas River, allowing, during high water phase, a higher fluvial water input over entire the embankment separating the two systems (lake-river), provided lotic characteristics to Batata Lake. Instead of this, Mussurá Lake maintained lentic conditions even during high water phase, because their waters are dammed by Trombetas River (ESTEVES et al. 1994).

Phytoplankton diel distribution with highest concentrations during the second part of the day has been recorded by several authors (GARCÍA DE EMILIANI 1990; TORGAN et al. 1981). This behaviour was also previously found in Batata Lake during the falling water phase in 1989 (MELO & HUSZAR 2000). Highest phytoplankton densities from the end-morning to early-afternoon, mainly in the euphotic zone in both lakes could be an effect of a higher cell division frequency, as documented for picocyanobacteria by PICK & BÉRUBÉ (1992). Another fact to be considered is a lower pressure of predation by grazers, since these can migrate through deep layers during the day in order to avoid fish predation (LAMPERT & TAYLOR 1985).

Flagellate dominance in plankton is favoured by stability of water column and/or by low optical depth, and by additional factors such as grazing pressure and nutrient status (JONES & ILMAVIRTA 1988). So, the great contribution of flagellates during this study, especially in Mussurá Lake, with higher population densities, if compared to Batata Lake, seems to be related to the slow frequency of mixing during the high water periods and to the reduced euphotic zone.

These results agreed with those presented by ESTEVES et al. (1994), showing the great importance of geographical localization on the floodplain over the mixing regimes of the lakes, mainly the connectivity with the main river. In addition, it underscores the point that the mixing regimes comprise an important regulating factor of the vertical regime of phytoplankton in floodplain lakes during a diel cycle as previously shown for other kind of systems by GANF (1974), REYNOLDS (1994) and DOKULIL (1994), among others.

In short, the two lakes have displayed a similar pattern of diel variation in the phytoplankton community as a whole, that is, highest densities at the end of the morning and beginning of the afternoon. However, they differed as to total phytoplankton densities as well as to their vertical distribution in water column. Greater population densities have been recorded in Mussurá Lake, which has also displayed a stratified phytoplankton vertical profile, with highest values in the most superficial layers, during the entire diel cycle. On the other hand, despite Batata Lake having lower phytoplankton densities accumulated in the superficial layers during daytime, it tended toward a more even phytoplankton distribution in the water column from the end of night time until sunrise.

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Table 1: Average percentage of phytoplankton species that showed 5 % or more of total phytoplankton densities during this study.

Batata Lake	**Mussurá Lake**
12 % *Chlorella homosphaera*	16 % *Chlorella homosphaera*
9 % *Scenedesmus ellipticus*	5 % *Monoraphidium nanum*
10 % *Mougeotia delicata*	9 % *Chromulina gyrans*
6 % *Komma caudata*	7 % *Chrysococcus punctiformis*
18 % *Cryptomonas marsonii*	7 % *Komma caudata*
11 % *Cryptomonas pyrenoidifera*	8 % *Cryptomonas curvata*
	11 % *Cryptomonas marsonii*

