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Original Research

Phytoplankton in Relation to Water Quality of a Mesotrophic Lake

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Abstract

The dynamic of phytoplankton in Lake Dejguny was investigated in relation to the environmental conditions influencing water quality. The phytoplankton biomass and chlorophyll concentration in water were relatively low (typical of mesotrophic lakes), with a decreasing tendency when the water transparency significantly increased. The phytoplankton was not significantly correlated with the content of nutrients in water. The vast majority of phosphorus was in a form unavailable to phytoplankton, and the TN:TP ratio evidenced the role of nitrogen and phosphorus in colimitation of its development. The general evaluation of trophy based on TSI and TLI indicated meso-eutrophy or even slight eutrophy, because of partial assessments: TSI_{TP}, TLI_{TP}, and TLI_{TN} and domination of filamentous blue-green algae, which revealed a more advanced degree of eutrophication.

Keywords: phytoplankton, trophic status (TSI, TLI), biomass, colimitation

Introduction

Phytoplankton, as an important element of the structure of various lake ecosystems, is very flexible in its ability to adapt to different environmental conditions such as light, temperature, and concentration of nutrients (mainly nitrogen and phosphorus). Moreover, it reacts rapidly to changes in environmental conditions and, therefore, it is classified in the group of basic biological indicators of lake status. The concentration of chlorophyll *a* (an estimator of phytoplankton biomass), the contents of total nitrogen and total phosphorus, and Secchi disk visibility are the basis for evaluating trophic status [1-3]. In Poland, these parameters are currently used to assess the quality of water, which is classified based on, among others, chlorophyll *a* concentration (the biological component) in classes I-V, or on physical and chemical components (which support the biological component) in at least class II or lower than class II [4]. In accordance with the requirements of the Water Framework Directive [5], the biomass of phytoplankton and the concentration of chlorophyll *a* are the foundation for an assessment of ecological status (from high to bad ecological status), and are applied in many countries [6-9]. The species of fauna typical of mesotrophy, such as marine relict *Limnocalanus macrurus* G.O. Sars (zooplankton species) [10], and *Coregonus albula* L. (plankton-eating fish species) [11] were observed in Lake Dejguny. They are susceptible to deteriorating environmental conditions.

In 2006 the trophic conditions of Lake Dejguny (according to Pyka et al. [12]) indicated a meso-eutrophic status with a tendency toward progressive eutrophication, mainly through internal enrichment [13] as well as a result of human pressure [14]. The relationship between phytoplankton and environmental conditions served as the basis for studies on the mesotrophic, vendace-type lake undergoing progressive eutrophication.

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Materials and Methods

The analyses of phytoplankton and physical and chemical parameters were carried out in Lake Dejguny, located in the Great Masurian Lake District (northeastern Poland). This is a stratified reservoir with an area of 765.3 ha and a maximum and average depth of 45.0 and 12.0 m, respectively. According to the fishing classification, Lake Dejguny is a vendace-type lake with a population of plankton-eating species *Coregonus albula*.

The samples were collected from April to November between 2006 and 2008 in one station situated at the deepest location (Fig. 1). The integrated water samples (at 1 m depth intervals) from the 0-10 m zone during spring (April, May) and autumn (October, November) circulation and from the epilimnion during summer (June, August) stratification were taken for the evaluation of phytoplankton. The quantitative analysis of phytoplankton was performed with an inverted microscope using the Utermöhl method [15] in accordance with international and European monitoring standards [16]. The biomass was calculated with the cell volume assessment method [17]. The qualitative analysis of phytoplankton was carried out with a light microscope [18].

The concentration of chlorophyll *a* and pheophytins was determined with the method described by Lorenzen [19]. The content of total suspension (total seston) was determined with the weighing method of Hermanowicz et al. [20] after filtering water samples through glass filters (45 μm) and drying to a fixed mass at 105ºC. The mineral seston was left after roasting the samples at 550ºC and the content of organic seston was calculated as the difference between two fractions. The temperature and oxygen concentration in the vertical profile every meter at the deepest location were measured with a model 58 YSI oxygen probe. The water reaction was measured *in situ* with the apparatus OAKTON pH/Con model 300. The concentration of nitrate ions (NO_3^-) was determined using high-performance liquid ion chromatography on the HPLC set, Shimadzu-type Prominence (with column SHODEX SI-524E). Phosphates, total phosphorus (after mineralization) and ammonium nitrogen were determined by means of colorimetry on a Shimadzu UV 1601 spectrophotometer. The physical and chemical analyses of water were performed with standard methods [20, 21].

