The Vertical Distribution of Phytoplankton Assemblages of Lake James, North Carolina in Relation to Mixing Depth and Nitrate and Phosphate Concentrations[1]

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ABSTRACT. Phytoplankton, nitrate (NO_3^-) (mg L^{-1}), and phosphate (PO_4^{3-}) (mg L^{-1}) concentrations were studied in Lake James, NC, during 1997 and 1998. Depths of 2.0, 10, and 30 m were chosen for sampling to determine the vertical distribution of phytoplankton. At 2.0 and 10 m, the species diversity of Heterokontophyta was mainly represented by *Mallomonas caudata* (Ivanov); Chlorophyta by *Chlamydomonas polypyrenoideum* (Prescott); Bacillariophyta by *Melosira granulata* (Ehrenberg) Ralfs and *Asterionella formosa* (Hassall), respectively. At 30 m, the species diversity of Cryptophyta was mainly represented by *Rhodomans minuta* (Skuja); Bacillariophyta by *Cyclotella glomerata* (Bachmann), *Synedra ulna* (Nitzsch) Ehrenberg, and *Tabellaria fenestrata* (Lyngbye) Kützing; and Cyanophyta by *Chroococcus limeticus* (Lemmermann) and *Oscillatoria limnetica* (Lemmermann). The purpose of this study was to determine the vertical distribution of phytoplankton in relation to nitrate and phosphate concentrations and the mixing depth in the water column of Lake James, North Carolina, USA.

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INTRODUCTION

Aquatic ecosystems are subjected to high spatial and temporal variability. As a result, the relative abundance and species composition of planktonic organisms frequently varies in time and space. Light climate, mixing events, nutrient concentrations, and their availability relative to other elements can be important for the vertical distribution patterns of phytoplankton in the water column (Richerson and others 1970; Calijuri and others 2002; Teubner 2003).

Nitrogen and phosphorus are critically important and can be limiting to phytoplankton growth. In addition, specific rate of phosphorus and nitrogen loading may determine the number of species coexisting and their abundance in the water column (Levine and Schindler 1999).

In general, studies on phytoplankton community dynamics in deep lakes consider mixing events to be the main factor controlling the vertical distribution of species in the water column (Gaedeke and Sommer 1986; Reynolds 1987; Reynolds and others 2000; Smayda 2002).

Under stable conditions, phytoplankton growth may be limited by the scarcity of nutrients in the upper layers, but when mixing occurs, it entrains nutrient-rich water from the deeper layers and, this in turn, can result in higher primary production (Harris 1983; MacIntyre and others 1999). Hence, the extent of the mixed layer in the water column can have a strong influence on phytoplankton species composition and their abundance during thermal stratification (Viner 1985; Goldman and Jassby 1990).

Seasonal dynamics of phytoplankton have been studied intensively (Mohamed 2002; Anneville and others 2002; Tietjen and Wetzel 2003; Chang and others 2003; Murrell and Lores 2004), but studies addressing the vertical distribution of phytoplankton in relation to both nutrient concentrations and mixing depth are scarce. The goal of this study was to understand how nitrate and phosphate concentrations and mixing depth affected the vertical distribution of phytoplankton in the water column of Lake James, NC.

STUDY AREA

Lake James is a freshwater reservoir located at the latitude of 35° 44' and longitude of 81° 55' in North Carolina. The lake is formed by the impoundment of three-headwater streams of the Catawba River. These streams are the Catawba River, Paddy's Creek, and Linville River—each being separately dammed to form one interconnected lake (Fig. 1). The lake has a total area of 26 km^2, an average depth of 20 m and a maximum depth of 35 m.

MATERIALS AND METHODS

Sampling was carried out monthly at the deepest part of the lake between March 1997 and December 1998. Samples were drawn from three depths (2.0, 10, and 30 m) using a Kemmerer water sampler. Phytoplankton samples were analyzed according to Utermöhl sedimentation method (Utermöhl 1958). Enumeration and identification of phytoplankton were performed using a compound microscope equipped with water immersion lenses and a phase contrast attachment from Lugol-fixed samples.

Concentrations of nitrate (NO_3^-) and phosphate (PO_4^{3-}) were determined spectrophotometrically according to standard methods (APHA 1995). Temperature was measured using a Hydrolab® multiprobe at 1.0-m depth intervals. The mixing depth was estimated from temperature profiles. The euphotic depth was calculated as 1.7 times Secchi disk depth as reported by Scheffer (1998).

