

## Qualitative and quantitative changes of diatoms with relation to physiochemical water parameters in the littoral zone of the urban Lake Jeziorak Mały

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### Abstract

Phytoplankton in the littoral zone of the urban Lake Jeziorak Mały (Mazurian Lakeland) were studied between April and October of 2002 and 2003. Five diatom species (*Fragilaria delicatissima*, *Aulacoseira granulata*, *Fragilaria capucina*, *Diatoma vulgare*, *Fragilaria crotonensis*) and one genus (*Rhizosolenia* sp.), comprising the major proportion of total abundance and biomass of diatoms, were chosen for the study. The relationships between the biomass of these diatoms and water temperature, oxygen content, electrolytic conductivity, orthophosphates, silicon and calcium concentrations were analyzed. The biomass of species *F. delicatissima*, *A. granulata* and *F. capucina* tended to be the highest of the six, which were also associated with the widest temperature range, 10.0°C to 18.7°C. These three species exhibited maximum biomass at the highest orthophosphate concentrations. By contrast, *F. crotonensis* developed in the narrowest water temperature range, 10.0°C to 13.7°C. The maximum biomass of this species was noted at high silicon and calcium concentrations. The

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diatoms (except *F. capucina* and *Rhizosolenia* sp.) contributed to statistically significant observed reductions in nutrient concentrations during their growth. These results indicate that a range of factors is involved in the productivity and limitation of the studied diatoms, with water temperature being of particular importance.

## INTRODUCTION

Phytoplankton production underpins energy flow in aquatic ecosystems, and they are sensitive markers of changes in these environments. The most important factors contributing to community diversity and productivity in lakes, including the phytoplankton, are light levels, water temperature, phosphorus and, for diatoms, the availability of silicon (Krebs 1996). Particular phytoplankton species have specific environmental and physiochemical requirements, which demarcate their occurrence (e.g. see Pelechaty and Burchardt 1998).

As a result of the definable requirements of diatoms, they are often used as indicators of water quality e.g. pollution, salinity levels etc. (Kawecka and Eloranta 1994). The susceptibility of diatoms to environmental factors was first demonstrated, with relation to the pH of lake waters, by Hustedt (Hustedt 1939 cited in Guzkowska and Gasse 1990a). Subsequently numerous authors have demonstrated the ecology of diatom communities with respect to physicochemical parameters in a wide range of lakes (Reynolds 1984, 1986; Dokulil and Padisak 1994, Huszar and Caraco 1998), including urban lakes, where waters are frequently polluted by urban runoff (Guzkowska and Gasse 1990a). Availability of silicon is particularly relevant for diatoms and, in freshwater, can only be absorbed in significant quantities at a high Si:P ratio (Lampert and Sommer 1996).

The urban Lake Jeziorak Mały is an example of a highly eutrophic water body, where apart from blue-green algae (Zębek 2005a, 2005b and 2006), the great majority of phytoplankton are diatoms (Zębek and Bonar 2002). The aim of the present study was to determine the environmental requirements of certain diatom taxa in the littoral zone of Lake Jeziorak Mały, and was conducted during 2002 and 2003.

## MATERIALS AND METHODS

### *Research area*

The urban Lake Jeziorak Mały covers a total area of 26 ha (maximum depth 6.4 m; mean depth 3.4 m; water volume 891 000 m<sup>3</sup>). For many decades the lake received untreated municipal sewage from the town of Iława. Since 1991, however, effluent has been treated at a local wastewater treatment plant. Work

to improve the lake water quality began in 1997 and has been ongoing since that time, including the installation of separators for the pretreatment of storm water influent, and a fountain-based water aeration system.

### *Samples*

Samples were collected monthly from April to October 2002 and 2003, at six sites located in the littoral zone of Lake Jeziorak Mały. The littoral zone is diverse, with some anthropogenic influences. Sample sites were in three groups: separators (two sites situated at pipe outlets, which drain storm water), stations with stony-gravel substrates (two sites with stones and rubble constructed in 1997) and stations overgrown by vascular plants (two sites with no anthropogenic transformation, which have muddy bottoms covered with rotting plant remnants).

The samples were collected with a 10 dm<sup>3</sup> calibrated bucket (20 l at each site), filtered through a no. 30 plankton net, and preserved in Lugol's solution followed by a 4% formaldehyde solution. A total of 78 samples were collected.

The following physicochemical water parameters were determined: temperature (°C), oxygen content (mgO<sub>2</sub> dm<sup>-3</sup>) (using an HI 9143 oxygen meter), electrolytic conductivity (μS cm<sup>-1</sup>) (using a CONMET 1 conductometer), and orthophosphate (mgPO<sub>4</sub> dm<sup>-3</sup>), silicon (mgSi dm<sup>-3</sup>) and calcium (mgCa dm<sup>-3</sup>) concentrations (using a NOVA 400 spectrophotometer).

Diatom samples were prepared following standard procedures, as described by Battarbee (Battarbee 1986 cited in Stoermer et al. 1987). 10% hydrochloric acid was used to remove carbonates and 30% hydrogen peroxide was used to oxidize the organic matter. The diatoms were mounted onto slides using Naphrax.

Qualitative and quantitative determinations of diatoms were performed with an Eclipse 800 optical microscope at ×100 magnification, under oil immersion. The microscope was coupled (via a camera) to a computer with the MultiScan program. Diatom identification was aided by the following works of Krammer and Lange-Bertalot (1986, 1988, 1991a and 1991b). Diatoms were divided into groups according to their ecological requirements (Van Dam et al. 1994, Hoffmann 1994). The frequency of particular taxa was expressed as a percentage of the total count, the total amounting to 500 valves. Diatom biomass was determined by cell volume measurements (Luścińska and Oleksowicz 1984, Pliński et al. 1984). Measurements of cell length, width and thickness were assessed using the MultiScan program. Mean biomass was calculated for 10 individuals of each diatom species. Cell volume was expressed as a volume of a stereometric figure corresponding to a given species. Cell mass

was calculated from cell volume, assuming that  $1 \text{ mm}^3 = 1.0 \text{ mg}$ , allowing expression of biomass in  $\text{mg dm}^{-3}$ .