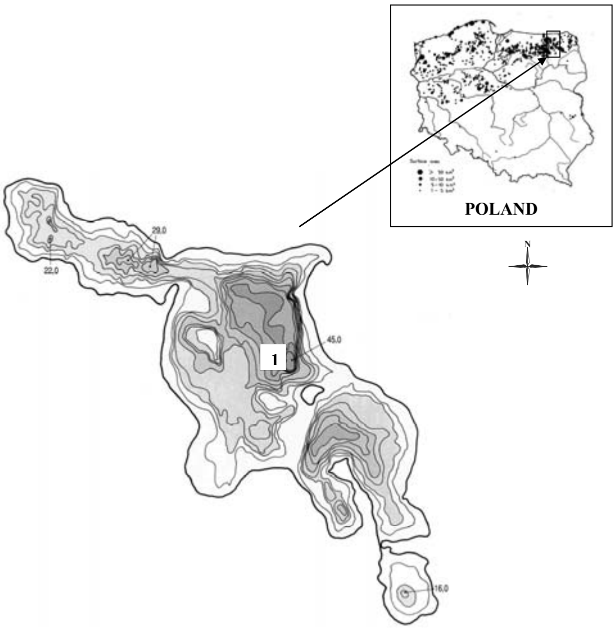

Fig. 1. Location of the sampling site 1 in Lake Dejguny (the deepest point of the lake).

The trophic status of Lake Dejguny was determined based on Trophic State Index (TSI) [1, 2] and Trophic Level Index (TLI) [3]. The calculations of these two parameters were based on Secchi disk visibility (SD) and the concentration of chlorophyll *a* (Chl), total nitrogen (TN), and total phosphorus (TP). Originally, the assessment of trophic status on the basis of TSI was carried out with the mean value from the summer stagnation period, because of the highest compatibility and usefulness of the index, while the TLI with the annual average value. For comparability, TSI and TLI calculations included the whole vegetation period.

The significance of the changes in total biomass of phytoplankton in water was tested with post hoc tests: Tukey's HSD (honestly significant difference) test and Fisher's LSD (least significant difference) test for comparing groups with uneven lot sizes [22]. It was assumed that the significance level was 0.05. Pearson's correlation was used to determine the relationship between TSI and TLI and their components, as well as between the characteristics of phytoplankton and environmental parameters. The principal component analysis (PCA) with a correlation matrix was used to correlate the biological parameters with physical and chemical parameters [22].

Results and Discussion

Environmental Variables

In 2006-08 the average seasonal values of Secchi disk visibility ranged from 3.36 to 4.15 m. Statistically higher significant values were recorded in 2006 and 2008 (Tukey's HSD test, p=0.039) (Table 1). The mean temperature and concentration of dissolved oxygen in 0-10 m layers (spring, autumn) and in the epilimnion (summer) did not differ significantly in the examined period. Any significant changes in water reaction, content of seston (total, mineral, and organic seston) and mineral forms of nitrogen and phosphorus were not detected. The concentration of chlorophyll was significantly and statistically different (Fisher's LSD test, p=0.041; 2006 *vs* 2008), and TP (Fisher's LSD test, p=0.022; 2006 vs 2007).

The content of chlorophyll (given as a sum of chlorophyll *a* and pheophytins) recorded during three vegetation periods changed on average from 4.50 to 8.05 $\mu g \cdot dm^{-3}$ (Table 1). The proportion of active form of chlorophyll constituted from 13 to 79%. The mean concentration of chlorophyll *a* was 1.36, 1.30, and 2.12 $\mu g \cdot dm^{-3}$ in 2006, 2007, and

Table 1. Mean values of physicochemical parameters over the growth season (April-November) in 2006-08 in Lake Dejguny.