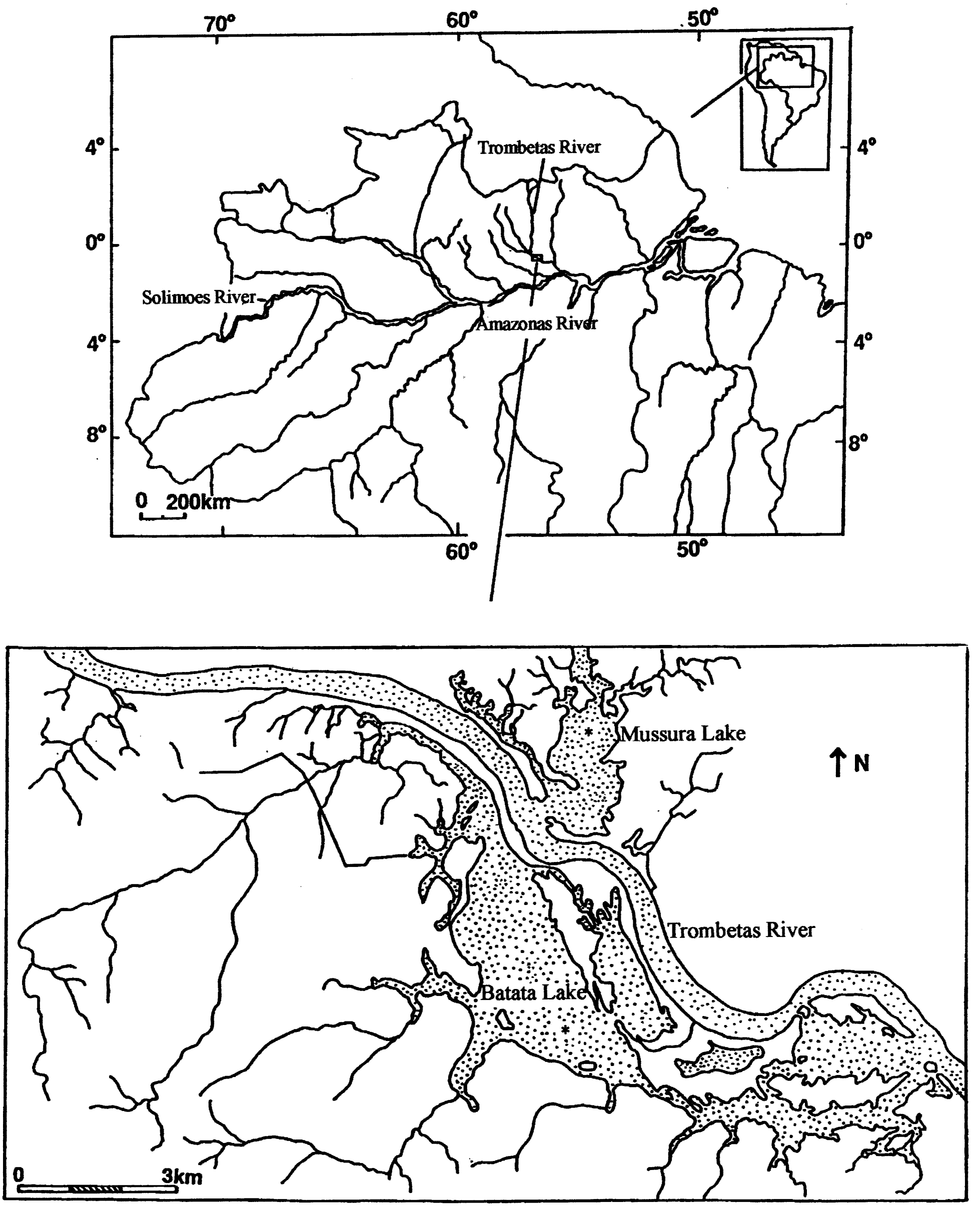

Fig. 1:
Map to show the location of Batata Lake and Mussurá Lake and its relation to the Trombetas River and the sampling stations (*).

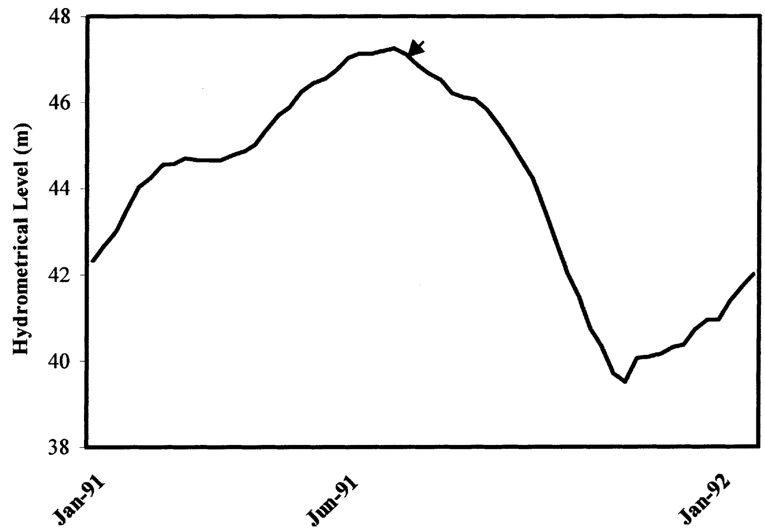

Fig. 2:
Hydrometrical level (m) of the Trombetas River from January to December 1991, showing the sampling date (arrow) for study period.