The species chosen for the diatom community analysis: *Fragilaria delicatissima* (W. Smith) Lange-Bertalot, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Fragilaria capucina* Desmazieres, *Diatoma vulgare* Bory, *Fragilaria crotonensis* Kitton and *Rhizosolenia* sp. Ehrenberg, were selected as a result of their dominance in the observed diatom abundance (Table 1). In order to verify that this choice was representative of the experimental material, the following parameters were calculated: standard deviation, coefficient of variation, median, modal value and coefficient of asymmetry representing skewness of distribution (Guilford 1964). Calculations to statistical analysis be leanings on individual observations. The Pearson correlation coefficient was applied in order to determine the significance of relationships between biomass and water temperature, electrolytic conductivity, orthophosphate, silicon and calcium concentrations. These relationships are presented in the form of straight line regression equations (Guilford 1964, Marszałkiewicz 1972).

**Table 1**

Mean abundance and biomass of diatoms in the littoral zone of Lake Jeziorak Mały in the months April to October 2002 and 2003

Taxa	Abundance of diatoms		Biomass of diatoms			
	mean abundance (indiv. $\text{dm}^{-3}$ )	proportion in the total abundance of diatoms (%)	frequency of occurrence	mean biomass ( $10^{-4} \text{ dm}^{-3}$ )	proportion in the total biomass of diatoms (%)	mean biomass of single individual ( $10^{-7} \text{ mg}$ )
<i>Fragilaria delicatissima</i>	1313	27.03	77/78 samples	7.92	8.58	6.03
<i>Aulacoseira granulata</i>	100	2.06	69/78 samples	5.88	6.36	58.85
<i>Fragilaria capucina</i>	421	8.66	66/78 samples	1.35	1.46	3.22
<i>Diatoma vulgare</i>	61	1.26	56/78 samples	4.80	5.19	78.10
<i>Fragilaria crotonensis</i>	685	14.10	25/78 samples	7.62	8.25	11.12
<i>Rhizosolenia</i> sp.*	50	1.03	24/78 samples	26.25	28.41	526.68
remaining taxa (51)	2226	45.86		38.58	41.75	
Total taxa of diatoms 57	4856	100		92.40	100	

\* *Rhizosolenia* sp. occurred only from July to September

## RESULTS AND DISCUSSION

### *General characteristics of the diatoms communities*

In pond-type lakes, such as Jeziorak Mały, the littoral zone can influence the trophic state of the water as well as acting as a substrate for living organisms. According to Burchardt (1998), maximal primary productivity in

eutrophic water bodies occurs in the littoral zone, which also functions as a biofilter, collecting both water and organisms flowing down from the catchment. Hillbricht-Ilkowska and Pieczyńska (1993) (cited in Radwan et al. 1998) also point out that the littoral zone is an effective filter of pollutants inflowing from the catchment. The effectiveness of stopping invading organisms depends on the diversity of the inhabiting biota, including phytoplankton communities.

With the exception of blue-green algae, diatoms were the primary colonizers of the littoral zone of Lake Jeziorak Mały in April to October 2002 and 2003. Table 1 show that the mean abundance of diatoms was 4856 individuals  $\text{dm}^{-3}$  and the mean biomass was 92.40  $\text{mg dm}^{-3}$ , made up of a total of 57 diatom taxa. Among the six diatom taxa selected as representatives, *F. delicatissima* and *A. granulata* were the most abundant and *F. crotonensis* and *Rhizosolenia* sp. the least abundant. *Rhizosolenia* sp. was only present in samples collected from July to September. The six studied diatoms comprised 54.14% of the total number of diatoms, and 58.25% of the total biomass of diatoms. Of these six the highest mean abundance was recorded for *Fragilaria delicatissima* (1313 indiv.  $\text{dm}^{-3}$ ) and the lowest mean abundance for *Rhizosolenia* sp. (50 indiv.  $\text{dm}^{-3}$ ), whilst the biomass was highest for *Rhizosolenia* sp. ( $26.25 \times 10^{-4}$   $\text{mg dm}^{-3}$ ) and lowest for *Fragilaria capucina* ( $1.35 \times 10^{-4}$   $\text{mg dm}^{-3}$ ). The mean biomass of individuals showed considerable differences, from  $3.22 \times 10^{-7}$   $\text{mg}$  for *Fragilaria capucina* to  $526.68 \times 10^{-7}$   $\text{mg}$  for *Rhizosolenia* sp. (Table 1).

The mean values of physicochemical parameters in Lake Jeziorak Mały were as follows: water temperature 18.5°C, oxygen content 7.83  $\text{mgO}_2 \text{ dm}^{-3}$ , electrolytic conductivity 386  $\mu\text{S cm}^{-1}$ , orthophosphate concentration 0.48  $\text{mgPO}_4 \text{ dm}^{-3}$ , calcium 101  $\text{mgCa dm}^{-3}$  and silicon 0.83  $\text{mgSi dm}^{-3}$  (Table 2).

Gervais et al. (1999) reported electrolytic conductivity of 490-590  $\mu\text{S cm}^{-1}$  and calcium concentrations of 65-119  $\text{mgCa l}^{-1}$  in a shallow eutrophic lake. However, in an urban lake electrolytic conductivity of 660 to 890  $\mu\text{S cm}^{-1}$ , calcium concentration levels of 109 to 180  $\text{mgCa l}^{-1}$ , orthophosphate concentration of 0.08  $\text{mgPO}_4 \text{ l}^{-1}$  and silicon content of 13.4  $\text{mgSi l}^{-1}$  have been reported (Guzkowska and Gasse 1990b).

