DIVERSITY AND STABILITY OF PHYTOPLANKTON IN A SHALLOW LAKE ASSOCIATED TO A FLOODPLAIN SYSTEM IN THE SOUTH OF THE BRAZIL

*Iula Roberta Ávila**
*Carla Matsubara**
*Patrícia Schott**
*Leonardo Maltchik**

Abstract

The flood pulse concept supports the idea that the flood is an important event to explain the organization of aquatic communities. The objective of this study was to analyze the effects of flood pulse on phytoplankton richness, density and composition in a shallow lake associated with a Sinos river's floodplain system over an annual cycle (2000-2001). This study was conducted in a shallow lake associated to a floodplain system in the lower reach of the Sinos river. Fifteen phytoplankton samples were collected during an annual cycle. A total of 33.094 specimens of phytoplankton, distributed in 75 genera, were collected. Most of the genera belonged to the Chlorophyta division (60%), followed by Heterokontophyta (17.34%). The richness and density of phytoplankton varied during the annual cycle ($F= 19.952$; $p<0.001$ and $F=14.378$; $p< 0.001$ respectively). The community demonstrates low resistance and high resilience to floods. These results showed that water temperature and transparence were the studied environmental variables that most explained the variation of phytoplankton composition in the studied period.

***Key words:** Phytoplankton, floodplain system, wetlands, stability, neotropical region.*

* Laboratório de Ecologia e Conservação de Ecossistemas Aquáticos, UNISINOS, 93022-000, São Leopoldo, RS, Brasil. maltchik@cirrus.unisinos.br. www.saude.unisinos.br/laboratorios/lecea

Resumo

O conceito do pulso de inundação sustenta a idéia de que a inundação é um evento importante para explicar a organização das comunidades aquáticas. O objetivo deste trabalho foi analisar o efeito do pulso da inundação na riqueza e densidade de fitoplâncton em uma lagoa associada a uma planície de inundação do rio dos Sinos, RS, ao longo de um ciclo anual (2000-2001). Este estudo foi realizado numa lagoa associada a uma planície de inundação no trecho inferior do Rio dos Sinos. Quinze amostras de fitoplâncton foram coletadas durante o ciclo anual. Foi encontrado um total de 33.094 espécimes distribuídos entre 75 gêneros. A maior parte dos gêneros pertencia à divisão Chlorophyta (60%), seguidos de Heterokontophyta (17.34%). A riqueza e a densidade variaram ao longo do ciclo anual ($F= 19.952$; $p<0.001$ e $F=14.378$; $p< 0.001$ respectivamente). A comunidade demonstrou baixa resistência e alta resiliência frente aos pulsos de inundação. Estes resultados mostraram que temperatura e transparência da água foram as variáveis ambientais que mais explicaram a variação da composição de fitoplâncton no período estudado.

Palavra-chave: *Fitoplâncton, planície de inundação, banhados, estabilidade, regiões neotropicais.*

Introduction

Hydrologic disturbance has received substantial attention from ecologists mainly because it is a major organizer in many aquatic ecosystems (Souza, 1984; Grimm & Fisher, 1989). The concept of disturbance in aquatic ecosystems may be defined in terms of the physical event, e.g. intensity, frequency, duration and predictability (Lake, 1990; Poff, 1992) or in terms of the biotic response (White & Pickett, 1985). In this sense, the definition of perturbation proposed by Bender et al. (1984) and Glasby & Underwood (1996) is useful because describes the combination of cause (disturbance) and effects (response).

Studies related to disturbance ecology in aquatic ecosystems have concentrated efforts on understanding the effects of floods in communities, mainly of high intensity. However, response of communities to disturbance by flood of low intensity is scarce (Lake, 2000). The concept of disturbance in aquatic ecosystems is controversial (Benke et al., 2000). While in streams the floods may be seen as catastrophic events (Resh et al., 1988), in floodplain systems these events can be considered positive for the structure and the functioning of the aquatic communities (Fisher & Grimm, 1988; Junk *et al.*, 1989; Henry et al., 1994; Maltchik & Florin, 2002). However, floods are disturbances in floodplains (Lake, 2000), even if they are predictable (Poff, 1992).