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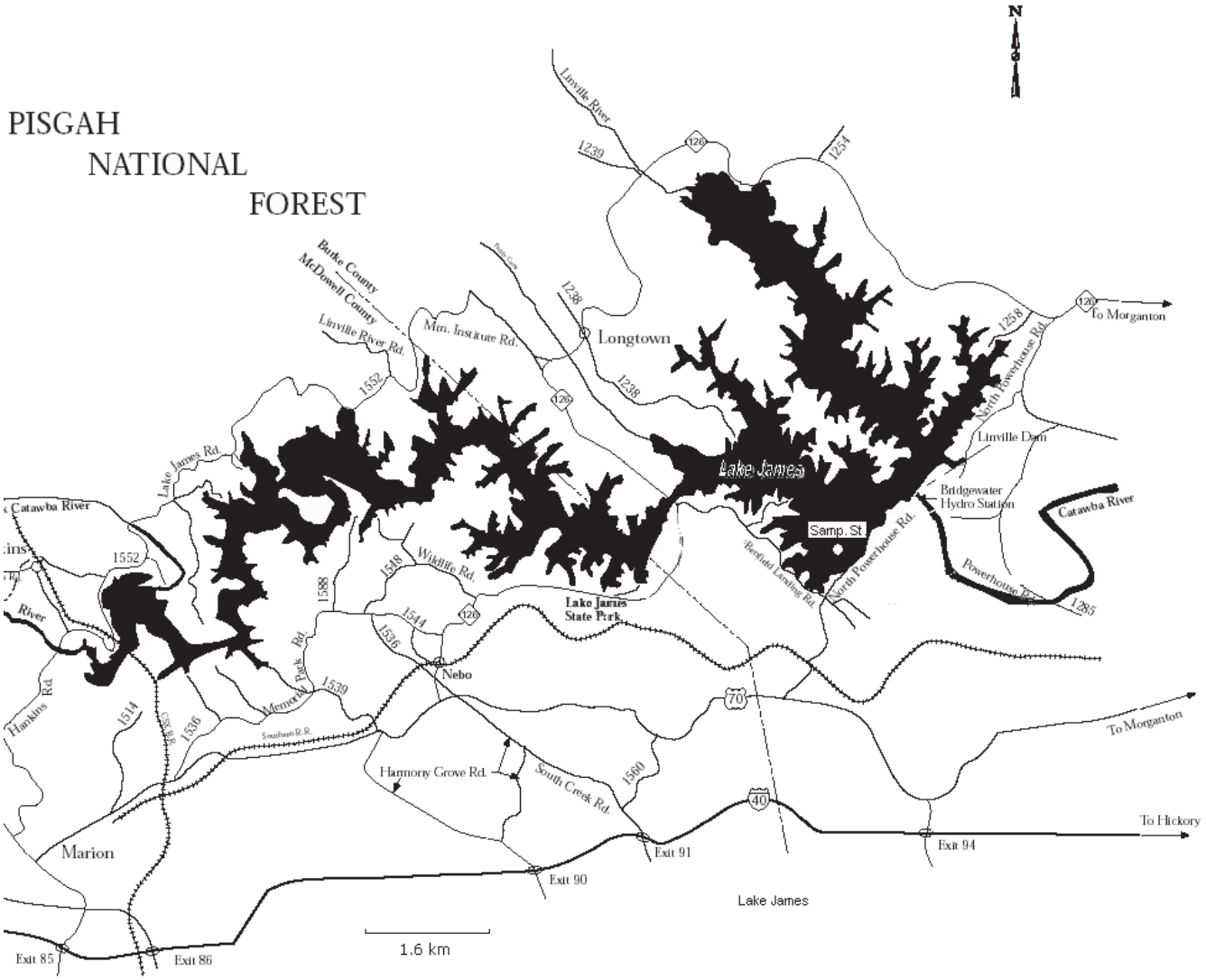

FIGURE 1. Site map of phytoplankton sampling stations (1997-1998) in Lake James, NC.

Correlation coefficients between the number of species, NO_3^-, PO_4^{3-}, and mixing depth were calculated. The statistical differences in species number and the overall abundance between the sampled depths and seasons were determined using an ANOVA test. The statistical analyses were performed using SAS statistical software (SAS System for Windows v6.12). The statements of significance are at $p \leq 0.05$, unless otherwise stated.

RESULTS

A total of 75 phytoplankton species were identified during the study. Bacillariophyta was represented by 28, Chlorophyta by 25, Cyanophyta by 11, Heterokontophyta by 7, Cryptophyta by 3, Pyrrophyta by 2, and Euglenophyta by 1 species, respectively (Table 1).

The following species were the most abundant throughout the study period. *Mallomonas caudata* (44 cells mL^{-1}) and *Dinobryon divergens* (Imhof) (15 cells mL^{-1}) in the genera of Heterokontophyta; *Rhodomans minuta* (16 cells mL^{-1}) in Cryptophyta; *Cyclotella glomerata* (18 cells mL^{-1}), *Melosira garanulata* (15 cells mL^{-1}), *Navicula petersenii* (Hustedt) (12 cells mL^{-1}),

TABLE 1

Species of phytoplankton collected from Lake James during 1997 and 1998.

CYANOPHYTA
Cyanophyceae
Choroococcales
Chroococcaceae
Chroococcus limeticus (Lemm.)
Chroococcus turgidus (Kuetz)
Chroococcus dispersus (Lemm.)
Merismopediaceae
Merismopedia elagans (Smith)
Microcystaceae
Microcystis firma (Schmidle)
Nostocales

TABLE 1 (*Cont.*)

Species of phytoplankton collected from Lake James during 1997 and 1998.

- Nostocaceae
  - *Nostoc pruniforme* (Ag.)
  - *Anabaena spiroides* (Lemm.)
- Oscillatoriales
- Oscillatoriaceae
  - *Lyngbya limnetica* (Lemm.)
  - *Lyngbya birgei* (Smith)
  - *Oscillatoria agardhi* (Gomont)
  - *Oscillatoria limnetica* (Lemm.)

HETEROKONTOPHYTA

- Chrysophyceae
- Synurales
- Synuraceae
  - *Mallomonas caudata* (Ivanov)
  - *Mallomonas acaroides* (Perty)
  - *Synura uvella* (Ehr.)
- Chromulinales
- Dinobryaceae
  - *Dinobryon divergens* (Imhoff)
  - *Dinobryon sociale var. americanum* (Bachm)
  - *Uroglenopsis americana* (Calkins)
  - *Uroglenopsis volvox* (Ehr.)

PYRRHOPHYTA

- Pyrrhophyceae
- Gonyaulacales
- Ceratiaceae
  - *Ceratium hirundinella* (Müller)
- Peridiniales
- Peridiniaceae
  - *Peridinium aciculiferum* (Lemm.)

BACILLARIOPHYTA

- Bacillariophyceae
- Centrales
- Attheyaceae
  - *Attheya zachariasi* (Brun)
- Stephanodiscaceae
  - *Cyclotella bodanica* (Eulen)

TABLE 1 (*Cont.*)

Species of phytoplankton collected from Lake James during 1997 and 1998.