The results presented here, and data from literature, indicate that in Lake Jeziorak Mały, in spite of the high mean water temperature, conditions are favorable for the development of diatoms due to the high oxygen content and silicon concentration. It should be noted, however, that in Lake Jeziorak Mały water from the catchment flows through the separators, which disturbs the annual pattern of water temperature in the littoral zone. Warmer waters are supplied to the lake in the spring and fall, with cooler waters in the summer

Table 2

Characteristics of datasets in terms of the representativeness of the experimental materials collected in Lake Jeziorak Mały in 2002 and 2003

Variable	Number of measurements (N)	Mean (X)	Standard deviation (δ)	Coefficient of variation (V) %	Median (Me)	Modal value (Mo)	Coefficient of asymmetry (As)
<i>Fragilaria delicatissima</i> ( $10^{-3}$ mg dm <sup>-3</sup> )	62	7.92	14.21	179.42	2.80	1.63	+0.44
<i>Aulacoseira granulata</i> ( $10^{-4}$ mg dm <sup>-3</sup> )	62	5.88	8.69	147.79	0.88	0.06	+0.67
<i>Fragilaria capucina</i> ( $10^{-4}$ mg dm <sup>-3</sup> )	62	1.35	2.45	181.48	0.34	0.003	+0.55
<i>Diatoma vulgare</i> ( $10^{-4}$ mg dm <sup>-3</sup> )	62	4.80	6.50	135.42	1.17	0.08	+0.73
<i>Fragilaria crotonensis</i> ( $10^{-3}$ mg dm <sup>-3</sup> )	25	7.62	7.62	100.00	0.17	0.17	+0.98
<i>Rhizosolenia</i> sp. ( $10^{-4}$ mg dm <sup>-3</sup> )	28	26.25	23.85	90.86	15.80	0.52	+1.08
water temperature (°C)	62	18.5	4.1	22.16	19.05	20.7	-0.54
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	62	7.83	4.37	55.81	7.08	8.01	-0.04
electrolytic conductivity (μS cm <sup>-1</sup> )	62	386	172	44.56	345	330	+0.32
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	62	0.48	0.81	168.75	0.26	0.23	+0.31
calcium (mgCa dm <sup>-3</sup> )	62	101	86	85.15	71	160	-0.69
silicon (mgSi cm <sup>-3</sup> )	62	0.83	0.66	79.52	0.63	0.66	+0.26

(Zębek 1997), which might influence the mean water temperature of the lake and result in the high abundance of diatoms.

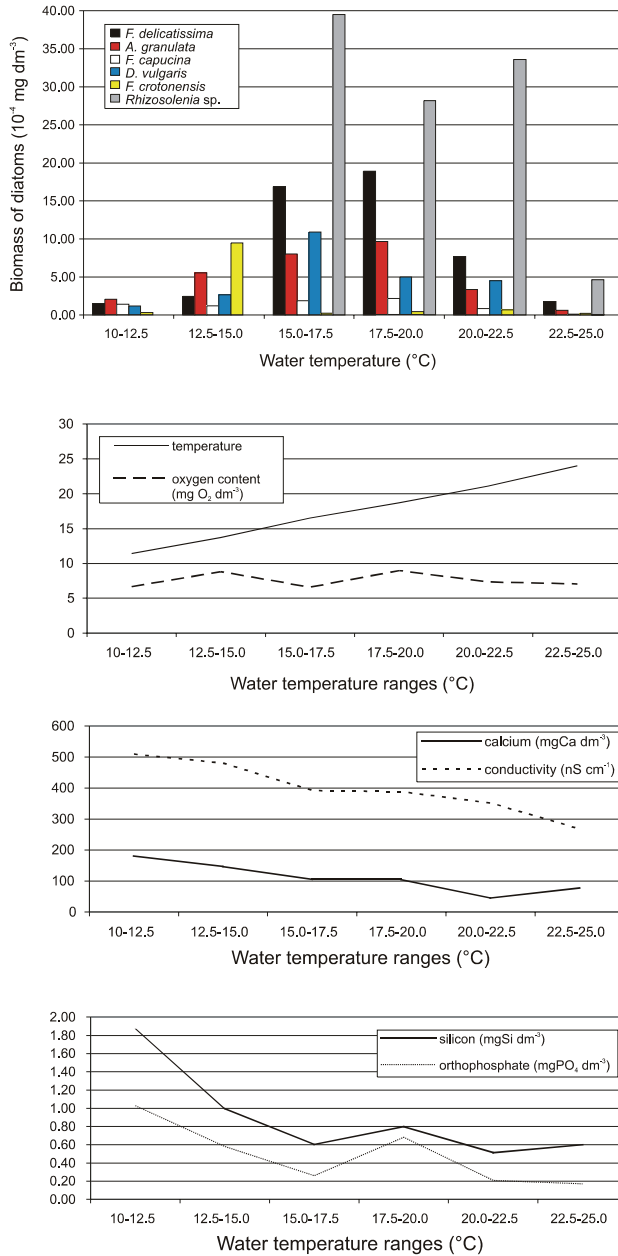
### ***Relationships between the biomass of diatoms and water physicochemical parameters***

High observed abundances and biomass of diatoms in shallow eutrophic lakes are caused by numerous factors. In order to examine these factors in Lake Jeziorak Mały, the relationships between the biomass of *Fragilaria delicatissima*, *Aulacoseira granulata*, *Fragilaria capucina*, *Diatoma vulgare*, *Fragilaria crotonensis*, *Rhizosolenia* sp. and selected water physicochemical parameters were analyzed. An evaluation of the significance of relationships between experimental variables was preceded by a determination of the representativeness. The data included in Table 2 show that standard deviations

were higher than the arithmetic means for the biomass of the diatoms (except *Rhizosolenia* sp.) and orthophosphate concentration. However, standard deviations were lower than the arithmetic means for the remaining physicochemical parameters (water temperature, oxygen content, electrolytic conductivity, and calcium and silicon concentrations). The coefficients of variations for the studied diatoms, expressed as the ratio of standard deviation to arithmetic mean, were high, ranging from 90.86% to 181.48%. Among the physiochemical parameters the highest variation was noted for orthophosphate concentration (168.75%) and the lowest for water temperature (22.16%). Data distributions, determined by the coefficient of asymmetry, were moderately positively skewed for the biomasses of the studied diatoms, electrolytic conductivity, orthophosphate and silicon concentrations, and moderately negatively skewed for the other variables (water temperature, oxygen content and calcium concentration). Data distributions were close normal only for oxygen content ( $A_s = -0.04$ ). Thus it was assumed that the data distributions and variations are close to normal and monomodal (Guilford 1964).

