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Research Article

Quantitative changes of *Planktolyngbya brevicellularis, Limnothrix redekei* and *Aphanizomenon gracile* in the annual cycle *vs*. physicochemical water parameters in the urban Lake Jeziorak Mały

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Abstract

The study was conducted on net phytoplankton in the urban Lake Jeziorak Mały (Mazurian Lakeland) in the littoral zone in the years 1998 – 2003. The blue-green algae community was dominated by three species: *Planktolyngbya brevicellularis (Cronberg &Komarek)*, *Limnothrix redekei* (Van Goor) Meffert and *Aphanizomenon gracile* Lemm. Changes in the numbers of blue-green algae were analyzed in the annual cycle, with respect to water temperature and orthophosphate concentration. One abundance peak of *Planktolyngbya brevicellularis* was recorded in July, of *Limnothrix redekei* in May, and for *Aphanizomenon gracile* there were two peaks in numbers in May and in August. The relationship between water temperature and the occurrence of blue-greens was statistically significant, whereas in the case of orthophosphate concentration, the coefficient of correlation was statistically significant only for *Planktolyngbya brevicellularis*. On the basis of equations of multiple regression the proportion of orthophosphate concentration was affirmed to be higher than water temperature. This may suggest that the blue-green species contributed to reducing the phosphorus content of the water, and the largest part in this phenomenon could be played by Planktolyngbya brevicellularis, which developed in the widest temperature range and in this way was a competitor species for remaining species.

INTRODUCTION

Blue-greens belong to the prokaryotic algae group and are common in a variety of water bodies, both oligotrophic and eutrophic; however, they dominate only under conditions of increased trophy, forming blooms (Reynolds 1978, Spodniewska 1986, Bucka 1989). Blue-greens, like other algae, are subject to ecological succession. Lampert and Sommer (1996) give a definition of succession as an orderly process of directional changes in the species structure of the biocenosis, which may proceed for several hundred, or even several thousand, years, or which may be a regular and repeatable sequence of changes in the biocenosis, resulting from cyclical environmental changes (*e.g.* annual blue-greens).

Ecological succession may be affected by a variety of factors such as seasonal changes in water temperature and intensity of solar radiation or water mixing and resuspension of biogenic elements, including phosphorus, from sediments (Sommer *et al.* 1986, Reynolds 1993a, Mayer *et al.* 1997, Noges and Laugaste 1998, Jeppensen *et al.* 2000, Coops and Hosper 2002).Particular phytoplankton species, including the blue-greens, have various requirements as regards physicochemical water parameters. According to Pełechaty and Burchardt (1998), a particular state of the natural environment or intensity of environmental factors provide conditions for the occurrence of a given species, characterized by a specified range of tolerance to *e.g.* water temperature or orthophosphate concentration.

In water reservoirs the appearance of one species and retreat of another follows in an annual cycle which includes blue-greens (Lampert and Sommer 1996). This phenomenon may be caused by competition for food. Blue-greens can fit between or compete with different algae for *e.g.* sources of phosphorus (Baker 1981, Krebs 1996).

The urban Lake Jeziorak Mały can be taken as an example of a strongly eutrophicated water body, where net phytoplankton communities were dominated by the blue-greens from April to October in the years 1998-2003. The objective of the present study was to determine changes in the numbers of *Planktolyngbya brevicellularis (*Cronberg & Komarek), *Limnothrix redekei*

(Van Goor) Meffert and *Aphanizomenon gracile* Lemm. in the annual cycle, as related to water temperature and orthophosphate concentration. The study was conducted in Lake Jeziorak Mały in the years 1998 - 2003.

MATERIAL AND METHODS

Research area

The urban lake Jeziorak Mały covers an area of 26 ha; its maximum depth is 6.4 m, mean depth 3.4 m, and water volume 891 000 m^3. For many decades this lake received municipal sewage from the town of Iława. Since 1991 effluent has been treated at a local wastewater treatment plant, and since 1997 restoration works have been carried out in the lake, including the installation of separators for pretreatment of storm water influents, and a fountain-based water aeration system.