The structure and functioning of large order rivers are strongly influenced by floodplain wetlands. The flood pulse concept supports the idea that the flood pulse is the main driving force constraining the existence, productivity and interactions of the major biota in river floodplain systems, and that the overwhelming bulk of riverine animal biomass derives from production within the floodplains and not from the downstream transport of organic matter produced (Junk et al., 1989).

Benke et al. (2000) regarded that ecological importance of the flooding is far broader than a simple exchange of organic matter between the main channel and the floodplain system. The floods provide a temporary habitat for fishes and other aquatic organisms several times greater than the area of the river channel (Ross & Baker, 1983; Welcomme, 1985). This concept supports that the flood pulse is the most important event in the biota organization of floodplain wetlands, influencing the algae (Garcia, 1997), macrophyte (Henry et al., 1994), macroinvertebrate (Castella et al., 1984; Junk et al.,1989; Van den Brink & Van der Velde, 1991; Bournaud et al., 1992) and fish communities (Vazzoler et al., 1997).

Shallow lakes associated with floodplain systems are areas of reproduction and refuge for many species of river fishes and aquatic plants (Minshall et al., 1985; Amoros & Roux, 1988; Junk et al., 1989). A great number of studies have shown high taxes of phytoplankton production in floodplain lakes from the Amazon region (Schmidt, 1973a,b; Fisher, 1979). In Brazil, most of the functional studies in floodplain have been developed in the Amazon region, where the annual thermal amplitude is low (Piedade, 1985; Piedade et al., 1994; Nessimian et al., 1998) and in the Parana basin, where the flooding is regulated by intense dammings (Thomaz et al., 1991; Agostinho et al., 2001). The floodplains are important wetland systems in southern Brazil, however, the studies on the effects of flood pulses on aquatic communities in shallow lakes associated with floodplain systems are still scarce (Stenert et al., 2003; Santos et al., 2003). The objective of this study was to analyze the effects of flood pulse on phytoplankton richness, density and composition in a shallow lake associated with a Sinos river's floodplain system over an annual cycle (2000 – 2001).

Study area

This study was carried out in the Sinos river basin (~ 4000 km^2), located in southern Brazil (Rio Grande do Sul). The Sinos river is a seventh order permanent river (Strahler, 1952) of the Jacuí/Guaiba catchment. It is 190 km long, from its origin at 900 m above sea level, to its confluence with the Jacuí River at 10 m above sea level. The annual precipitation in the Sinos river basin ranges from 1200 to 2000 mm/y and is distributed along the year, without the existence of a dry period (Cf - Koeppen's climate classification). The increase in the discharge due to high precipitation originates a series of floods resulting in the temporary inundation of its floodplains.

During the flooding event, the water penetrates into the floodplain system along the different river reaches. The surface water velocity in the floodplain systems during flooding event is very low. The discharge of Sinos River in front of the studied floodplain varies between 2.9 and 71 m^3/s (COMITESINOS 2000). Following Tiner's classification (Tiner, 1999), the flood events of the Sinos River basin are frequent (more than fifty floods along 100 years). The studied floodplain has approximately 30 ha, and presents several permanent and intermittent shallow lakes.

This study was conducted in a shallow lake associated to a floodplain system in the lower reach of the Sinos river (29º16'14"S, 49º50'53.2"W). The studied lake is shallow (average depth ≅ 30 cm), permanent and is fed by water from precipitation, runoff and flooding from the Sinos river in different combinations. The studied lake is irregular, has an area of approximately 1.0 ha and is approximately 300 m distant from the Sinos river. The substrate is composed basically of silt and sand and the riparian vegetation of grass.

Methods

The following definition to flood is here accepted: "a flood is a body of water which rise to overflow land which is not normally submerged" (Ward, 1978). The flood duration is the amount of time that the floodplain system is in standing water and it was classified as long (between seven and thirty) and short (between two and seven days) (Tiner, 1999).

A total of 15 phytoplankton collections were carried out during an annual cycle (between July 2000 and June 2001). In each collection, six phytoplankton samples were taken at random along a longitudinal transect (30 meters). Phytoplankton samples were collected using bottles of 200 mL (10 cm water depth). The samples were fixed *in situ* with 2 ml of formaldehyde 10%, kept in the dark, and taken to the laboratory.