In order to undertake a detailed analysis of the relationships between the biomass of diatoms and physiochemical parameters, the results were plotted with relation to water temperature range (Fig. 1). The highest mean biomass was used to determine the temperature range of the development of each studied diatom taxa. Similarities and differences of water temperature requirements for the different taxa were recorded. High biomass of *Fragilaria delicatissima*, *Aulacoseira granulata* and *Fragilaria capucina* were seen at temperatures between 10.0 and 20.0°C. The mean biomass these three species reached at 18.7°C were  $18.89 \times 10^{-4} \text{ mg dm}^{-3}$ ;  $9.61 \times 10^{-4} \text{ mg dm}^{-3}$  and  $2.11 \times 10^{-4} \text{ mg dm}^{-3}$ , respectively. However, the maximum mean biomass of *Diatoma vulgare* and *Fragilaria crotonensis* were observed in narrower temperature ranges. *D. vulgare* developed at water temperatures of 10.0 to 17.5°C and *F. crotonensis* from 10.0 to 15.0°C. The highest mean biomass of these two species occurred at 16.5°C ( $10.90 \times 10^{-4} \text{ mg dm}^{-3}$ ) and 13.7°C ( $9.45 \times 10^{-4} \text{ mg dm}^{-3}$ ), respectively. The opposite tendency was reported for *Rhizosolenia* sp. Two biomass peaks were observed in the temperature ranges 15.0 to 17.5°C and 20.0 to 22.5°C. Both *Rhizosolenia* sp. ( $39.5 \times 10^{-4} \text{ mg dm}^{-3}$ ) and *D. vulgare* reached their highest mean biomass at a water temperature of 16.5°C (Fig. 1).

These results imply that the six studied diatom taxa can be characterized by their water temperature requirements. *Fragilaria delicatissima*, *Aulacoseira granulata* and *Fragilaria capucina* develop in the widest temperature range, whilst the other taxa show maximal biomass in narrower temperature ranges. The cryophilic species, *Fragilaria crotonensis*, reached its highest biomass at a lower water temperature, 13.7°C.



**Fig. 1.** Mean biomass of diatoms and physiochemical parameters in various water temperature ranges in the littoral zone of Lake Jeziorak Mały (means of the years 2002 and 2003).

The highest values of the other physiochemical parameters, electrolytic conductivity, orthophosphate, calcium and silicon concentrations, were observed at the lowest temperature, and decreased with increasing temperature. Species with the widest temperature tolerance (*F. delicatissima*, *A. granulata* and *F. capucina*) attained their highest biomass at the highest orthophosphate concentration ( $0.68 \text{ mgPO}_4 \text{ dm}^{-3}$ ). The highest biomass of *D. vulgaris* and *Rhizosolenia* sp. coincided with lower overall productivity, but with higher electrolytic conductivity. The maximum production of *F. crotonensis* was recorded at the highest electrolytic conductivity, calcium and silicon concentrations ( $480 \text{ }\mu\text{S cm}^{-1}$ ,  $147 \text{ mgCa dm}^{-3}$  and  $1.00 \text{ mgSi dm}^{-3}$ , respectively) (Fig. 1).

According to Hutchinson (1967) and Round (1981) (cited in Celekli and Kulkoyluoglu 2006), the genus *Fragilaria* spp. is typical of nutrient-rich water bodies. Van Dam et al. (1994) classified *F. delicatissima*, *F. capucina* and *F. crotonensis* as mesotrophic species. According to Hoffmann (1994), the trophic values for these species are as follows: *F. delicatissima* 2.0 (oligo-mesotrophic), *F. capucina* 4.5 (eutrophic) and *F. crotonensis* 2.55 (mesotrophic). Poulickova et al. (2004) recorded domination of *F. delicatissima* at electrolytic conductivity of  $250 \text{ }\mu\text{S cm}^{-1}$  and a silicon concentration of  $0.22 \text{ mgSi l}^{-1}$  in the littoral zone of a mesotrophic lake. Guzkowska and Gasse (1990b) reported a great abundance of *F. capucina* at a low orthophosphate concentration ( $0.05 \text{ mgPO}_4 \text{ dm}^{-3}$ ). Caracao (1998) and Huszar et al. (2003) reported a high biomass of *F. crotonensis* at a low water temperature ( $15^\circ\text{C}$ ), and Morabito et al. (2002) at a low electrolytic conductivity ( $149 \text{ }\mu\text{S cm}^{-1}$ ). According to Salmaso (2003), the optimum conditions for development of this species is a temperature of  $14^\circ\text{C}$  and silicon concentration of  $0.55 \text{ mgSi l}^{-1}$ .

Hutchinson (1967) and Round (1981) (cited in Celekli and Kulkoyluoglu 2006), reported high biomass of *Aulacoseira granulata* in lakes with a wide range of environmental conditions, with low, medium or high levels of pollution. Van Dam et al. (1994) and Reynolds (1984), classified *A. granulata* as a eutrophic water species, and Hoffmann (1994) classified it as a meso-eutrophic water species (trophic index 3.99). Gervais et al. (1999) reported a high biomass of this species in water with a calcium concentration range of 65 to  $119 \text{ mg l}^{-1}$  and an electrolytic conductivity range of 490 to  $590 \text{ }\mu\text{S cm}^{-1}$ . According to Nixdorf (1994) high biomass of *A. granulata* was correlated with high silicon concentrations ( $6 \text{ mgSi l}^{-1}$ ) in a shallow eutrophic lake.

*Diatoma vulgaris* is a species characteristic of eutrophic lakes and often occurs in the littoral zone of lakes (Van Dam et al. 1994, Goma 2004). Hoffmann (1994) classified this as a eutrophic species (trophic index of 4.4). *D. vulgaris* has been reported in shallow eutrophic lakes (Werner and Smol 2005) and as a component of plant periphyton (Kuczyńska-Kippen et al. 2004).