Sample collection and material analyses

Samples were collected once a month, from March to October in the years 1998 – 2003, at six sites located in the littoral zone. The samples were taken with a 10 dm^3 calibrated bucket (20l at each site), poured through a plankton net No. 30 and preserved with Lugol's solution and then with a 4% formaldehyde solution. 226 samples were taken altogether. The following physicochemical water parameters were determined: temperature (°C) – with an HI 9143 oxygen meter and orthophosphate concentration (mg PO_4 dm^{-3}) – with a NOVA 400 spectrophotometer. The quantitative and qualitative determinations of blue-greens were performed under an optical microscope Alphaphot YS2 NIKON, at magnification of 10x, 20x, 40x and 60x. The microscope was coupled (via a camera) with a computer equipped with the MultiScan program. Computer images were printed with a MINOLTA laser printer. Individuals were counted in a 1 ml plankton chamber, and expressed per dm^3.

The analyses were performed on three blue-green species considered dominant in terms of numbers: *Planktolyngbya brevicellularis (*Cronberg & Komárek), *Limnothrix redekei* (Van Goor) Meffert and *Aphanizomenon gracile* Lemm. Among the blue-greens changes to the nomenclature introduced by Cronberg and Komárek (1994) were taken into consideration, distinguishing two species within the genus *Planktolyngbya*: *Planktolyngbya limnetica* (former name: *Lyngbya limnetica)* and *Planktolyngbya brevicellularis*. According to Cronberg and Komarek (1994), the same species was known under several names, or separate species were identified as one. This suggests that in previous studies the species *Planktolyngbya brevicellularis* and *Planktolyngbya limnetica* could have been referred to as *Lyngbya limnetica* (Zębek 2005a).

The Pearson correlation coefficient was applied in order to determine the statistical significance of relationships between water temperature and the numbers of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* (Guilford 1964, Marszałkowicz 1972). These coefficients were calculated on the basis of individual observations (N= 226). Tables 1 and 2 and figures 1 and 2 show the data, which are given as a total number of specimens divided by the number of measurements. These relationships are presented in the form of straight line regression equations. The coefficients of multiple correlation were also counted, which determined the degree of dependence between the studied variables (numbers of particular blue-green species, water temperature and orthophosphate concentration). These relationships are presented in the form of multiple regression equations. The ranking of factors was counted with equations of multiple correlation and expressed in percentages. To verify the representativeness of the experimental materials collected, the following characteristics of the sets examined were calculated: standard deviation, coefficient of variation, median, modal value and coefficient of asymmetry representing distribution skew (Guilford 1964).

Table 1

Mean abundance and proportion of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* in the total numbers of blue-greens in Lake Jeziorak Mały (means of the years 1998 - 2003)

Planktolyngbya brevicellularis		*Limnothrix redekei*		*Aphanizomenon gracile*		remaining species		Total numbers of blue-greens
indiv.dm^{-3}	%	indiv.dm^{-3}	%	indiv.dm^{-3}	%	indiv.dm^{-3}	%	indiv.dm^{-3}
11304	65.66	1825	10.60	2583	15.00	1505	8.74	17217

Table 2

Characteristics of datasets in terms of the representativeness of the experimental materials collected in Lake Jeziorak Mały in the years 1998 - 2003

Variable	Number of measurements (N)	Mean (X)	Standard deviation (σ))	Coefficient of variation (V) %	Median (Me)	Modal value (Mo)	Coefficient of asymmetry (As)
Abundance of *Pl.brevicellularis* (indiv.dm^{-3})	226	11304	17956	158.85	4778	1	+0.63
Abundance of *L.redekei* (indiv.dm^{-3})	210	1825	4081	223.62	156	1	+0.45
Abundance of *A. gracile* (indiv.dm^{-3})	220	2583	5635	218.15	420	1	+0.46
Water temperature (°C)	226	18.3	4.7	25.68	19.2	14.1	+0.89
Orthophosphate concentration (mgPO_4dm^{-3})	226	0.33	0.53	160.61	0.16	0.01	+0.60