Parameters	2006	2007	2008	Mean±standard deviation
Chlorophyll* (Chl, µg·dm^{-3})	8.05***	7.19	4.50***	6.69±2.94
Total seston (TS, mg·dm^{-3})	3.11	3.17	2.55	2.95±0.71
Mineral seston (MS, mg·dm^{-3})	1.91	1.90	1.42	1.75±0.56
Organic seston (OS, mg·dm^{-3})	1.20	1.27	1.12	1.19±0.39
Secchi disk visibility (SD, m)	3.36***	3.98	4.15***	3.81±0.61
pH	8.37	8.33	8.29	8.33±0.33
Temperature** (T, ºC)	12.4	14.8	14.1	13.7±5.19
Dissolved oxygen** (O_2, mg·dm^{-3})	10.1	8.8	10.1	9.7±3.32
Oxygenation (%)	93.7	77.4	96.9	89.0±28.81
Total nitrogen (TN, mg·dm^{-3})	0.944	0.843	0.988	0.926±0.11
NH_4-N (mg·dm^{-3})	0.067	0.058	0.062	0.063±0.04
NO_3-N (mg·dm^{-3})	0.027	0.031	0.134	0.061±0.15
Total phosphorus (TP, mg·dm^{-3})	0.088***	0.055***	0.069	0.072±0.22
PO_4-P (mg·dm^{-3})	0.022	0.019	0.022	0.021±0.01
TN:TP	11	17	14	14±5.62

*Chlorophyll – given as a sum of chlorophyll *a* and pheophytins

**mean values from water layers 0-10 m during spring and autumn circulation, and from epilimnion during summer stratification

***statistically significant difference, $p<0.05$

2008, respectively, which indicated the first water quality class (high ecological status) [4]. The transparency of water was relatively high and the average visibility of the Secchi disk in all years of the study did not exceed the boundary value for classes I-II as in 2004-05 [13]. The concentrations of total nitrogen and total phosphorus were relatively low and classified the lake to at least second class (at least good ecological status). The low content of total seston, including mainly the organic component, was comparable with the values measured in clean oligotrophic lakes [23, 24].

Trophic State Index versus Trophic Level Index

The partial values of Trophic State Index were diversified. The lowest values were recorded for TSI_{SD} (38-47; on average 41.4) then for TSI_{Chl} (42-55; 48.3), and TSI_{TN} (50-55; 53.3), while the highest for TSI_{TP} (55-73; 65.2) (Fig. 2). The mean TSI value (51) in the summer stagnation period in 2006-08 indicated a state of meso-eutrophy [1, 25], and according to Håkanson and Boulion [26] even eutrophy. The

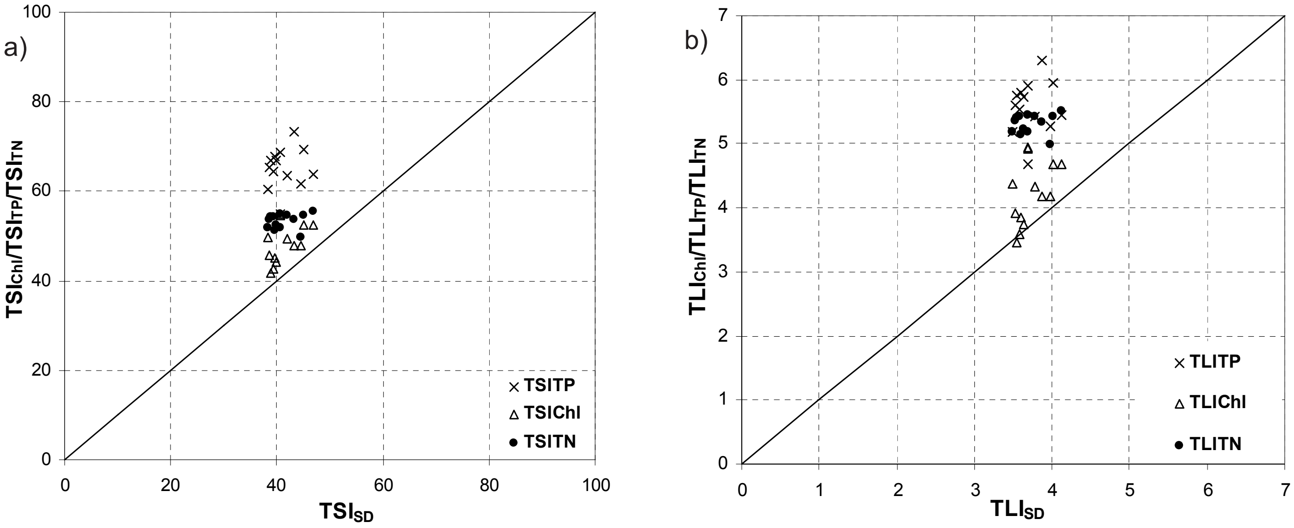

Fig. 2. The assessment of trophy status according to TSI (a) and TLI (b) based on chlorophyll a concentration (TSI_{Chl}, TLI_{Chl}), total phosphorus (TSI_{TP}, TLI_{TP}), and total nitrogen (TSI_{TN}, TLI_{TN}) concentrations and Secchi disk visibility (TSI_{SD}, TLI_{SD}).