*Rhizosolenia* sp. has been recorded in a variety of water bodies, both oligotrophic and eutrophic, often occurring in early summer. Van Dam et al. (1994) classified this genus as mesotrophic, and Reynolds (1984) and Burns et al. (1997) as oligotrophic. Higher water temperatures generally favor the development of this genus. High biomass of *Rhizosolenia* sp. has been reported in July in a small mesotrophic lake (Environment Agency Wales, 2004), and in August, at a calcium concentration of  $8.14 \text{ mgCa l}^{-1}$  and a silicon concentration of  $0.48 \text{ mgSi l}^{-1}$ , in a eutrophic lake (Danilov and Ekelund 2001). A great abundance of *Rhizosolenia* sp. was reported in a gravel pit lake in summer at  $23^\circ\text{C}$ , which had a low orthophosphate concentration ( $0.012 \text{ mgPO}_4 \text{ l}^{-1}$ ) and an electrolytic conductivity of  $463 \text{ }\mu\text{S cm}^{-1}$  (Szelağ – Wasilewska and Goldyn 2005).

The results of the analysis presented here, when compared to data from literature, indicate that the diatoms observed in Lake Jeziorak Mały are typical of eutrophic waters. The six species studied have differing environmental requirements. *F. delicatissima*, *A. granulata* and *F. capucina* prefer high orthophosphate concentrations, whilst *F. crotonensis* is seen at its highest abundances when high calcium and silicon concentrations occur. However, the highest biomass of *D. vulgaris* and *Rhizosolenia* sp. were observed at lower nutrient concentrations than for the other diatoms. A decrease in orthophosphate, calcium and silicon concentrations concurrent with an increase in the biomass of the studied diatoms suggests that these organisms might influence the levels of nutrients in the water.

For the purpose of a more detailed analysis, the biomass of each of the four most abundant diatom species was compared to the physiochemical parameters of the water. For ease of analysis these were separated into two groups on the basis of their border temperature. The border value was the water temperature at which the diatoms reached their highest biomass. In this instance the values were  $18.7^\circ\text{C}$  for *F. delicatissima*, *A. granulata* and *F. capucina* and  $16.5^\circ\text{C}$  for *D. vulgaris* (Table 3). On this basis, two data samples were collected and the Pearson correlation coefficients were calculated. The coefficients illuminated a statistically significant correlation between water temperature, oxygen content, electrolytic conductivity, orthophosphate, calcium and silicon concentrations and the biomass of the studied diatoms, on at least one occasion each. The results in Table 3 show that in the temperature range in which the biomass of the diatom was maximal, the majority of the coefficients of correlation were statistically significant. In the second range of water temperatures, only in four of the 24 cases were the correlation coefficients statistically significant. The coefficients of correlation and the equations of line regression were as follows:

**Table 3**

Pearson correlation coefficients (r) between physiochemical water parameters and the biomass of diatoms, calculated in two water temperature ranges in the littoral zone of Lake Jeziorak Mały in 2002 and 2003

<b><i>Fragilaria delicatissima</i></b>	<b>10.0 – 18.7°C N=26</b>	<b>18.8 – 25.0°C N=36</b>
water temperature (°C)	0.7856*	- 0.2803*
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	0.1030	0.0040
electrolytic conductivity (µS cm <sup>-1</sup> )	- 0.2621*	- 0.0240
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	- 0.0502	0.2051
calcium (mgCa dm <sup>-3</sup> )	- 0.2218*	0.0508
silicon (mgSi cm <sup>-3</sup> )	- 0.2317*	0.1320
<b><i>Aulacoseira granulata</i></b>	<b>10.0 – 18.7°C N=26</b>	<b>18.8 – 25.0°C N=36</b>
water temperature (°C)	0.4273*	- 0.3658*
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	0.5696*	- 0.0491
electrolytic conductivity (µS cm <sup>-1</sup> )	- 0.0397	0.3307*
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	- 0.2871*	0.1173
calcium (mgCa dm <sup>-3</sup> )	- 0.4062*	- 0.1344
silicon (mgSi cm <sup>-3</sup> )	- 0.4368*	- 0.1182
<b><i>Fragilaria capucina</i></b>	<b>10.0 – 18.7°C N=26</b>	<b>18.8 – 25.0°C N=36</b>
water temperature (°C)	0.7856*	- 0.2705
oxygen content (mg O <sub>2</sub> ·dm <sup>-3</sup> )	- 0.1079	- 0.0267
electrolytic conductivity (µS·cm <sup>-1</sup> )	- 0.0415	0.0465
orthophosphate concentration (mg PO <sub>4</sub> ·dm <sup>-3</sup> )	- 0.1596	0.1729
calcium (mg Ca·dm <sup>-3</sup> )	- 0.1979	-0.0105
silicon (mg Si·cm <sup>-3</sup> )	- 0.1310	0.0317
<b><i>Diatoma vulgare</i></b>	<b>10.0 – 16.5°C N=18</b>	<b>16.6 – 25.0°C N=44</b>
water temperature (°C)	0.4681*	- 0.3082*
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	0.1446	- 0.2184
electrolytic conductivity (µS cm <sup>-1</sup> )	- 0.1020	0.1181
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	- 0.5657*	0.0929
calcium (mgCa dm <sup>-3</sup> )	- 0.1940	- 0.0659
silicon (mgSi cm <sup>-3</sup> )	- 0.5453*	- 0.2184
<b><i>Fragilaria crotonensis</i></b>	<b>10.0 – 25.0°C N=25 bored temperature 13.7°C</b>	
water temperature (°C)	- 0.2770*	
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	0.0637	
electrolytic conductivity (µS cm <sup>-1</sup> )	0.1828	
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	- 0.3456*	
calcium (mgCa dm <sup>-3</sup> )	0.0242	
silicon (mgSi cm <sup>-3</sup> )	- 0.3372*	
<b><i>Rhizosolenia</i> sp.</b>	<b>15.5 – 25.0°C N=28 bored temperature 16.6°C</b>	
water temperature (°C)	- 0.5324*	
oxygen content (mgO <sub>2</sub> dm <sup>-3</sup> )	- 0.0343	
electrolytic conductivity (µS cm <sup>-1</sup> )	0.2586*	
orthophosphate concentration (mgPO <sub>4</sub> dm <sup>-3</sup> )	0.0539	
calcium (mgCa dm <sup>-3</sup> )	0.0558	
silicon (mgSi cm <sup>-3</sup> )	0.0173	