The qualitative and semi-quantitative analyses were processed between slide and coverslip in the optic binocular microscope Marotec. The material was identified to genera level following the literature of Van Den Hoek et al.(1998), Joly (1963), Bicudo & Bicudo (1970), Prescott (1978) and Cox (1996), and the specific works of Bicudo & Ungaretti (1986), Martins-da-Silva (1997) and Taniguchi et al. (1998). Of the sedimented material, three slides per sample were observed, quantifying the number of individuals of the different genera. The work was carried out with a superior amostral efficiency of 80% (Pappas & Stoermer, 1996). A phytoplankton individual was considered as any cell, cenoby, colony and filament. In the quantification, only the organisms that presented chloroplasts were considered, with the exception of *Peranema*, which is a representative of pigment-lacking Euglenophyta.

Water temperature and conductivity at the moment of the sampling were measured using digital equipment (Water test – model 90). The water depth was measured with a PVC tube graduated in centimeters and the water transparency was obtained with the aid of the Secchi disc.

The number of genera represented the richness, and the number of organisms represented the density of phytoplankton in each sampled area. Ordination was performed using PC-ORD 4.2 (McCune & Mefford, 1997). A multivariate analytical approach (canonical correspondence analysis – CCA) was used to examine the relationships between the measured environmental variables and the phytoplankton composition and abundance. The environmental variables used in CCA ordination were: water depth, transparence, temperature and conductivity. The biological variables were all genera of phytoplankton. Since the ordination axis is constrained to be a linear combination of ecological variables, CCA is a technique for direct gradient analysis (ter Braak, 1986). A Monte-Carlo simulation (1,000 interactions) test was performed to test the significance of the eigenvalue corresponding to the first CCA canonical axis (ter Braak & Smilauer, 1998).

To examine resistance and resilience to floods, displacements of phytoplankton richness and density before and after floods were compared. The resistance of phytoplankton community was estimated for each sequence by comparing the average richness and density before and after each flood using a *t* test. If these differences were not significant ($P > 0.1$), the phytoplankton community was considered resistant to floods (Grimm & Fisher, 1989; Maltchik & Medeiros, 2001; Maltchik, 2000). A Pearson correlation test was used to analyze the relationships between phytoplankton, richness and density with the flood duration. The variation of the richness and density of phytoplankton over the annual cycle was quantified through a Variance Analysis (ANOVA, One-Way).

Results

During the studied period, four floods of different duration occurred. Three floods (07/12/00, 02/10/01 and 04/28/01) were characterized as of long duration (≅ 15 a 19 days) and one flood (09/25/00), was characterized as of a very long duration (>38 days) (Table 1). All four floods were enough to inundate all the floodplain system, reaching approximately 200 cm depth on the edge of the studied lake (Table 1).

A total of 33.094 specimens of phytoplankton, distributed in 75 genera, were collected. Most of the genera belonged to the Chlorophyta (60%), followed by Heterokontophyta (17.34%). Of the Chlorophyta, the Desmidiaceae was the most represented (12 genera). Only three genera were considered dominant (*Trachelomonas*, *Euglena* and *Nitzschia*) (Figure 1).

The phytoplankton composition varied during the annual cycle (Figure 2). The physical data of the studied lake are shown in Table 1. The CCA ordination method represents the environmental variables, sampling units and genera relating among themselves on the two main ordination axis. Based on genera-environment data, the eigenvalues of axis 1 and 2 were 0.197 and 0.136, respectively. The cumulative percentage of variance that explained the first two axis accounted for 18.7% (11.1–7.6%, respectively, for the first and second axis) of genera data (Table 2). The water temperature and transparence were the studied environmental variables that most explained the variation of phytoplankton composition in the studied period. (Figure 3).

The phytoplankton richness varied during the annual cycle (F= 19.952; p<0.001) (Figure 4). The lowest richness (2 genera) coincided with the flood of the beginning of the annual cycle (07/12/00). The floods influenced in different ways the phytoplankton richness. While that flood of 10 February (19 days) increased the richness, the flood of 28 April (19 days) diminished it (Table 3). The change of phytoplankton richness was not correlated with the duration of the floods (Pearson, p= -0.57) (Table 3), however, the highest loss coincided with the longest duration flood (-76.31%, 38 days). The resilience of the phytoplankton richness varied between 15 and 48 days (Table 3) and it was not correlated with the duration of the floods (Pearson, p= -0,522).