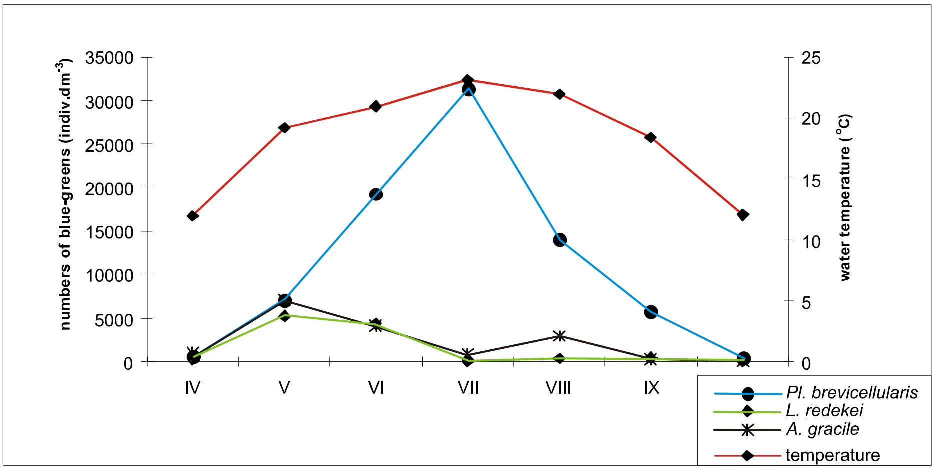

Fig. 1. Changes in the numbers of blue-green algae in the annual cycle vs. water temperature in Lake Jeziorak Mały (means of the years 1998-2003).

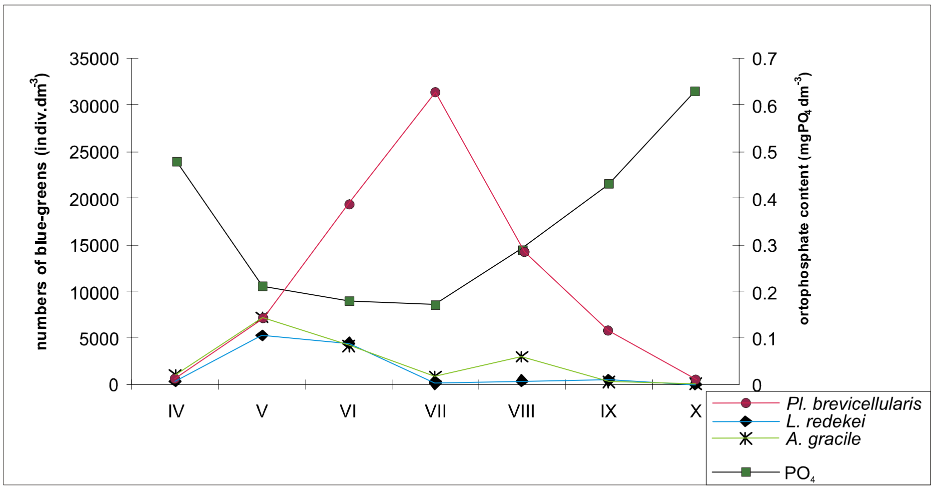

Fig. 2. Changes in the numbers of blue-green algae in the annual cycle vs. orthophosphate concentration in Lake Jeziorak Mały (means of the years 1998-2003).

RESULTS AND DISCUSSION

In the years 1998 – 2003 in Lake Jeziorak Mały the blue-green algae community was dominated by three species: *Planktolyngbya brevicellularis, Limnothrix redekei* and *Aphanizomenon gracile* (Zębek 2005a). Numerous authors have demonstrated the domination of these species in medium- and strongly-polluted lakes. Cronberg and Komarek (1994) observed considerable numbers of *Planktolyngbya brevicellularis* in mesotrophic lakes in Sweden. A great abundance of *Limnothrix redekei* was noted in shallow eutrophic (Bohr and Bogaczewicz 1974, Henning and Kohl 1981, Meffert 1989, Nixdorf 1994, Kisand *et al.* 2001) and polytrophic (Rojo and Cobelas 1994, Meyer *et al.* 1997) water bodies. Hickel (1988), Meffer (1989), Noges and Laugaste (1998), Noges *et al*. (1998), Kisand *et al*. (2001) found *Aphanizomenon gracile* in shallow eutrophic lakes.

In Lake Jeziorak Mały, the highest mean annual numbers and the highest proportion of total phytoplankton numbers was recorded for *Planktolyngbya brevicellularis* (11304 individuals dm^{-3} – 65.66%). *Limnothrix redekei* and *Aphanizomenon gracile* were the other predominant species and reached lower mean numbers in the range of 1825 individuals dm^{-3} (10.60%) and 25.83 individuals dm^{-3} (15.00%) respectively (Table 1).