\* statistically significant correlation coefficients

*Fragilaria delicatissima* (W. Smith) Lange-Bertalot

In water with a temperature range of 10.0°C to 18.7°C, a statistically significant correlation was observed between the biomass of *F. delicatissima* and water temperature, electrolytic conductivity, and calcium and silicon concentrations (Table 3). The equations of the line of regression, suggest that an increase in water temperature of 1°C was followed by an increase in the biomass of  $5.11 \times 10^{-4} \text{ mg dm}^{-3}$ . However, a decrease in electrolytic conductivity of  $1 \mu\text{S cm}^{-1}$  was accompanied by a biomass increase of  $0.02 \times 10^{-4} \text{ mg dm}^{-3}$ . A biomass increase of  $0.04 \times 10^{-4} \text{ mg dm}^{-3}$  was associated with a decrease in calcium concentration of  $1 \text{ mgCa dm}^{-3}$ , and a biomass increase of  $4.45 \times 10^{-4} \text{ mg dm}^{-3}$  was accompanied by a decrease in silicon concentration of  $1 \text{ mgSi dm}^{-3}$  (Fig. 2).

*Aulacoseira granulata* (Ehrenberg) Simonsen

In water with a temperature range of 10.0°C to 18.7°C, a statistically significant correlation was observed between the biomass of *Aulacoseira granulata* and water temperature, oxygen content, orthophosphate concentration, and calcium and silicon concentrations (Table 3). An increase in the water temperature by 1°C was followed by an increase in the biomass of this species by  $1.89 \times 10^{-4} \text{ mg dm}^{-3}$ , and an increase in the biomass by  $1.33 \times 10^{-4} \text{ mg dm}^{-3}$  was accompanied by an increase in oxygen content by  $1 \text{ mgO}_2 \text{ dm}^{-3}$ . Further, an increase in biomass by  $2.86 \times 10^{-4} \text{ mg dm}^{-3}$  was accompanied by a decrease in orthophosphate concentration by  $1 \text{ mgPO}_4 \text{ dm}^{-3}$ , a biomass increase of  $0.05 \times 10^{-4} \text{ mg dm}^{-3}$  was accompanied by a decrease in calcium concentration by  $1 \text{ mgCa dm}^{-3}$ , and a biomass increase of  $5.70 \times 10^{-4} \text{ mg dm}^{-3}$  was accompanied by a decrease in silicon concentration of  $1 \text{ mgSi dm}^{-3}$  (Fig. 2).

*Fragilaria capucina* Desmazieres

In water with a temperature range of 10.0°C to 18.7°C, a statistically significant correlation was seen between the biomass of *Fragilaria capucina* and water temperature (Table 3). An increase in water temperature by 1°C was followed by an increase in the biomass of this species by  $0.17 \times 10^{-4} \text{ mg dm}^{-3}$  (Fig. 2).

*Diatoma vulgare* Bory

In water with a temperature range of 10.0°C to 16.5°C, a statistically significant correlation was observed between the biomass of *Diatoma vulgare* and water temperature, and orthophosphate and silicon concentrations (Table 3). An increase in water temperature by 1°C was followed by an increase in the

biomass of this species by  $1.25 \times 10^{-4}$  mg dm<sup>-3</sup>. An increase in biomass of  $4.93 \times 10^{-4}$  mg dm<sup>-3</sup> was accompanied by a decrease in orthophosphate concentration of 1 mgPO<sub>4</sub> dm<sup>-3</sup>, and a biomass increase of  $2.67 \times 10^{-4}$  mg dm<sup>-3</sup> was accompanied by a decrease in silicon concentration of 1 mgSi dm<sup>-3</sup> (Fig. 2).