The phytoplankton density varied during the annual cycle (F=14.378; p< 0.001) (Figure 5) and the lowest density was registered in the beginning of the annual cycle, coinciding with the first flood event (07/12/00). Just one flood lowed the density of phytoplankton (Table 3), and it was not related with the longest duration flood. The resilience of the phytoplankton density varied between 9 and 48 days during the annual cycle (Table 3) and it was not correlated with the duration of the floods (Pearson, p=0.522).

Discussion

Junk et al. (1989) demonstrated the importance of floods in the structure and functioning of floodplain systems. Most of the studies related to the phytoplankton community have been carried in the main channel of river systems (Descy, 1987; Admiraal *et al*., 1990). Unfortunately, less attention has been given to the phytoplankton community in lakes associated to floodplain systems (Roijackers, 1985, 1986; Roijackers & Kessels, 1986). In the studied lake, the lowest phytoplankton richness and density coincided with the first flood event. These low values may be consequence of dilution due to water input from precipitation and flood events. In desert streams, the specific conductance of surface water declines rapidly during flooding event (Fisher & Minckley, 1978).

In desert rivers, the resistance of algal assemblage was negative related to the flood magnitude (Grimm & Fisher, 1989). In this survey, no relation was observed (positive or negative) between duration of flood and the resistance of phytoplankton. The lack of any relationships may have been influenced by the low number of analyzed events during the annual cycle and by the little difference of duration between them.

In the studied lake, the strong algae oscillations (richness and density) occurred independently of floods. The low resistance of algae community in the studied shallow lake may be related to the extreme variation of the surface water during the studied period. Margalef (1978) regarded that the organization of plankton can be destroyed at any moment by the action of water turbulence. The present results showed that other parameters, biotic and/or abiotic, are also important on the phytoplankton dynamic. Our study showed that the temperature and transparency were environment variables that most explained the variation in the phytoplankton composition and abundance.

Another important property of community stability in aquatic ecosystems is the flood frequency. Maltchik & Pedro (2000) regarded that the flood frequency retarded the onset of aquatic macrophyte reestablishment in intermittent streams. In the studied shallow lake, the floods were distributed along the annual cycle, impeding a more accurate interpretation of the influence of this attribute in the community's stability. The communities in intermittent aquatic ecosystems are considered very resilient (Fisher *et al.*, 1982; Grimm & Fisher, 1989; Maltchik *et al.*, 1999; Maltchik & Pedro, 2000). The resilience of the phytoplankton community was high in the studied lake, varying between 9 and 48 days.

Medeiros & Maltchik (2000, 2001a,b) regarded that the floods impeded the establishment of dominant species in a tropical semiarid streams. In the studied lake, the floods did not change the phytoplankton composition. *Trachelomonas*, *Euglena* and *Nitszchia* were dominant in the majority of the collections made during the anual cycle, indicating that the Euglenophyceae and Bacillariophyceae were the taxa most resistant. These results supported the arguments of the Grimm and Fisher (1989) that algal assemblage dominated by diatomaceas were more resistant to flood events.

The present results showed that the phytoplankton community can vary along the annual cycle in shallow lakes in southern Brazil and that the water transparence and temperature can have as an important role as flood pulse in this community dynamics.

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Table 1. Physical characteristics of the studied shallow lake over an annual cycle (jul/2000-jun/2001).

Date	12/7	27/7	10/8	24/8	8/9	25/9	24/10	2/11	9/11	22/11	6/12	8/1	10/2	1/3	19/4	28/4	10/5	28/6
Duration of flood (days)	15	-	-	-	-	38	-	-	-	-	-	-	19	-	-	19	-	-
Days after floods (days)	0	15	29	43	58	-	28	37	44	57	71	104	-	19	68	-	12	61
Water temperature (°C)	12.8	9.9	15.5	18.6	18.6	-	24	25.6	27.4	36.4	32.2	31.4	-	30	25	-	16.4	15.7
Water depth (cm)	200	23.6	21.7	19.4	17.8	200	19.5	13.3	10.5	10.3	16.3	13.8	200	20.8	20	200	180	43
Conductivity (mS/cm)	33	49	48	48	36	-	35	56	54	44	13	24	-	39	40	-	40	14
Transparence (cm)	10	40	40	40	40	-	5	25	15	15	3	20	-	50	15	-	40	20