In line with the objective of the study, changes in the numbers of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* in the annual cycle were analyzed with respect to water temperature and orthophosphate concentration. Statistical relationships were also determined between these variables. An evaluation of the significance of relationships between physicochemical water parameters and the abundance of blue-greens was preceded by a determination of the representativeness of the experimental variables.

The data included in Table 2 show that standard deviations were higher than the arithmetical mean for the numbers of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* and orthophosphate concentration, and lower for water temperature. Standard deviations did not exceed double the mean value. The coefficients of variations, expressed as a standard deviation to arithmetic mean ratio, were high and as follows: *Planktolyngbya brevicellularis* – 158.85%, *Limnothrix redekei* – 223.62% and *Aphanizomenon gracile*- 218.15%, which reflects the rank of these species in the community of blue-greens (Table 1). High variation was noted for orthophosphate concentration (160.61%), and low for water temperature (25.68%).

Data distributions, determined by the coefficient of asymmetry, were moderately positively skewed for all variables. Thus, it was assumed that data distributions and variation are close to normal and monomodal (Guilford 1964).

Changes in the numbers of blue-green algae in the annual cycle in the years 1998 – 2003 vs. water temperature and orthophosphate concentration

Changes in the numbers of blue-green algae in the annual cycle in shallow eutrophic lakes such as Lake Jeziorak Mały may be affected by a variety of factors, including water temperature, orthophosphate concentration and mixing or biogenic resuspension of sediments (phosphorus) (Padisak *et al*. 1990, Reynolds 1990, Puchalski 1991 and Krebs 1996). Changes in the abundance of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* were analyzed from March to October in Lake Jeziorak Mały with respect to changes in water temperature and orthophosphate concentration.

Figure 1 shows that an increase in water temperature was followed by an increase in the densities of studied blue-green species from April to September. However, they reached lower abundance at lower water temperature (below 20^{o}C) in September. One abundance peak of *Planktolyngbya brevicellularis* was recorded (31325 individuals dm^{-3}) in July at the highest water temperature (23.1^{o}C). *Limnothrix redekei* also reached one abundance peak (5237 individuals dm^{-3}) in May at water temperature 19.2^{o}C. However, in the case of *Aphanizomenon gracile* two abundance peaks were noted in May (7159 individuals dm^{-3} – 19.2^{o}C) and in September (2963 individuals dm^{-3} – 22.0^{o}C). Thus, it was assumed that in July, when *Planktolyngbya brevicellularis* reached the highest numbers, a phenomenon of competition and reduction in numbers of remaining species of blue-greens followed.

Numerous authors have demonstrated the maximum abundance of studied blue-green species in summer and in spring. Padisak *et al*. (1990), Nixdorf *et al*. (2003) noted the highest abundance of *Planktolyngbya limnetica* in September in a shallow eutrophic lake, as Salmaso did (2003) in a deep eutrophic lake. In the case of *Limnothrix redekei* abundance peaks were also observed in September (Mayer *et al.* 1997, Noges and Laugaste 1998, Noges *et al.* 1998). According to numerous authors *Aphanizomenon gracile* reaches maximum numbers in July (Huszar *et al*. 2003, Nixdorf et *al.* 2003) and in September (Noges *et al.* 1998, Mischke and Nixdorf 2003). However, Nixdorf (1985, 1994) noted the abundance peak of *Limnothrix redekei* from April to May in a shallow eutrophic lake, as did Huszar and Caraco (1998) for *Aphanizomenon gracile*. The results of the above analysis in Lake Jeziorak Mały were similar to what has been noted in the cited literature.

Numerous authors, as was previously mentioned, have noted that changes in the numbers of blue-greens in the annual cycle are affected by water temperature and competition for nutrients, and also orthophosphate concentration in water. In Lake Jeziorak Mały the mean orthophosphate concentration ranged from 0.17 mg PO_4 dm^{-3} in July to 0.63 mg PO_4 dm^{-3} in October. Figure 2 shows the relationship between the occurrence of blue-green algae and orthophosphate level in the annual cycle. In April, when the amounts of these biogenic elements were high (0.48 mg PO_4 dm^{-3}), the abundance of studied blue-greens was very low. In May an increase in the numbers of