#### *Fragilaria crotonensis* Kitton

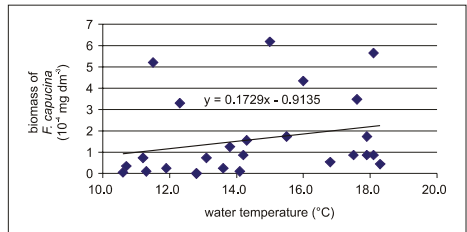
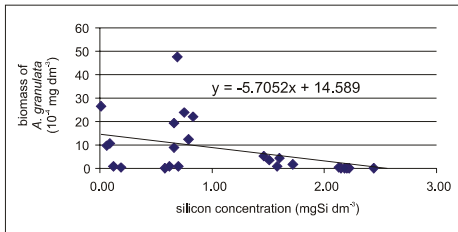
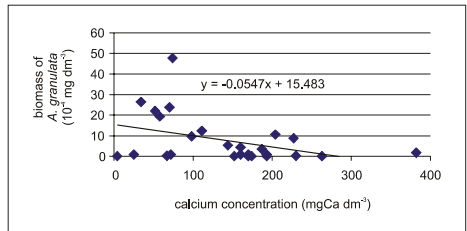
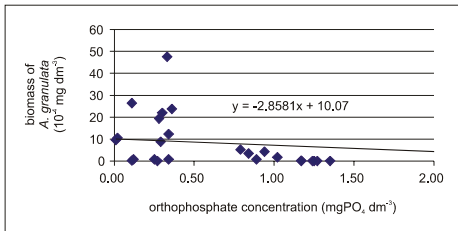
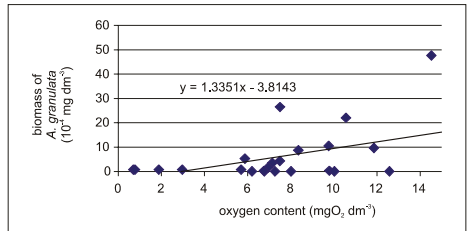
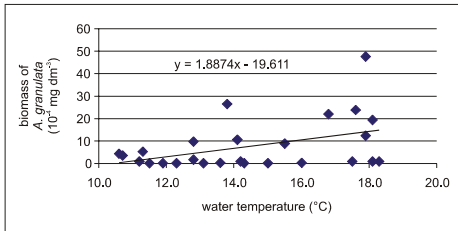
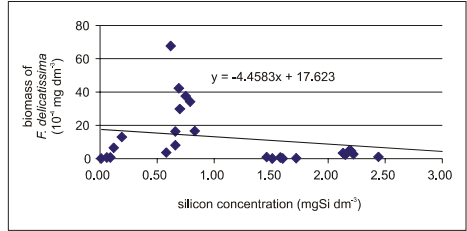
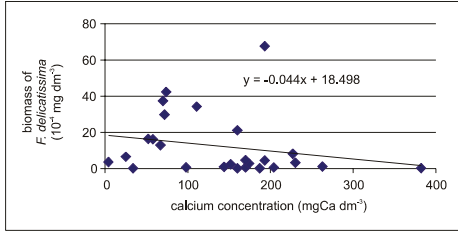
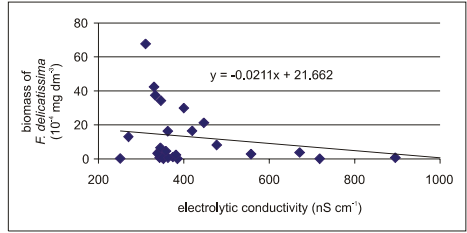
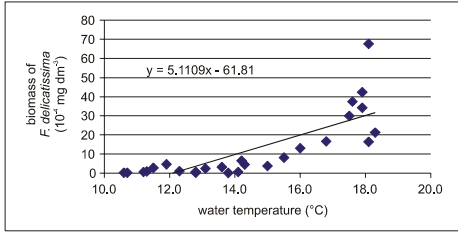
In water with a temperature range of 10.0°C to 25.0°C, a statistically significant correlation was seen between the biomass of *Fragilaria crotonensis* and water temperature, and orthophosphate and silicon concentrations (Table 3). A decrease in water temperature by 1°C was followed by an increase in the biomass of this species of  $0.67 \times 10^{-4}$  mg dm<sup>-3</sup>. An increase in the biomass of  $5.46 \times 10^{-4}$  mg dm<sup>-3</sup> was accompanied by a decrease in orthophosphate concentration of 1 mgPO<sub>4</sub> dm<sup>-3</sup>, and a biomass increase of  $2.81 \times 10^{-4}$  mg dm<sup>-3</sup> was accompanied by a decrease in silicon concentration of 1 mgSi dm<sup>-3</sup> (Fig. 2).

#### *Rhizosolenia* sp. Ehrenberg

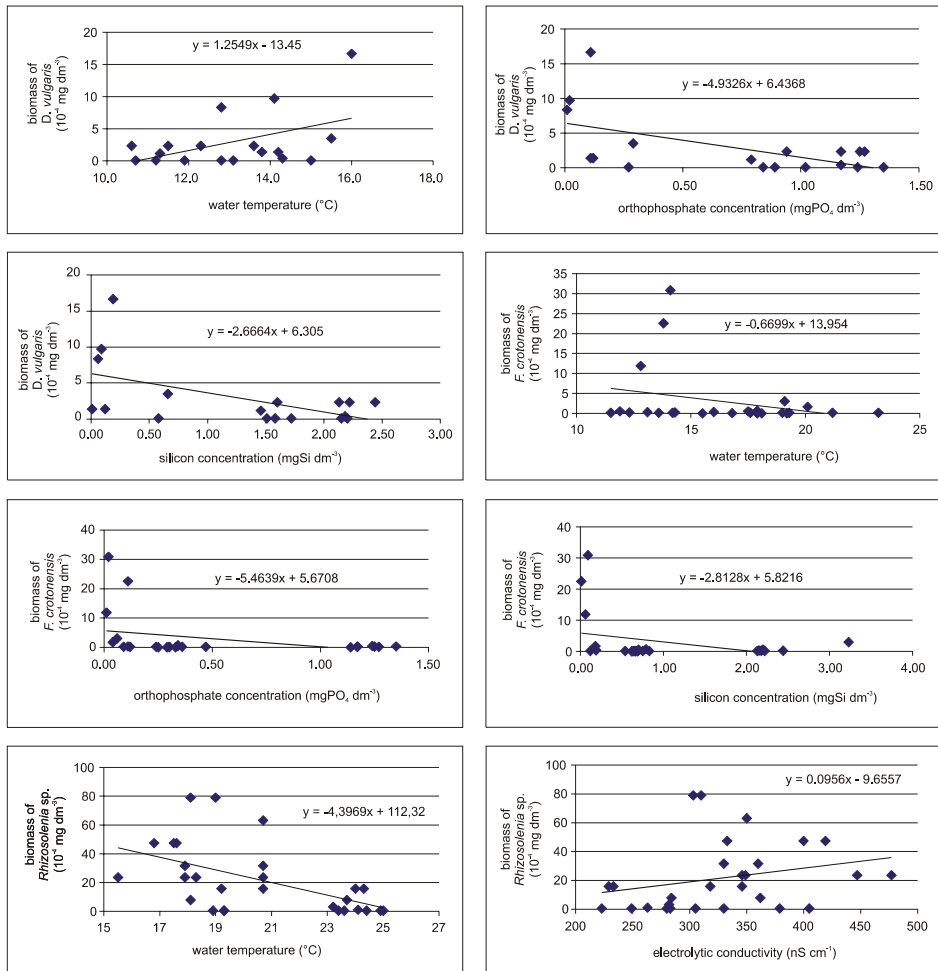
In water with a temperature range of 16.5°C to 25.0°C, a statistically significant correlation was observed between the biomass of *Rhizosolenia* sp. and water temperature and electrolytic conductivity (Table 3). A decrease in water temperature by 1°C was followed by an increase in the biomass of this genus of  $4.40 \times 10^{-4}$  mg dm<sup>-3</sup>, and an increase in electrolytic conductivity by 1 μS cm<sup>-1</sup> was accompanied by an increase in the biomass of  $0.09 \times 10^{-4}$  mg dm<sup>-3</sup> (Fig. 2).