  - *Cyclotella ocellata* (Pant)
  - *Cyclotella glomerata* (Bachm.)
  - *Cyclotella comata* (Kuetz)
  - *C. kutzingiana* (Thwaites)
  - *Stephanodiscus asterae* (Kuetz)
- Melosiraceae
  - *Melosira granulata* (Ehrenberg)
  - *M. ambigua* (Grunow) O.Müll.
  - *M. granulata var. angustissima* O.Müll.
- Rhizosoleniaceae
  - *Rhizosolenia eriensis* (Smith)
  - *Rhizosolenia gracilis* (Smith)
- Pennales
- Achnanthaceae
  - *Achnanthes lanceolata* (Breb)
- Bacillariaceae
  - *Nitzschia palea* (Kuetz)
  - *Nitzschia vermicularis* (Kuetz)
- Eunotiaceae
  - *Eunotia sp.*
- Fragilariaceae
  - *Asterionella formosa* (Hassall)
  - *Asterionella gracillima* (Hantz.)
  - *Fragilaria acuta* (Ehr.)
  - *Fragilaria pinnata* (Ehr.)
  - *Fragilaria crotonensis* (Kitton)
  - *Synedra ulna* (Nitzsch)
  - *Synedra acus* (Grun)
- Naviculaceae
  - *Navicula petersenii* (Hustedt)
  - *Navicula monoculata* (Hustedt)
- Tabellariaceae
  - *Tabellaria fenestrata* (Lyngb.)
  - *Tabellaria flocculosa* (Roth)

CRYPTOPHYTA

- Cryptophyceae
- Cryptomonadales
- Cryptomonadaceae
  - *Cryptomonas erosa* (Ehr.)

TABLE 1 (*Cont.*)

Species of phytoplankton collected from Lake James during 1997 and 1998.

- Pyrenomonadales
- Chroomonadaceae
  - *Chroomonas acuta* (Utermothl)
- Pyrenomonadaceae
  - *Rhodomonas minuta* (Skuja)

EUGLENOPHYTA
- Euglenophyceae
- Euglenales
- Euglenaceae
  - *Euglena elastica* (Presch)

CHLOROPHYTA
- Chlorophyceae
- Chlorococcales
- Chlorellaceae
  - *Ankistrodesmus fractus* (Brunn)
  - *A. convolutus* (Corda)
- Scenedesmaceae
  - *Actinastrum gracillimum* (Smith)
  - *Crucigenia rectengularis* (Braun)
  - *Coelastrum microporum* (Naegeli).
  - *Coelastrum limneticum* (Lemm.)
  - *Scenedesmus alternans* (Reinsc)
  - *S. bicaudatus* (Chodat)
- Micractiniaceae
  - *Golenkinia radiata* (Chodat)

TABLE 1 (*Cont.*)

Species of phytoplankton collected from Lake James during 1997 and 1998.

- Oocystaceae
  - *Errerella bornhemiensis* (Conrad)
  - *Franceia droescheri* (Lemm.)
  - *Oocystis lacustris* (Chodat)
  - *Oocystis borgei* (Snow)
- Hydrodictyaceae
  - *Pediastrum boryanum* (Turp)
- Zygnematales
- Desmidiaceae
  - *Euastrum pectinatum* (West)
  - *Cosmarium margaritatum* (Lund)
  - *Staurastrum rotula* (Norsdt.)
  - *Staurastrum cornatum* (Arch.)
- Zygnemataceae
  - *Mougeotia elagantula* (Witrr)
- Volvocales
- Volvocaceae
  - *Eudorina elagans* (Ehr.)
- Phacotaceae
  - *Phacotus lenticularis* (Stein.)
- Chlamydomonadaceae
  - *Chlamydomonas polypyrenoideum* (Prescott)
  - *C. sphagnicolo* (Fritsch)
  - *Carteria cordiformis* (Diesing)
  - *Gloeocystis gigas* (Kuetz)

Tabellaria fenestrata (7 cells mL^{-1}), *Synedra ulna* (4 cells mL^{-1}), and *Asterionella formosa* (Hassall) (6 cells mL^{-1}) in Bacillariophyta; *Chlamydomonas polypyrenoideum* (20 cells mL^{-1}) and *Coelastrum limneticum* (Lemmermann) (18 cells mL^{-1}) in Chlorophyta; *Oscillatoria limnetica* (Lemmermann) (11 cells mL^{-1}) and *Chroococcus limeticus* (Lemmermann) (20 cells mL^{-1}) in Cyanophyta, respectively.

At 2.0 and 10 m, the species diversity of Heterokontophyta was mainly represented by *Mallomonas caudate*, Chlorophyta by *Chlamydomonas polypyrenoideum*, Bacillariophyta by *Melosira granulata* and *Asterionella formosa*, respectively. At 30 m, the species diversity of Cryptophyta was mainly represented by *Rhodomans minuta*; Bacillariophyta by *Cyclotella glomerata, Synedra ulna,* and *Tabellaria fenestrata*; and Cyanophyta by *Chroococcus limeticus* and *Oscillatoria limnetica*, respectively.

At 2.0 and 10 m, the total number of species was high (about 65 species mL^{-1}) in spring and fall, and lower (about 55 species mL^{-1}) in summer. At 30 m, the total species number did not change significantly, oscillating about 7 species mL^{-1} throughout the year (Fig. 2a,b). The lake was thoroughly mixed between October and March. The euphotic depth exceeded the mixing depth only during summer and was not significantly different between seasons ($p > 0.05$) (Fig. 2c,d).

At 2.0 m, the species number of Heterokontophyta and Cyanophyta oscillated between 5 and 10 species mL^{-1}. Bacillariophyta species number was about 30 species mL^{-1} and Chlorophyta species number was about 25 species mL^{-1}, respectively (Fig. 3a,b). At the