Planktolyngbya brevicellularis and maximum abundance of *Limnothrix redekei* and *Aphanizomenon gracile* was accompanied by a decline in orthophosphate concentration to 0.21 mg PO_4 dm^{-3}. In June and July, far higher growth of *Planktolyngbya brevicellularis* was accompanied by a decline in orthophosphate concentration to 0.17 mg PO_4 dm^{-3}, when this species reached maximum abundance (31325 individuals dm^{-3}). Then in August, September and October the opposite tendency was noted. A rapid increase in the orthophosphate concentration to the value of 0.63 mg PO_4 dm^{-3} was noted at a decrease in the numbers of *Planktolyngbya brevicellularis.*

Particular authors give different levels of phosphorus at which the numbers of studied blue-green algae increase. Noges *et al*. (1998) observed a great abundance of *Planktolyngbya limnetica* at amounts of phosphorus from 0.38 to 0.83 mg P m^{-2} d^{-1}, and Salmaso (2003) at 9 μg P dm^{-3}. According to Mayer *et al*. (1997), *Limnothrix redekei* was more abundant at phosphorus concentration of 0.35 to 0.86 mg P dm^{-3}, whereas Meffert (1989) noted orthophosphate content of 0.12 mg PO_4 dm^{-3} and Wernicke and Nicklish (1986), 0.08 mg PO_4 dm^{-3}. Barbiero and Kann (1994) observed an increase in the numbers of *Aphanizomenon* at phosphorus concentration above 0.33 mg P dm^{-3}, and Baker (1981) at low orthophosphate content (0.02 to 0.15 mg PO_4 dm^{-3}). Noges *et al*. (1998) noted the occurrence of *Aphanizomenon gracile* at phosphorus concentration of 0.06 to 0.27 mg P $m^{-2}d^{-1}$, Huszar *et al*. (2003) from 0.01 to 0.03 mg PO_4 dm^{-3}. Kisand *et al*. (2001) noted a great decrease in the orthophosphate concentration (to a value of 0.01 mg PO_4 dm^{-3}) in the months from June to September at high numbers of *Planktolyngbya limnetica*, *Limnothrix redekei* and *Aphanizomenon gracile.*

Trojan (1980) pointed to the fact that the blue-greens require nutrients (especially phosphorus) to grow and reproduce. According to Pearsall (1932) as cited in Baker (1981), blue-greens often occurred in water at high biogenes, whereas maximum biomass was reached at low nutrient level. The data shown in Figure 2 and cited literature suggest that the studied blue-green species, particularly *Planktolyngbya brevicellularis,* could contribute to a reduction in the concentration of orthophosphates in water in the summer.

Relationships between water temperature and orthophosphate concentration and numbers of blue-green algae

Changes in the abundance of *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* in the annual cycle in Lake Jeziorak Mały may be caused by numerous factors. The above data suggest that water temperature and orthophosphate concentration might possibly influence the abundance of studied blue-green species, and vice-versa: blue-greens have an influence on the orthophosphate concentration in water.

The data shown in Figure 3 suggest that a temperature increase by 1^{o}C results in an increase in the numbers of *Planktolyngbya brevicellularis* by 1635 individuals dm^{-3}, of *Limnothrix redekei* - by 184 individual dm^{-3} , and of *Aphanizomenon gracile* – by 156 individuals dm^{-3}. The highest correlation coefficient was recorded for *Planktolyngbya brevicellularis* (r=0.4278) at a significance level of 1%. Slightly lower correlation coefficients were noted for *Limnothrix redekei* (r=0.2070) and *Aphanizomenon gracile* (r=0.1300) at a significance level of 5%. The distribution of points in the coordinate system shows that the responses of particular algal species to water temperature rise were different; differences in the requirements of blue-greens as for water temperature were observed. The widest range (13^{o}C to 24.8^{o}C) was noted for *Planktolyngbya brevicellularis*. *Limnothrix redekei* was most abundant in a narrower range of 13^{o}C to 20.5^{o}C. However, the greatest numbers of *Aphanizomenon gracile* were noted in a range of 13^{o}C to 19.0^{o}C (Figure 3). Similar results were obtained in investigations conducted earlier in the years 1996 and 1998 (Zębek 1998, 2005a).