The above data suggest that in most cases (except *F. crotonensis*), an increase in the biomass of these taxa was the result of an increase in water temperature. In the case of *F. crotonensis*, an increase in the biomass followed a decrease in water temperature, confirming that a lower water temperature favors the development of this species. The statistical analyses also illuminate the significant enhancement of development of *Rhizosolenia* sp. associated with increased electrolytic conductivity.

Laugaste et al. (1996) reported a relationship between diatom biomass and silicon concentration at a water temperature of 10°C. According to Dokulil and Padisak (1994), a statistically significant relationship was observed between the total abundance of phytoplankton and water phosphorus concentration ( $r^2 = 0.70$ ) in spring, when the phytoplankton was dominated by diatoms. Further, Huszar and Caracao (1998) recorded a statistically significant correlation between diatom biomass (which was predominated by *F. crotonensis*) and water temperature ( $r = -0.30$ ); and between diatom biomass and phosphorus content ( $r = 0.20$ ). Popowa et al. (2004) noted a negative correlation between the abundance of *F. capucina* and water phosphorus concentration, and a positive



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**Fig. 2.** Relationships between water physiochemical parameters and the biomass of diatoms in the littoral zone of Lake Jeziorak Mały in 2002 and 2003.

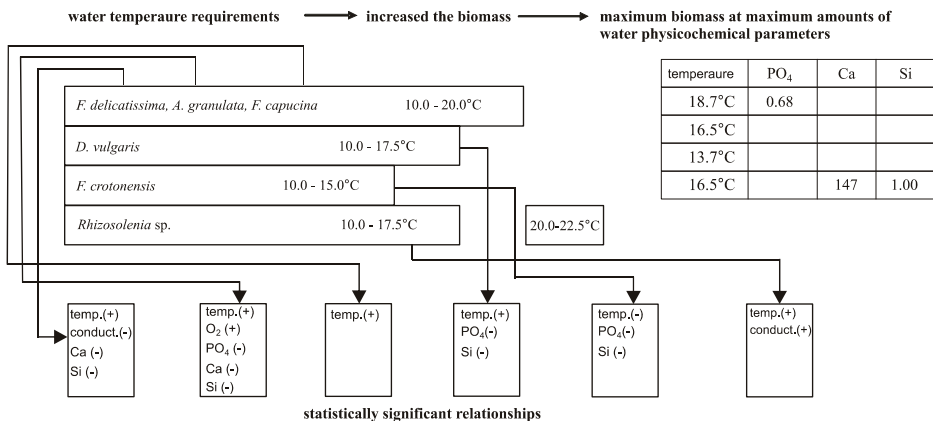
correlation between the abundance of *D. vulgaris* and phosphorus concentration. In concurrence with the findings here, Rengefors et al. (2003) reported no statistically significant relationship between the biomass of *Rhizosolenia* sp. and orthophosphate concentration.

Silicon is an important element to diatoms, and in freshwater waters is taken up in significant quantities only by this group of algae (Lampert and Sommer 1996). In Lake Jeziorak Mały, *F. delicatissima*, *A. granulata*, *D. vulgaris* and *F. crotonensis* contribute to the reduction of nutrient concentrations during their

growth, especially orthophosphate, calcium and silicon, as illustrated by the negative and statistically significant correlations. In the case of *Fragilaria capucina* and *Rhizosolenia* sp. a similar relationship was not confirmed. *F. capucina* was often present but had the lowest mean biomass of the studied taxa (Table 1), suggesting a smaller role in the removal of nutrients from the water. The genus *Rhizosolenia* sp. seldom occurred, and was only present in the summer months, when nutrients would be in high demand by the other phytoplankton groups e.g. blue-green algae (Zębek 2005b and 2006).

## CONCLUSION

The diatom community in the littoral zone of Lake Jeziorak Mały comprised 57 taxa in April to October 2002 and 2003. Of these, five species (*Fragilaria delicatissima*, *Aulacoseira granulata*, *Fragilaria capucina*, *Diatoma vulgare*, *Fragilaria crotonensis*) and one genus (*Rhizosolenia* sp.), representing the majority of total diatom abundance and biomass, were examined for their relationships with environmental factors. These taxa are typical of eutrophic waters, but have differing environmental requirements that are outlined in the figure below.



These data suggest that:

1. *F. delicatissima*, *A. granulata* and *F. capucina*, which were the most frequently occurring species, were the most tolerant to a range of environmental conditions of the taxa analyzed. These species developed in the widest temperature range and preferred more eutrophicated waters, with high phosphorus concentrations. *F. delicatissima* and *A. granulata*

- contribute to the reduction of nutrient concentrations during their growth (Ca and Si; and PO<sub>4</sub>, Ca and Si, respectively).
2. *D. vulgaris*, a species characteristic of the littoral zone and of plant periphyton, developed in a narrower water temperature range and preferred water with lower nutrient concentrations. It also contributes to an observable removal of nutrients from the water during its growth (PO<sub>4</sub> and Si).
  3. *F. crotonensis* developed in the narrowest water temperature range of the diatoms studied. This species preferred lower water temperatures, high electrolytic conductivity (480 μS cm<sup>-1</sup>) and high silicon and calcium concentrations. In spite of occurring only seldom, it can also contribute to noticeable removal of nutrients from the water column during growth (PO<sub>4</sub> and Si).
  4. *Rhizosolenia* sp. occurred in the summer only, when calcium and silicon concentrations were low and the phytoplankton was dominated by blue-green algae, these others competing for the available orthophosphate.

These various diatoms, as a result of their differing environmental requirements and impacts, thus shape the conditions for development of other phytoplankton groups, especially the blue-green algae. Small increases in water temperature in spring stimulate the growth of diatoms, illustrated by the increase in their biomass which took place above 10°C. In Lake Jeziorak Mały in April to October 2002 and 2003 diatoms decreased orthophosphate, calcium and silicon concentrations at water temperatures between 10 and 18.7°C, whilst above that upper level their abundance reduced, with blue green algae and other phytoplankton groups becoming dominant.

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