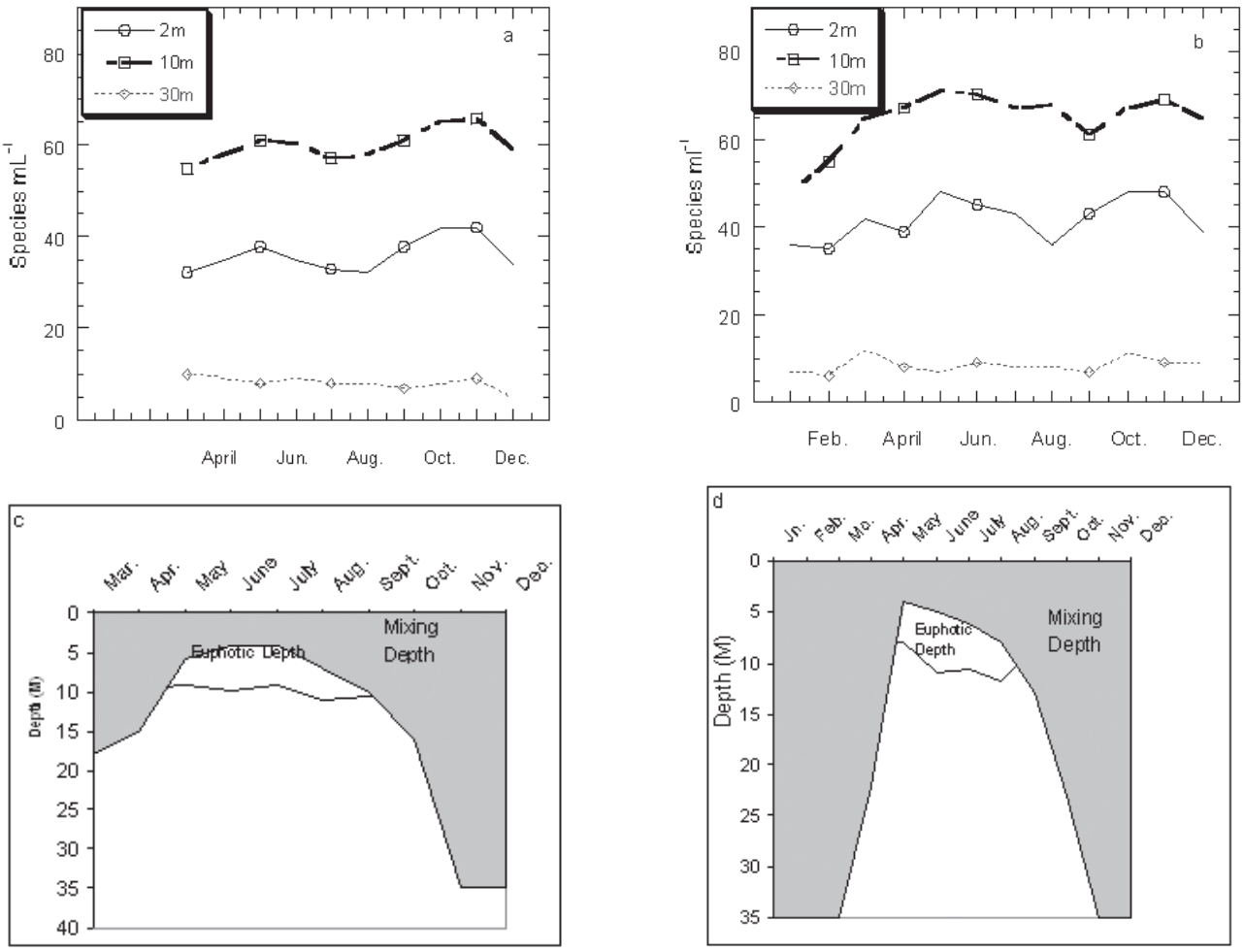

FIGURE 2. Total number of species, mixing, and euphotic depths. a) The total number of species in 1997; b) total number of species in 1998; c) mixing and euphotic depths in 1997; d) mixing and euphotic depths in 1998.

same depth, the individual number of Heterokontophyta was about 100 cells mL^{-1} in spring and about 30 cells mL^{-1} for the rest of the year. Chlorophyta density was about 50 cells mL^{-1} in spring and fall and about 100 cells mL^{-1} in summer. Bacillariophyta density was about 80 cells mL^{-1} in spring and fall and about 20 cells mL^{-1} in summer. Cyanophyta density was about 20 cells mL^{-1} in spring and fall and about 145 cells mL^{-1} in summer (Fig. 3c,d).

At 10 m, Bacillariophyta species number was about 35 species mL^{-1} in spring and fall and about 20 species mL^{-1} in summer. Chlorophyta species number was about 35 species mL^{-1} in summer and about 20 species mL^{-1} in spring and fall. Heterokontophyta species number oscillated between 2 and 5 species mL^{-1} throughout the year. Cyanophyta species number was about 5 species mL^{-1} in fall and spring and about 10 species mL^{-1} in summer (Fig. 4a,b). At the same depth, Heterokontophyta density was about 120 cells mL^{-1} in spring and about 20 cells mL^{-1} for the rest of the year. Chlorophyta density fluctuated between 20 and 75 cells mL^{-1} during the study. Bacillariophyta density was about 120 cells mL^{-1} in spring and fall and about 40 cells mL^{-1} in summer. Cyanophyta density oscillated about 30 cells mL^{-1} throughout the year (Fig. 4c,d).

At 30 m, the number of species all phytoplankton groups oscillated between 2 and 5 species mL^{-1} throughout the year, except diatoms which had a diversity of about 12 species mL^{-1} in summer and fall of 1997 and a Cyanophyta peak of 15 species mL^{-1} in summer of 1998 (Fig. 5a,b). At the same depth, Heterokontophyta, Chlorophyta, and Cyanophyta density oscillated between 3 and 12 cells mL^{-1} throughout the study period. Bacillariophyta density was about 8 cells mL^{-1} in spring and about 15 cells mL^{-1} for the rest of the year (Fig. 5c,d).

At 2.0 and 10 m, NO_3^- concentration was about 0.2 mg L^{-1} in spring and about 0.01 mg L^{-1} for the rest of the year, except a peak of about 0.2 mg L^{-1} in summer 1997. At 30 m, nitrate concentration was between 0.2 and 0.3 mg L^{-1} in spring and summer and about 0.01 mg L^{-1} in fall throughout the study period (Fig. 6a,b). At 2.0 and 10 m, PO_4^{3-} concentrations were about 0.05 mg L^{-1} in spring and fall and about 0.01 mg L^{-1} in summer during the study. At 30 m, phosphate concentration was about 0.01 mg L^{-1} throughout the study, except a peak of 0.03 mg L^{-1} in winter 1998 (Fig. 6c,d).