Many authors reported the presence of *Planktolyngbya limnetica* (*Lyngbya limnetica*) in shallow, strongly eutrophic lakes, under a temperature range similar to that of Lake Jeziorak Mały. Meffert (1989) observed large numbers of algae of the genus *Planktolyngbya* at a temperature of 16.6^{o}C to 19^{o}C under laboratory conditions. Salmaso (2003) noted the maximum abundance of *Planktolyngbya limnetica* at 18^{o}C. Many Polish authors reported mass occurrence of *Planktolyngbya limnetica* in a water temperature range of 13^{o}C to 20^{o}C, but as an accompanying species only, not the dominant one (Bohr and Bogaczewicz 1974, Spodniewska 1986, Chudyba and Endler 1992, Chudyba 1992, Chudyba and Czaplicka 1994). In the case of *Limnothrix redekei* Rojo and Cobelas (1994), Mayer *et al*. (1997) observed an increase in the numbers of this species at water temperatures higher than 20^o C. According to Wernicke and Nicklish (1986), the greatest abundance comes in a temperature range of 5^{o}C to 20^{o}C and the optimum temperature for *Limnothrix redekei* development is 24^{o}C. According to Baker (1981), the numbers of blue-green algae of the genus *Aphanizomenon* increase when water temperature rises from 12^{o}C to 18^{o}C, and according to Huszar *et al*. (2003) from 19.4^{o}C to 21.4^{o}C. A growing abundance of *Aphanizomenon gracile* was observed in summer by Meffert (1989) at 20 to 22^{o}C, and by Huszar and Caraco (1998) at 20.2^{o}C. The differences in their requirements as for water temperature suggest that *Planktolyngbya brevicellularis* is the most tolerant to temperature changes among the species analyzed. The response of this species to temperature rise was also the strongest, confirmation of which is the highest value of correlation coefficient - r=0.4278 (Table 3).