Table 2. The relationship (the Pearson correlation coefficient) between Trophic State Index (TSI) and Trophic Level Index (TLI) and their component indices.

Indices	TLI	TLI_{SD}	TLI_{Chl}	TLI_{TP}	TLI_{TN}
TSI	0.993*	0.754*	0.617*	0.491	0.327
TSI_{SD}	0.729*	0.999*	0.490	0.122	0.151
TSI_{Chl}	0.703*	0.491	0.999*	-0.267	0.107
TSI_{TP}	0.413	0.123	-0.267	0.999*	-0.026
TSI_{TN}	0.320	0.150	0.107	-0.026	0.999*

*statistically significant correlation, $p<0.05$

Table 3. Mean values of total biomass and the biomass of phytoplankton groups (mg·dm^{-3}) over the growth season (April-November) in 2006-08 in Lake Dejguny.

Phytoplankton group	2006	2007	2008	Mean±standard deviation
Cyanoprokaryota (CYAN)	1.40	0.51	0.39	0.81±0.79
Heterokontophyta:				
Chrysophyceae (CHRY)	0.26	0.08	0.08	0.15±0.36
Bacillariophyceae (BAC)	0.98	2.92*	0.65*	1.47±1.65
Euglenophyta (EUG)	<0.10	<0.10	<0.10	0.001±0.002
Dinophyta (DIN)	0.21	0.09	0.10	0.13±0.13
Cryptophyta (CRY)	0.28	0.15	0.28	0.24±0.28
Chlorophyta (CHLO)	0.07	0.10	0.11	0.09±0.06
Total biomass (TB)	3.21	3.85	1.60	2.91±1.80

*statistically significant correlation, $p<0.05$

values of Trophic Level Index, calculated on the basis of individual parameters, ranged between 3.5 and 6.3 (Fig. 2). The mean TLI value in the vegetation season was 4.7 which, according to Burns et al. [27], confirmed eutrophic status, and, according to Parparov et al. [28], the meso-eutrophic status of the lake. The values of each component revealed the following relationship: $TLI_{SD}<TLI_{Chl}<TLI_{TN}<TLI_{TP}$, which was similar to the components of TSI. The evaluation of trophy status based exclusively on TP (TLI_{TP} and TSI_{TP}) and TN (TLI_{TN}) indicated an advanced degree of eutrophication. A significantly high correlation was observed between the values of TSI and TLI and their components (Table 2). It may be thus concluded that both indices may be successfully used interchangeably for evaluating the trophic status of lakes. As opposed to TSI, the application of TLI to assess trophy status is less common, but it comprises the annual variations of tested parameters. According to Parparov et al. [28], TLI is suitable for evaluating the quality of natural water resources, particularly when eutrophication becomes a serious problem.

Phytoplankton Dynamics

The average total biomass of phytoplankton in the vegetation season in 2006-08 ranged from 1.60 to 3.85 mg·dm^{-3} (Table 3). The value of total biomass (below 6.00 mg·dm^{-3}) remained within the range typical of lowland, mesotrophic harmonic-type lakes in moderate climate and for mesotrophic alpine lakes [29-31]. The phytoplankton assemblages were composed of the members of six divisions: Cyanoprokaryota, Heterokontophyta, Euglenophyta, Dinophyta, Cryptophyta, and Chlorophyta. The diatoms constituted the largest biomass, ranging on average from 0.65 to 2.92 mg·dm^{-3} (Table 3). These values differed significantly (Fisher's LSD test, p = 0.047; 2007 vs 2008). The blue-green algae co-dominated in the phytoplankton (on average from 0.39-1.40 mg·dm^{-3}). The average proportion of other groups did not exceed 10% of total biomass. The typical species *Planktothrix agardhii* (Gom.) Anagn. & Kom., *Planktolyngbya limnetica* (Lemm.) Kom-Legn.&Cronb., and *Tabellaria flocculosa* (Roth) Kütz. occur in more or less eutrophicated waters [32-34], and *Cyclotella* spp., often found in alpine lakes [35], were predominant in the phytoplankton. The analogous structure of domination (diatoms and blue-green algae) was observed in spring in surface water [36] or in summer and autumn in Lake Hańcza [37] or with a similar trophic status. However, other species were predominant in the phytoplankton.