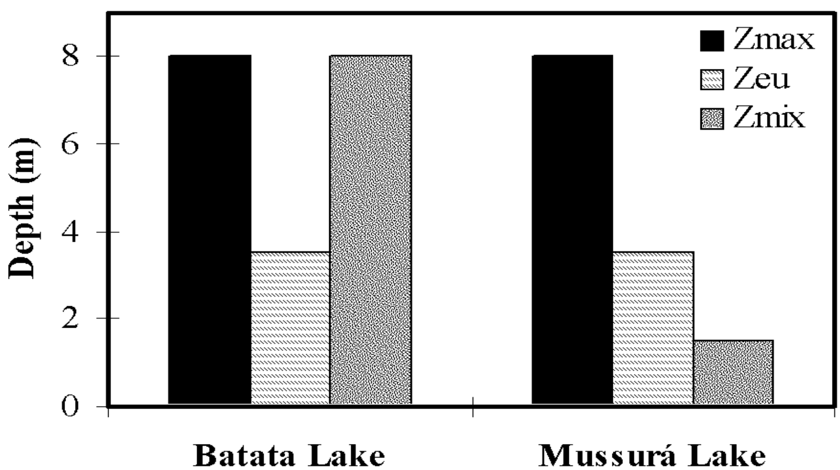

Fig. 3:
Maximum depth (Z_{max}), euphotic zone (Z_{eu}) and mixing zone (Z_{mix}) in Batata Lake and Mussurá Lake recorded for study period.

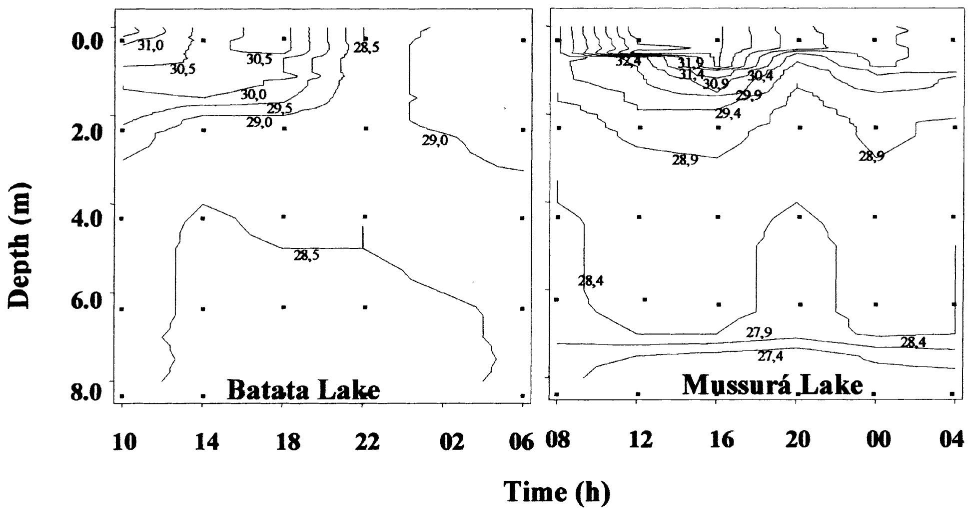

Fig. 4:
Depth-time diagrams of water temperature (°C) recorded for study period in Batata Lake and Mussurá Lake.