The correlation coefficient between the total number of species and mixing depth was only significant at 10 m

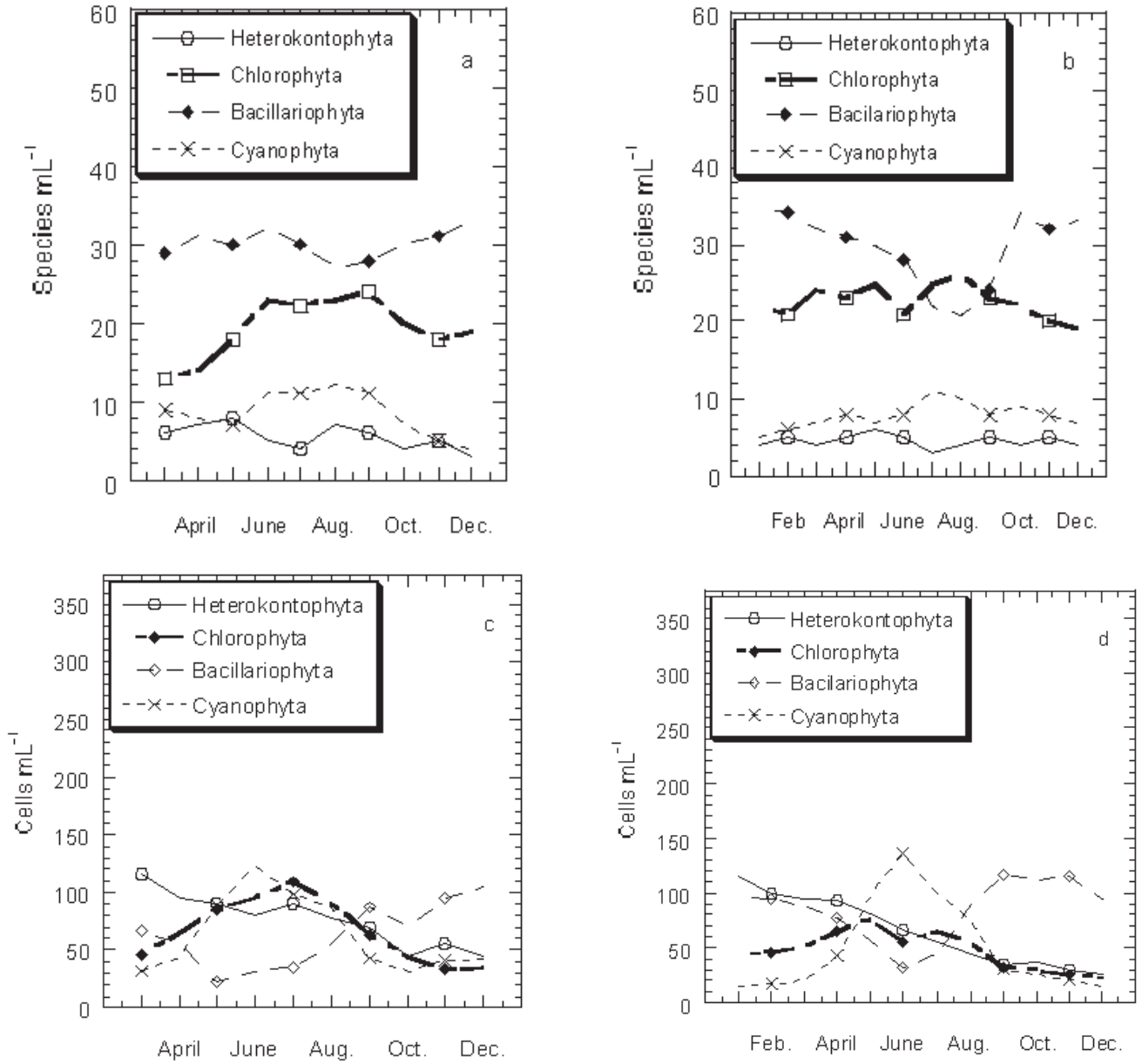

FIGURE 3. The number of species and cells of phytoplankton groups at 2.0 m. a) Species number of each group in 1997; b) species number of each group in 1998; c) cell number of each group in 1997; d) cell number of each group in 1998.

(r = 0.31, p <0.05), but not at 2.0 and 30 m (r = 0.11, p >0.05) throughout the study. Except the species number of Chlorophyta (0.38, p <0.05), none of the other groups showed significant correlations (r <0.3, p >0.05) with euphotic depth. Mixing depth was significantly correlated only with the species number of Bacillariophyta (r = 0.37, p <0.05). The total number of species, NO_3^-, and PO_4^{3-} were significantly correlated at 2.0 m (r = 0.32, p <0.05) and 10 m (r = 0.34, p <0.05), but not at 30 m (r = 0.19, p >0.05). The total number of individuals, NO_3^-, and PO_4^{3-} were also significantly correlated at 2.0 m (r = 0.37, p <0.05) and 10 m (r = 0.41, p <0.05), but not at 30 m (r = 0.21, p >0.05). The differences in total species number were significant between 2.0 and 30 m (F = 415, p <0.001) as well as between 10 and 30 m (F = 357, p <0.001), but not between 2.0 and 10 m depths (F = 0.35, p >0.05).

DISCUSSION

Bacillariophyta (28 species) and Chlorophyta (25 species) were the most dominant phytoplankton groups in Lake James. Cyanophyta (11 species), Heterokontophyta (8 species), Cryptophyta (3), Pyrrhophyta (2 species), and Euglenophyta (1 species) also contributed to phytoplankton, but they were represented by fewer species.

The total number of species was greater at 10 m than that at 2.0 and 30 m. This was probably a result of the light climate. At 2.0 m, phytoplankton were exposed to excessive amount of light particularly in summer, which is damaging to most algae (Oliver and others 2003). At 30 m, they were most likely limited by the lack of sufficient light. At 10 m, on the other hand, light intensity was probably optimum for most phytoplankton. Malinsky-Rushansky and others (2002) state that relatively

dim environments enhance phytoplankton productivity by providing habitat in which they can avoid phtoinhibition, while still having sufficient light for photosynthesis.

At 2.0 and 10 m, the total number of phytoplankton species was higher in spring and fall, but lower in summer. This pattern was probably a result of seasonal mixing, which occurs in spring and fall and moves nutrients to upper depths from deep layers (Reynolds 1984).

At 2.0 and 10 m, *Rhodomans minuta* (Cryptophyta) was abundant in early spring. This species likely took advantage of the mild temperature and high nutrient concentrations at that time of the year. Anneville and others (2002) reported that *Rhodomonas minuta*, which is a fast-growing small species (r-strategist), was selected by strong turbulence and high nutrient concentrations in Lake Geneva. Lake James is well mixed and the nutrient concentrations are higher in spring and fall.