In 2006-08 the tendency towards two peaks of total biomass (in spring and autumn) and the minimum in summer was observed (Fig. 3). The tendency of phytoplankton biomass to change was compatible with the changes in chlorophyll concentration and the correlation between them was very high (r=0.743) (Table 4). This close relationship enables

Table 4. The relationship (the Pearson correlation coefficient) between phytoplankton features and environmental variables.

	CYAN	CRY	DIN	CHRY	BAC	EUG	CHLO	TB	Chl	OS
CYAN	-	0.408	0.664*	-0.056	-0.107	0.181	-0.328	0.432	0.345	0.314
CRY	0.408	-	0.552	0.002	0.047	-0.302	-0.033	0.417	0.280	0.550
DIN	0.664*	0.552	-	0.111	-0.155	0.083	-0.064	0.327	0.374	0.634*
CHRY	-0.056	0.002	0.111	-	-0.276	0.573*	-0.223	-0.078	-0.128	0.419
BAC	-0.107	0.047	-0.155	-0.227	-	-0.165	0.016	0.811*	0.608*	-0.207
EUG	0.181	-0.302	0.083	0.573*	-0.165	-	-0.416	-0.012	-0.170	0.264
CHLO	-0.328	-0.033	-0.064	-0.223	0.016	-0.416	-	-0.152	-0.293	0.280
TB	0.432	0.417	0.327	-0.078	0.811*	-0.012	-0.152	-	0.743*	0.172
Chl	0.345	0.280	0.374	-0.128	0.608*	-0.170	-0.293	0.743*	-	-0.118
OS	0.314	0.550	0.634*	0.419	-0.207	0.264	0.280	0.172	-0.118	-
T	-0.246	-0.464	-0.200	-0.006	-0.554*	0.142	0.346	-0.692*	-0.812*	0.138
O_2	0.169	0.724*	0.222	0.219	0.248	-0.115	-0.337	0.463	0.456	0.133
SD	-0.715*	-0.380	-0.867*	-0.201	0.220	-0.307	0.325	-0.264	-0.434	-0.490
pH	0.187	0.507	0.275	0.498	-0.544	0.050	0.088	-0.216	-0.441	0.707*
NH_4-N	0.217	-0.146	0.626*	0.153	-0.406	0.388	-0.006	-0.224	-0.082	0.340
NO_3-N	-0.270	0.598*	0.109	0.087	0.089	-0.199	-0.122	0.075	0.216	0.174
TN	0.040	0.361	0.348	0.027	-0.220	-0.396	0.015	-0.196	0.163	-0.057
PO_4-P	-0.134	-0.391	-0.244	0.153	-0.446	0.243	-0.343	-0.526	-0.070	-0.365
TP	0.323	0.041	0.118	0.660*	-0.541	0.312	-0.110	-0.211	-0.186	0.316
TSI	0.698*	0.452	0.735*	0.356	-0.150	0.093	-0.302	0.355	0.586*	0.370
TLI	0.676*	0.460	0.713*	0.323	-0.038	0.055	-0.318	0.438	0.676*	0.321

*statistically significant difference, $p<0.05$
Identification codes are given in Tables 1 and 3.

the application of chlorophyll concentration as an estimator of phytoplankton biomass, which was approved by the regulation of the Minister of the Environment of November 9, 2011 [4]. It also is used as a component to assess the trophic status of lakes [1-3] or to evaluate ecological status [9].

According to Navarro and Thompson [38], the intensive growth of algae may significantly influence the quantity of organic seston (OS) in water. The changes in its content in the vegetation season (summer and autumn peak) were analogical to the changes in phytoplankton abundance (Fig. 3). The comparison of all curves that depict the seasonal changes with the models denoted by Oleksowicz [39] clearly indicates that it was typical of lakes with medium abundance in biogenic compounds. The coincidence in time of peaks of seston and chlorophyll *a* concentration also was observed in an oligotrophic lake [24].