Table 2. Canonical Correspondence Analysis: summary of results for the first two ordination axes.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.197	0.136	0.180
Cumulative % variance of species data	11.1	18.7	23.2
Species environmental correlations (Pearson)*	0.949	0.698	0.913
Monte Carlo test (p)	0.0160	0.8920	0.0400
Temperature**	0.956	0.000	-0.292
Water Depth**	-0.241	-0.149	0.608
Conductivity**	-0.358	-0.040	-0.842
Transparence**	-0.161	-0.973	-0.139

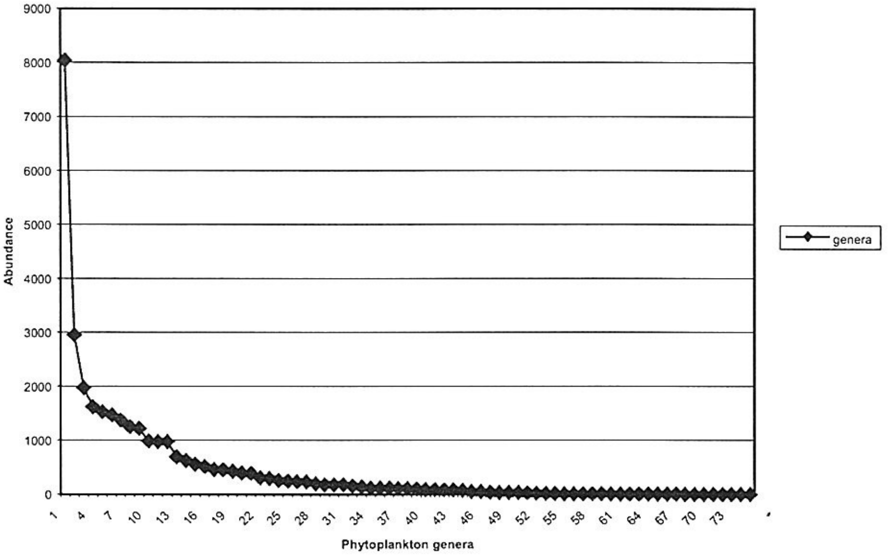
Total variance ("inertia") in the species data: 0.8349

* Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables. Set to 0.000 if axis is not canonical.

** Correlations with the main axis.

Table 3. Resistance (as percent change in richness and density) and resilience (as rate of change and recovery time to predisturbance conditions) of phytoplankton community in the shallow lake during the annual cycle (2000-2001).

Date	Flood duration (days)	Richness change (%)	Density change (%)	Resilience/Richness (days)	Resilience/Density (days)
12/jul	15	----	----	15 (p=0.0013)	15 (p= 0.0083)
25/sep	38	-76.31 (p=0.0056)	-4.87 (p=0.4624)	9 (p=1.42E-05)	9 (p= 0.1410)
10/feb	19	30.72 (p=0.0004)	-6.65 (p=0.3667)	----	48 (p= 0.0019)
28/apr	19	-66.41 (p=0.0005)	-93.32 (p=0.0003)	48 (p=0.0110)	48 (p= 0.0037)



1 Trachelomonas
2 Euglena
3 Nitzschia
4 Scenedesmus
5 Anabaena
6 Ankistrodesmus
7 Synedra
8 Peridinium
9 Gloeocystis
10 Cosmarium
11 Frustulia
12 Dictyosphaerium
13 Phacus
14 Oocystis
15 Cryptomonas
16 Pinnularia
17 Lepocinclis
18 Closterium
19 Staurastrum
20 Alaucoseira
21 Eudorina
22 Euastrum
23 Strombomonas
24 Oscillatoria
25 Navicula
26 Monoraphidium
27 Pediastrum
28 Mougeotia
29 Cymbella
30 Sphaerocystis
31 Arthrodesmus
32 Oedogonium
33 Eunotia
34 Gonatozygon
35 Sorastrum
36 Spirogyra
37 Pandorina
38 Sphaerozosma
39 Desmidium
40 Coelastrum
41 Kirchneriella
42 Sirogonium
43 Spondylosium
44 Chlamydomonas
45 Glenodinium
46 Quadrigula
47 Dynobrium
48 Micrasterias
49 Xanthidium
50 Surirella
51 Planktosphaeria
52 Stauroneis
53 Asterionella
54 Pleurotaenium
55 Amphora
56 Crucigenia
57 Zynema
58 Aphanocapsa
59 Micractinium
60 Selenastrum
61 Elakatothrix
62 Peranema
63 Tetraspora
64 Rhizosolenia
65 Syrogonium
66 Hyalotheca
67 Tetrastrum
68 Chroococcus
69 Microcystis
70 Tetraedron
71 Zygnema
72 Chodatella
73 Raphidonema
74 Ulothrix
75 Zygogonium