At 2.0 and 10 m, Bacillariophyta was dominant in spring and summer and Chlorophyta was dominant in summer. At 30 m, Bacillariophyta was dominant in the spring and Cyanophyta was dominant in summer. The seasonal development of phytoplankton, in particular the dominance of diatoms during the spring and fall, followed the common pattern in lakes of the temperate zone (Teubner and Dokulil 2002). Munawar and Munawar (1986) reported that Bacillariophyta species were usually common during cooler or windier conditions in the North American Great Lakes. Salmaso (2000) states that increase of diatoms at the end of the winter coincides with high nutrient availability and water column turbulence. In the early spring and late fall, Lake James is well mixed and the nutrient concentrations are greater than during summer.

Cyclotella ocellata (Pant), *Synedra ulna* and *Tabellaria fenestrata*, *Chroococcus limeticus* and *Oscillatoria limnetica* were mostly present at 30 m; their densities did not change seasonally. This pattern was probably produced by the stable physical and chemical conditions at this depth compared with more dynamic conditions at 2.0 and 10 m (Melo and Huszar 2000).

Chlorophyta species number and density were higher in summer and lower in fall and spring at 2.0 and 10 m.

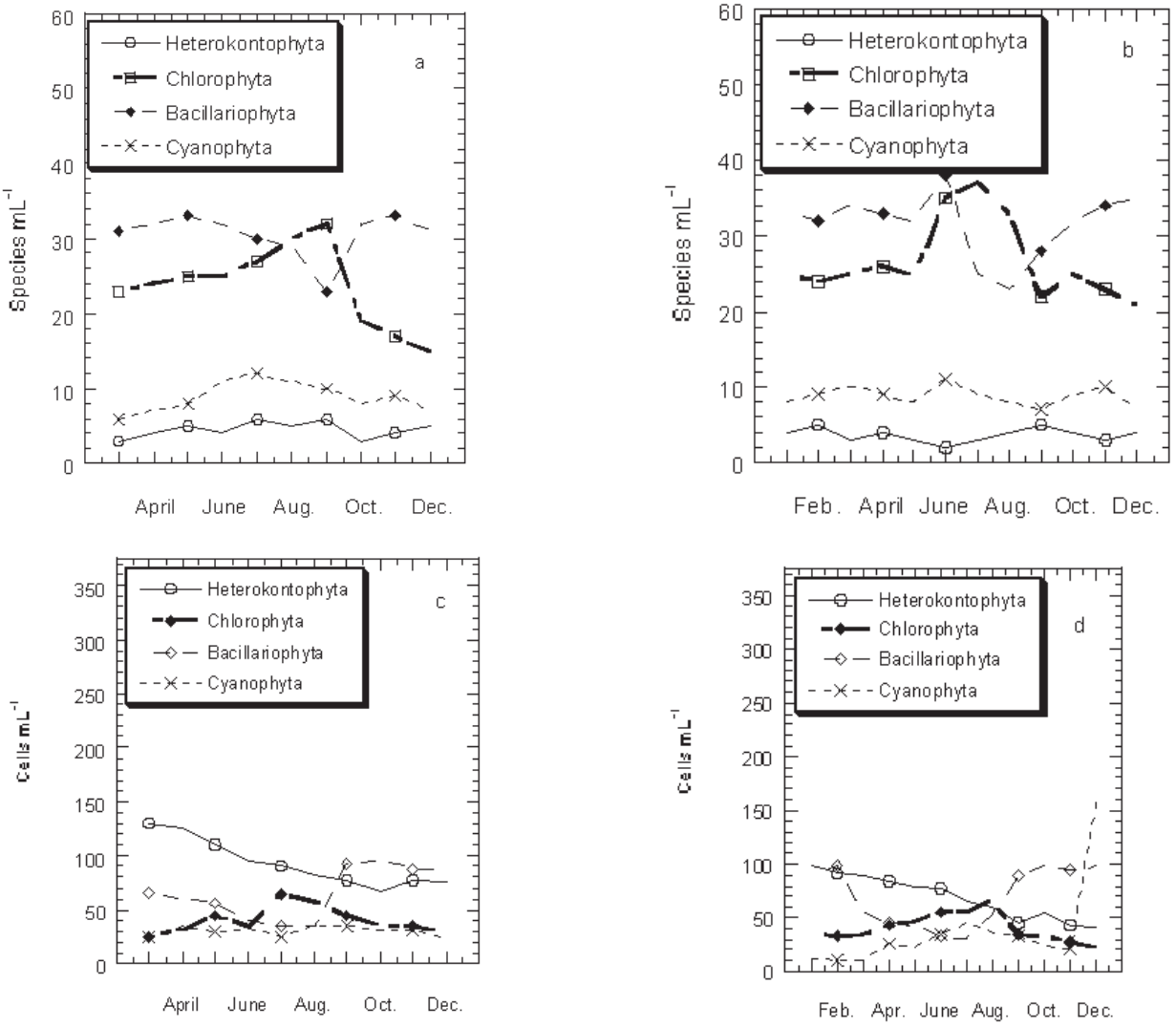

FIGURE 4. The number of species and cells of phytoplankton groups at 10 m. a) Species number of each group in 1997; b) species number of each group in 1998; c) cell number of each group in 1997; d) cell number of each group in 1998.