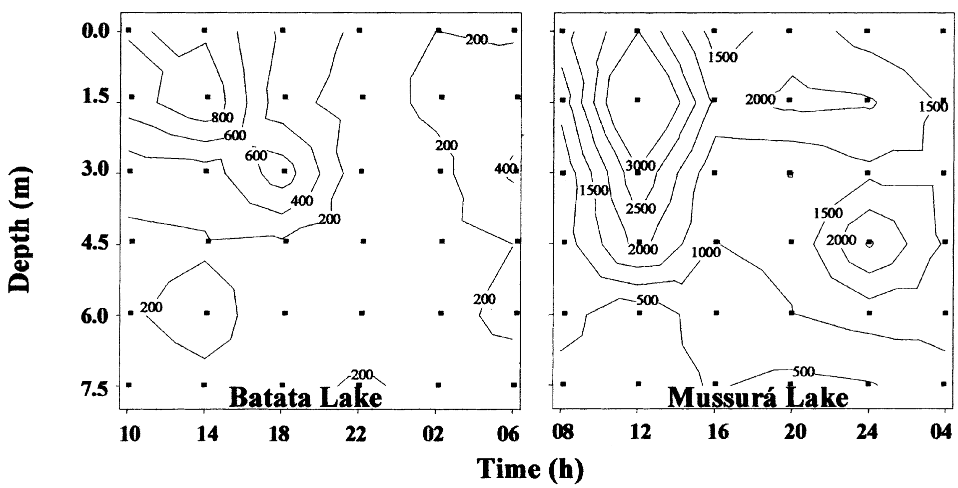

Fig. 5:
Depth-time diagrams of phytoplankton densities (ind. m^{-1}) recorded for study period in Batata Lake and Mussurá Lake.

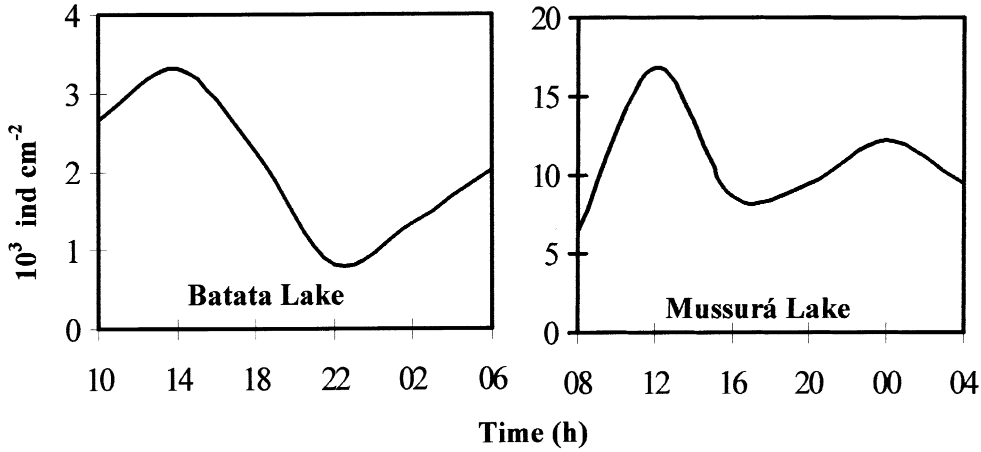

Fig. 6:
Phytoplankton diel variation (integrated data) in the water column (10^3 ind. cm^{-2}) in Batata Lake and Mussurá Lake.

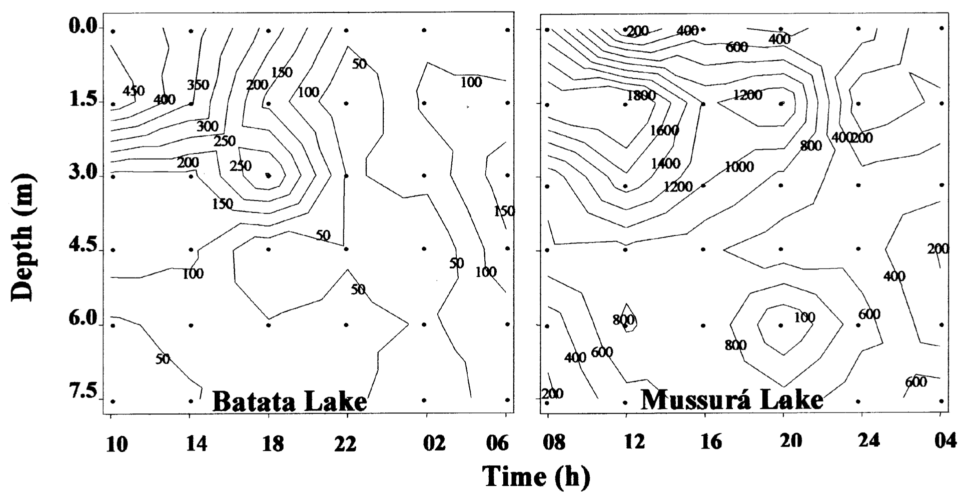

Fig. 7:
Depth-time diagrams of flagellates algae densities (ind. ml^{-1}) recorded for study period in Batata Lake and Mussurá Lake.