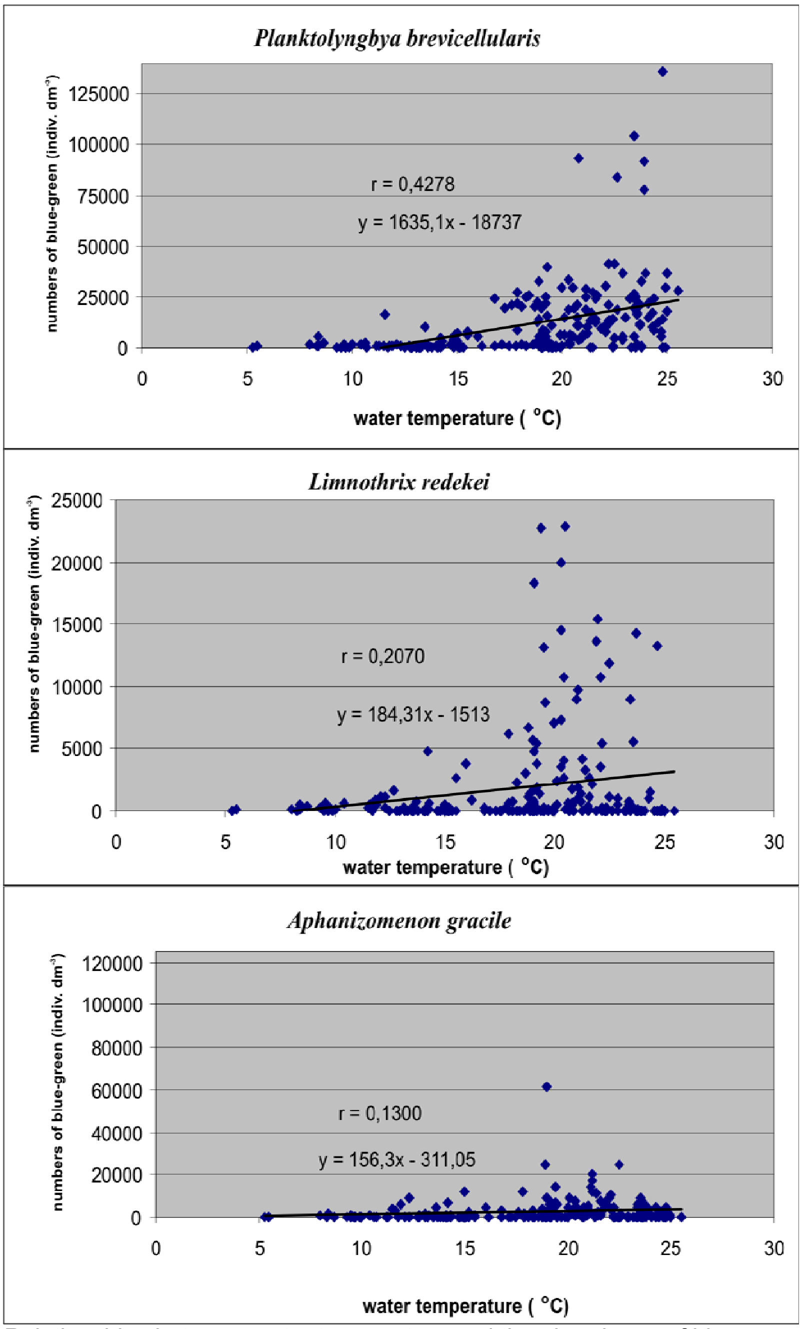

Fig. 3. Relationships between water temperature and the abundance of blue-green algae in the years 1998 - 2003.

Table 3

Coefficients of correlation between orthophosphate concentration and numbers of blue-green algae in Lake Jeziorak Mały in the years 1998 -2003

Coefficients of correlation	*Planktolyngbya brevicellularis* (indiv. dm^{-3})	*Limnothrix redekei* (indiv. dm^{-3})	*Aphanizomenon gracile* (indiv. dm^{-3})
Orthophosphate concentration ($mgPO_4\ dm^{-3}$) vs. numbers of blue-greens	**r = - 0.1481**	**r = - 0.1150**	**r = - 0.0075**

The second physicochemical water parameter analyzed in the investigations was orthophosphate concentration**.** Correlation coefficients showed statistically significant relationships only with the abundance of *Planktolyngbya brevicellularis* r= -0.1481. In the case of the remaining species the correlation coefficients were very low and not statistically significant (*Limnothrix redekei* r = - 0.1150, *Aphanizomenon gracile* r = 0.0075) (Table 3). According to Kisand *et al*. (2001), the highest count of R^2 (0.78) was between orthophosphate concentration and the abundance of phytoplankton, among which *Limnothrix redekei* and *Aphanizomenon gracile* were the dominant species in May, however no statistically significant relationships were found in September.

In farther analysis of the relationships between water temperature, orthophosphate concentration and the abundance of studied blue-green species multiple correlations were applied. The data shown in Figure 4, in the case of *Planktolyngbya brevicellularis* and *Limnothrix redekei,* relationships between water temperature, orthophosphate concentration and abundance of these species were statistically significant. The coefficients of multiple correlation

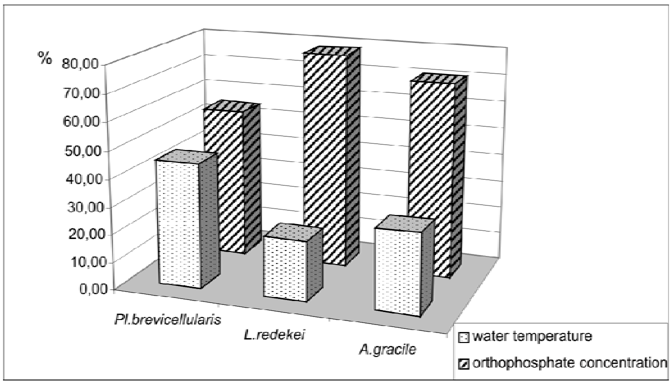

Fig. 4. Proportion of water temperature and orthophosphate concentration defining the rank of influence on numbers of particular species of blue-greens in Lake Jeziorak Mały (counted with equations of multiple regression).

were R=0.4313 and R=0.2211 respectively. However, the coefficient for *Aphanizomenon gracile* was very low (R=0.0469) and not statistically significant.

The equations of multiple regression for the studied blue-green species, shown in Table 4, suggest that a temperature increase by $1^{o}C$ results in an increase in the numbers of *Planktolyngbya brevicellularis* by 1586 individuals dm^{-3}, and an orthophosphate concentration decrease by 0.01 $mgPO_4$ dm^{-3} results in an increase in the numbers of this species by 1931 individuals dm^{-3}. A similar tendency was found for *Limnothrix redekei,* where a water temperature increase by $1^{o}C$ results in an increase in the numbers of this species by 166 individuals dm^{-3}, and orthophosphate concentration decrease by 0.01 $mgPO_4$ dm^{-3} was accompanied by a increase in numbers by 608 individuals dm^{-3}. However, a different situation was noted for *Aphanizomenon gracile*, a water temperature increase by $1^{o}C$ results in an increase in its numbers by 165 individuals dm^{-3} and orthophosphate concentration increase by 0.01 $mgPO_4$ dm^{-3} results in an increase of 404 individuals dm^{-3}.