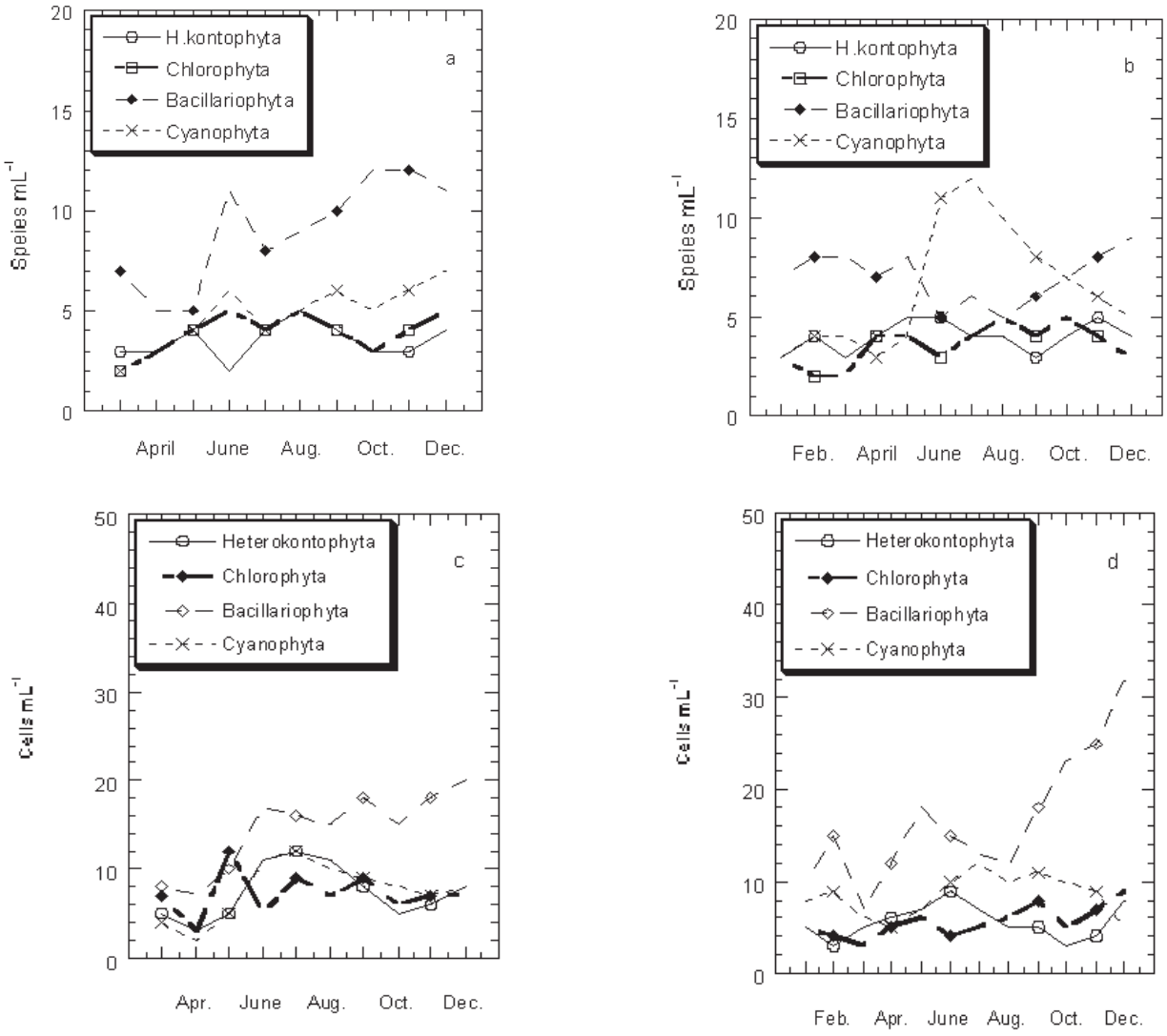

FIGURE 5. The number of species and cells of phytoplankton groups at 30 m. a) Species number of each group in 1997; b) species number of each group in 1998; c) cell number of each group in 1997; d) cell number of each group in 1998.

Species of this group reached a great abundance in mid summer. Optimum light and temperature were probably the most significant factors contributing to density peaks of chlorophytes in summer (Temponeras and others 2000). Higashi and Seki (2000) found that Chlorophyta species were the dominant phytoplankton in summer in an experimental oligotrophic pond.

At 30 m, Cyanophyta was dominant during summer throughout the study period. Insufficient underwater light probably played a critical role in the selection of Cyanophyta at this depth. Brookes and Ganf (2001) state that high temperature and low light intensity favor Cyanophyta in temperate lakes. The average Secchi disk depth in Lake James is about 4.0 m and euphotic depth hardly exceeded 12 m, meaning no light at 30 m and thus phytoplankton productivity was limited by the lack of light at this depth. High temperature and insufficient light conditions could have acted synergistically to favor Cyanophyta during warm seasons at 30 m in Lake James.

Chroococcus limeticus and *Oscillatoria limnetica* were the most abundant Cyanophytes in summer at 30 m. Reynolds (1984) states that species of *Chroococcus* and *Oscillatoria* can survive long periods of darkness. Smith (1986) also determined that low light intensity and high temperature favored Cyanophyta in lakes.

Mallomonas caudata, *Dinobryon divergens*, and *Chlamydomonas polypyrenoideum* were the most common species that were collected from the all three depths. This could be a result of their swimming abilities as they have flagella. These species can move to the depth where they can obtain sufficient light and nutrients (Horne and Goldman 1994; Higashi and Seki 2000).

Melosira granulata and *Cyclotella glomerata* were also frequently collected from all three depths. Reynolds and others (1982) state that these species are able to increase under almost any given environmental condition and are common at almost all depths of deep lakes.

The correlation coefficients between the mixing depth and total number of species were significant only at 10 m (r = 0.31, p <0.05), but not at 2.0 and 30 m during the thermal stratification. This was an expected result because during the stratification, the mixing depth was usually less than 10 m and never reached to

30 m, and 2.0 m was always within the range of mixed layer. Reynolds (1992) states that the vertical distribution of phytoplankton is fundamentally dependent on mixing properties of the lake and the occurrence of populations actively moving via flagella.

Under full isothermy, phytoplankton species were more evenly distributed in the water column but, during the stratification, about 90% of the species were collected in the upper layers. Smayda (2002) states that when the mixing is restricted to only the upper layers, despite penetration of light to the deeper layers, it imposes differentiated distribution of the phytoplankton, with fewer species and lower densities below the mixing layer.