Figure 1. Phytoplankton abundance per genera in the studied shallow lake in an annual cycle (2000-2001).

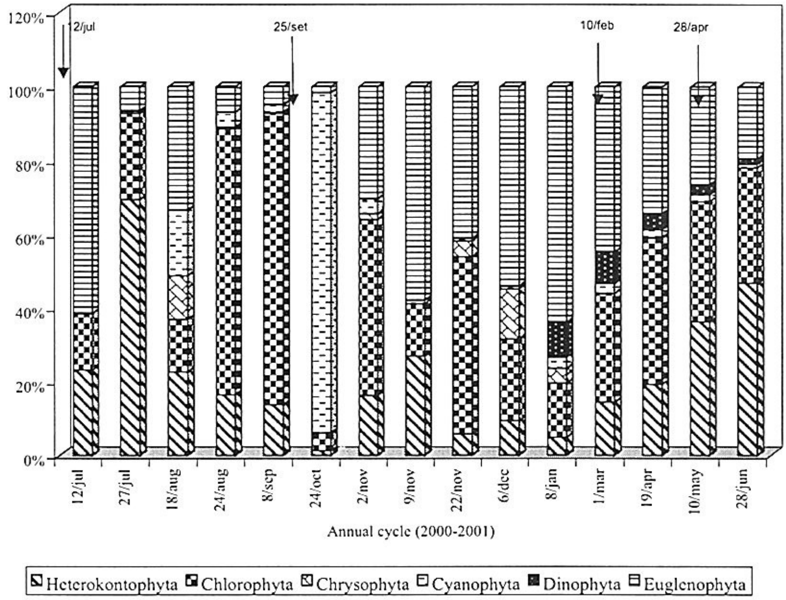


Figure 2. Composition of phytoplankton community in the studied shallow lake along an annual cycle (2000-2001). Arrow = flood occurrence

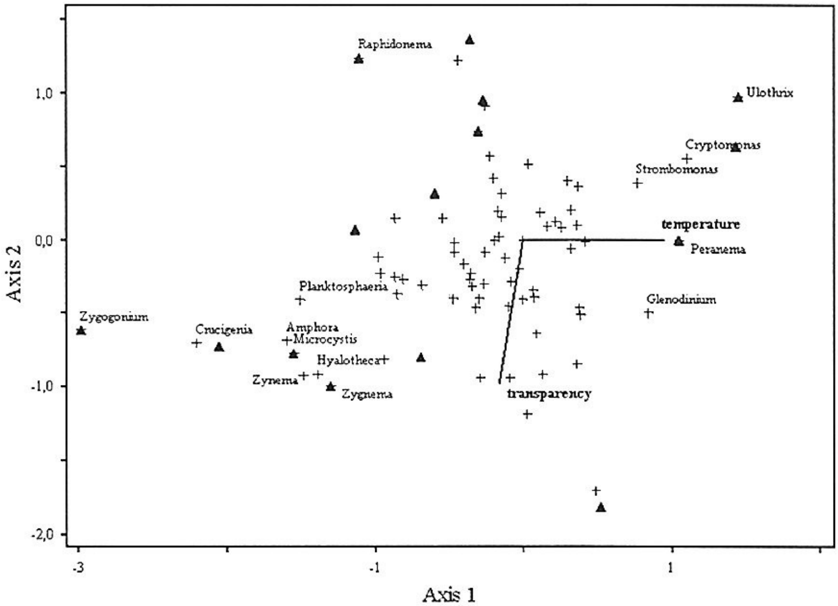


Figure 3. Diagram of Canonical correspondence analysis (CCA) representing the studied environmental variables, collections (▲) and phytoplankton composition (+) in relation to their scores on the two main axes of ordination. Only the genera and environmental variables having high discriminating power for distinguishing among collections are shown.