Phytoplankton versus Environmental Variables

An analysis of the relationship between phytoplankton parameters revealed significant and positive correlations between the abundance of blue-green algae and dinoflagellates, euglenids, and chrysophytes (Table 4). The diatoms had a significant impact on total biomass (r=0.811) and chloro-

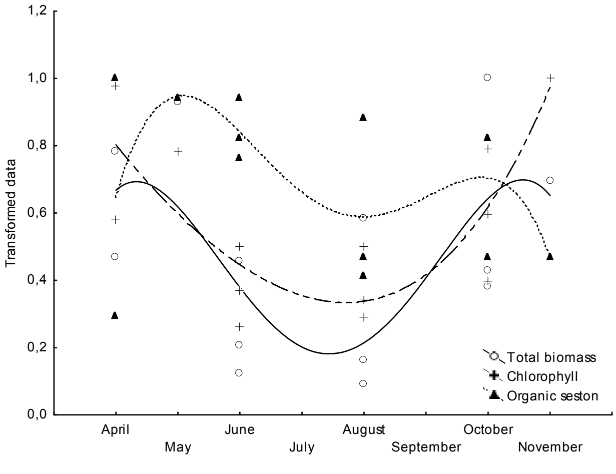

Fig. 3. Models of seasonal dynamic of phytoplankton based on total biomass, chlorophyll and organic seston in 2006, 2007, and 2008.
Total biomass = $-0.008x^4 + 0.144x^3 - 0.852x^2 + 1.742x - 0.353$; $R^2 = 0.721$
Chlorophyll = $-0.001x^4 + 0.027x^3 - 0.158x^2 + 0.175x + 0.764$; $R^2 = 0.895$
Organic seston = $-0.007x^4 + 0.120x^3 - 0.761x^2 + 1.838x - 0.545$; $R^2 = 0.999$

phyll concentration in water (r=0.608), while the dinoflagellates influenced the content of organic seston. A very significant correlation was found between TB and Chl, whereas their relationship with OS was not statistically significant.

Assuming the relationship between phytoplankton and environmental conditions, TB and Chl were not significantly correlated with mineral and total forms of nitrogen and phosphorus content (Table 4), despite the fact that these parameters are most often closely correlated [40-42]. This phenomenon may be associated with the fact that phosphorus is found mainly in a form unavailable to phytoplankton (the mean content of mineral P was 29%) through the process of phosphorus binding with calcium in the sediments [43]. The values of TN:TP ratio ranged from 8 to 30 (on average 14, Table 1). Despite this fact, the values from 10 to 17 were most often recorded, indicating that both nutrients may be uptaken and accumulated in algae cells [44]. Depending on the content of N and P, these nutrients stimulate or limit algae development, especially in unpolluted, clear lakes [42]. The study of phytoplankton in Lake Erie confirmed a colimitation by N and P with Fe during a summer period of thermal stratification, which may be more widespread [45]. The massive growth of blue-green algae that fix atmospheric nitrogen often coincides with low ratio [42]. Although the studies by Dolman et al. [46] do not support this thesis, they prove that blue-green algae show various reactions to a different degree of water enrichment in nitrogen and phosphorus. The abundance of blue-green algae may indicate a more advanced stage of eutrophication of lakes [47]. In the phytoplankton of Lake Dejguny, the co-dominant blue-green algae, mainly filamentous forms *Planktothrix agardhii* and *Planktolyngbya limnetica*, are a species that are unable to assimilate atmospheric nitrogen dissolved in water and are capable of toxin production [34, 48]. The maximum of *P. agardhii* biomass was observed with a low ratio in each year of the study (ca. 11). The ratio TN:TP>17 (when phosphorus becomes a growth limiting factor) coincided with the spring and summer peak of biomass of diatom *Tabellaria flocculosa* in 2007.