The effects of nutrients on phytoplankton distribution has been a central theme of modern limnology (Schindler 1977; Hecky and Kilham 1988; Maberly and others 2002). *N* and *P* have commonly been observed as limiting nutrients in aquatic systems. In aerated nutrient poor lakes, over 80% of nitrogen is present as NO_3^- and phosphorus as PO_4^{3-} (Elser and others 1990). Keeping this in mind, the distribution of phytoplankton was analyzed with respect to the relative concentration of NO_3^- and PO_4^{3-}. The results suggested that the vertical distribution of phytoplankton in Lake James was basically controlled by the relative concentrations of NO_3^- and PO_4^{3-}. At 2.0 and 10 m, nutrient concentrations were more dynamic than those at 30 m and the correlation coefficients between the number of species and the number of individuals, NO_3^- and PO_4^{3-} were significant at 2.0 and 10 m, but not at 30 m.

The dominance of Chlorophyta in spring at 10 m and the dominance of Cyanophyta during summer at 30 m is consistent with the patterns seen in lakes with relatively short supply of nutrients (Hecky and Kilham 1988). Furthermore, the lower number of species and their abundance in Lake James compared with eutrophic lakes suggest that, in general, phytoplankton growth was limited by the scarcity of nutrients (Munawar and Munawar 1986; Maberly and others 2002; Teubner 2003). Another indication of nutrient limitation on phytoplankton was the relatively higher abundance of phytoplankton in spring and fall when mixes occurred compared with stagnant summer conditions.

The analyses also revealed that the temperature and light regime was also important on the seasonal patterns of phytoplankton in Lake James. Chlorophytes

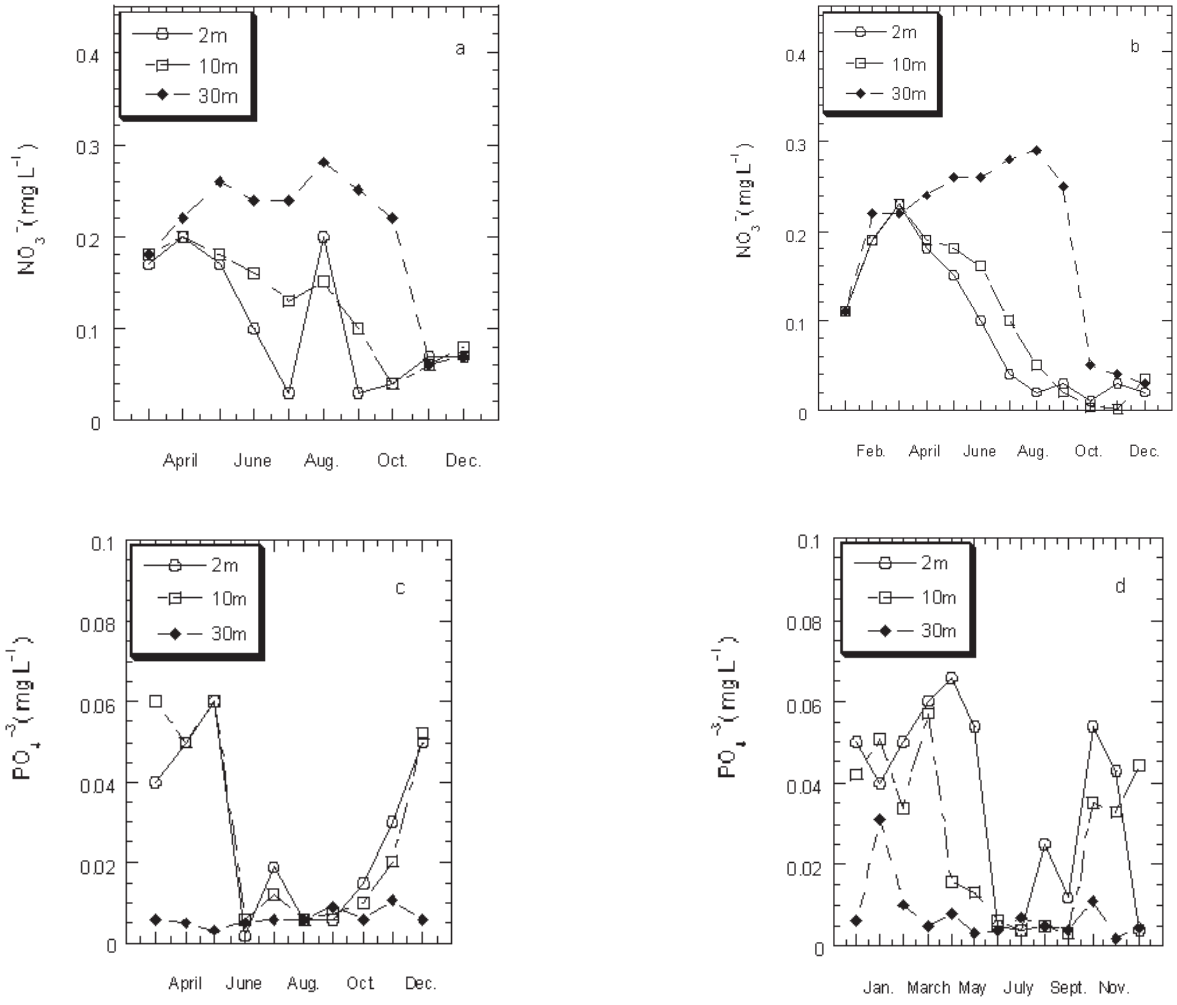

FIGURE 6. The concentration of NO_3^- (mg L^{-1}) and PO_4^{3-} (mg L^{-1}) at 2.0, 10, and 30 m. a) NO_3^- concentrations in 1997; b) NO_3^- concentrations in 1998; c) PO_4^{3-} concentrations in 1997; d) PO_4^{3-} concentrations in 1998.

were more abundant in spring, while diatoms were mostly abundant in winter and cyanophtes were abundant during summer. These results suggest that seasonal patterns of phytoplankton were regulated by the seasonal changes in temperature and light (Melo and Huszar 2000).

In summary, the results of this study showed that phytoplankton species numbers and their abundance were significantly different between 2.0 and 30 m and between 10 and 30 m, but not between 2.0 and 10 m during the summer stratification. Finally, the results also suggest that although the vertical distribution of phytoplankton was mostly regulated by the relative concentrations of nutrients, seasonal patterns of phytoplankton, especially in the upper layers, were mainly regulated by the temperature and light regime.

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