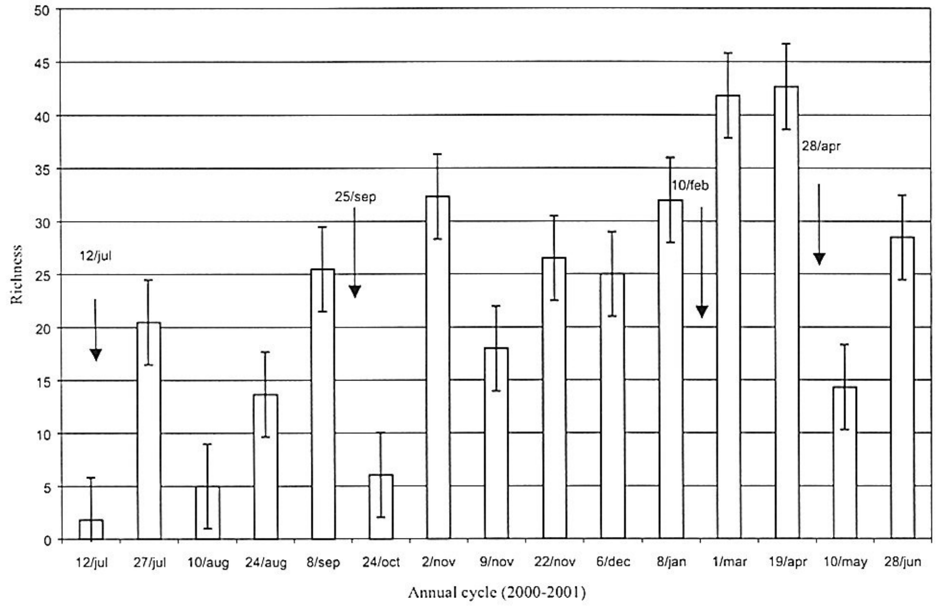


Figure 4. Richness of phytoplankton community in the studied shallow lake along an annual cycle (2000-2001). Arrow = flood occurrence

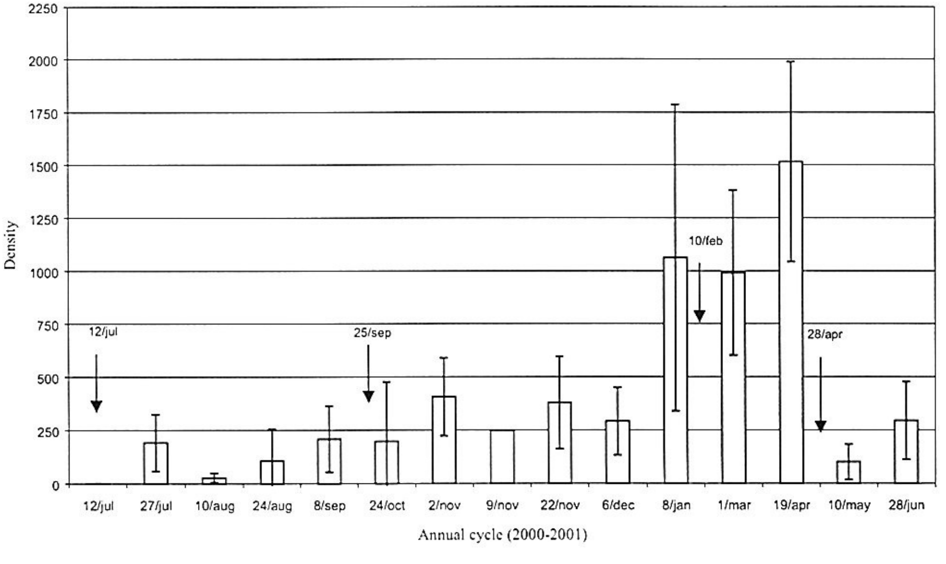


Figure 5. Density of phytoplankton community in the studied shallow lake along an annual cycle (2000-2001). Arrow = flood occurrence