The data shown in Figure 4, counted with equations of multiple regression, shows that the proportion of orthophosphate concentration noted was higher than water temperature for all studied species. This may suggest that *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile* contributed to a reduction in the phosphorus content of water, which was confirmed by a statistically significant value of the multiple correlation coefficients for this species (Table 4). This phenomenon was observed primarily in summer at high water temperature and domination of blue-greens (Zębek 2005 b).

Table 4

Coefficients of multiple correlation and equations of multiple regression between water temperature, orthophosphate concentration and numbers of blue-greens in Lake Jeziorak Mały in the years 1998 –2003

	Planktolyngbya brevicellularis	*Limnothrix redekei*	*Aphanizomenon gracile*
Coefficients of multiple correlation between water temperature (x_2), orthophosphate concentration (x_3) and numbers of blue-greens (x_1')	**R= 0.4313**	**R=0.2211**	**R=0.0469**
Equations of multiple regression	**$X_1'=-16700.7+1586.24x_2-1931.12x_3$**	**$X_1'=-1028.35+166.89x_2-608.30x_3$**	**$X_1'=-584.65+165.81x_2+404.02x_3$**

Hutchinson (1961) as cited in Reynolds (1993b), Sommer *et al*. (1993) and Krebs (1996) described a plankton paradox, which determined a contradiction between the principle of competitive expulsion and diversity of phytoplankton. According to Hutchinson, phytoplankton consists of a great number of species, using the same pool of alimentary elements. Despite often exceeding the deficit limits of these elements, particular species can coexist thanks to heterogeneous requirements. A small change in environmental conditions *e.g*. temperature or affluence in oxygen, will cause a change in the relations of domination before the expulsion of weaker species.

Krebs (1996) presented these relations as curves in the lifecycles of phytoplankton species. If the curves do not agree, certain environmental resources are not used and one or both species can take this part of the resources. According to Shapiro (1972) as cited in Baker (1981), blue-greens can compete for resources of phosphorus with other algae, especially at low concentration of this biogene.

CONCLUSION

On the basis of studies carried out, net phytoplankton and cited literature suggest that in shallow polytrophic lakes, *e.g*. Lake Jeziorak Mały, the most important factors influencing the abundance of blue-green algae in the annual cycle are water temperature and orthophosphate concentration. At low water temperatures phosphorus amount is high (*ad libitum*), and at high water temperatures phosphorus is a factor limiting the abundance and biomass of blue-greens. In Lake Jeziorak Mały the highest orthophosphate concentration was noted in October (0.63 $mgPO_4$ dm^{-3}) at 12.1°C and the lowest (0.17 $mgPO_4$ dm^{-3}) in July at 23.1°C (Figure 1 and 2).

Blue-greens, depending on their requirements as regards environmental factors, may take biogene from water to different degrees. The blue-green algae community was dominated by three species, differing in their requirements as for water temperature: *Planktolyngbya brevicellularis*, *Limnothrix redekei* and *Aphanizomenon gracile*. *Planktolyngbya brevicellularis* is the most tolerant to temperature changes among the species analyzed; this species developed in the widest temperature range (Figure 3). The highest coefficients of correlation between water temperature and numbers were also noted for *Planktolyngbya brevicellularis* (Table 3 and 4). The studied blue-green species could contribute to a reduction in the orthophosphate concentration in water. In summer, a considerable decline in the biogene at maximum abundance of these blue-greens was observed (Figure 2). The equations of multiple regression suggest that the higher increase in their numbers was the result of a decrease in orthophosphate concentration rather than an increase in water temperature (Table 4 and Figure 4). The response of this species to temperature rise was also the strongest, which results in linear equations and multiple regression (Figure 3 and Table 4). *Planktolyngbya brevicellularis* may be recognized as a competitive species for orthophosphate resources and contributed in the largest degree to reducing the content of this biogene in water. This phenomenon took place especially in summer.

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