The results of principal component analysis indicated that the first two components (PC1 and PC2) explained 68% of variability of data, which included the selected parameters of phytoplankton as well as the environmental parameters and indices (Fig. 4a). The analyzed characteris-

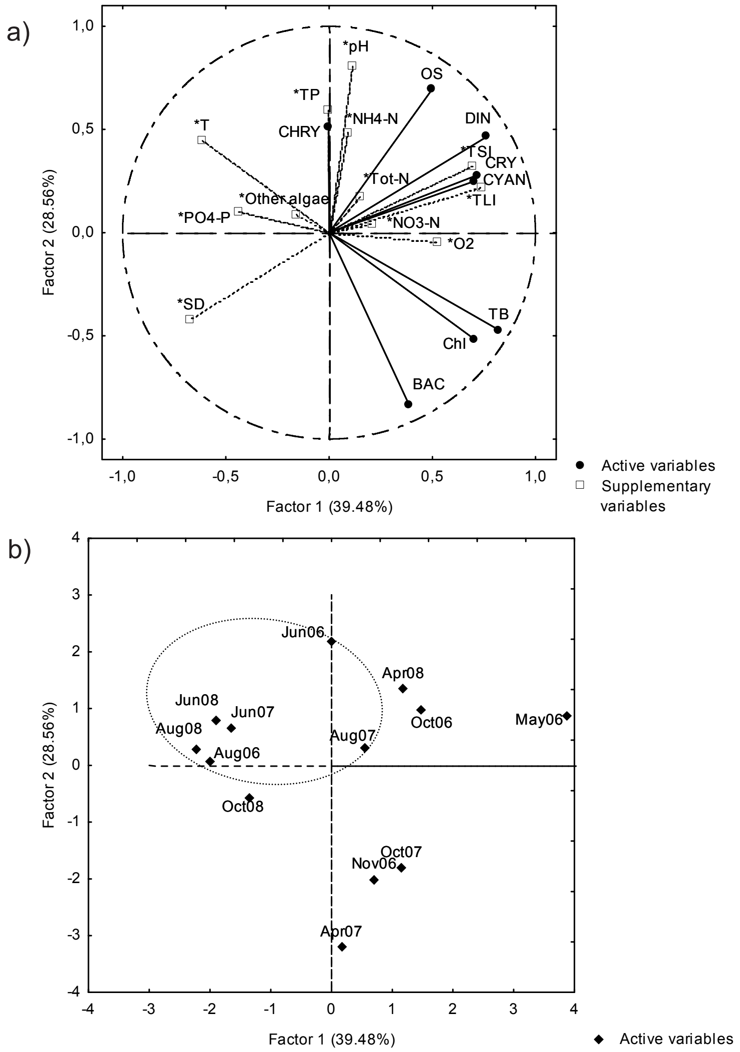

Fig. 4. Principal Components Analysis (PCA): ordination diagram of phytoplankton features in relation to environmental variables (a) and classification of samples (b); identification codes are given in Tables 1 and 3.

tics of phytoplankton (TB, Chl, OS, and biomass of predominant group) were negatively correlated with PC1, which explained 39% of total variability. Analogous, a close relationship also was observed in the case of TSI and TLI. The opposite correlation was observed between the content of TP, PO_4-P, temperature, and Secchi disk visibility. The second component explained 29% of total variability. TB, BAC, and Chl (strongly-correlated parameters) and SD had negative changes in relation to PC2 as opposed to the other parameters.

PC1 created the possibility to distinguish a specific group of summer samples from spring-autumn samples, with the inclusion of active parameters (the characteristics of phytoplankton) (Fig. 4b). There were two exceptions: the sample of October 2008 was comparable with the group of summer samples and the sample of August 2007, with the group of spring-autumn samples. PC2 indicated also the cohesion of samples from the summer stagnation period.

Conclusions

The tested biological (chlorophyll *a*) and physicochemical parameters classified Lake Dejguny as water purity class I-II, i.e. of at least good ecological status. The total biomass of phytoplankton was in the value range typical of lowland, mesotrophic harmonic-type lakes in moderate climate, and for mesotrophic alpine lakes. Over the 3-year study period, the lowest total biomass (composed mainly of diatom biomass) and the concentration of chlorophyll in water were recorded in 2008. These changes were accompanied by the increase in water transparency measured as Secchi disk visibility. The phytoplankton (total biomass, biomass of dominant groups, and concentration of chlorophyll) did not show a significant correlation with the content of mineral and total forms of nitrogen and phosphorus. The reason for this could be the fact that phosphorus was mainly in a form unavailable to phytoplankton, since the proportion of phosphates in the total content of phosphorus averaged 29%. The values of TN:TP ratio (10-17) evidenced about the role of nitrogen and phosphorus in colimitation of its development. The analysis of PCA indicated a relatively high cohesion of phytoplankton in relation to the environmental parameters, only in the summer period. In spite of many significant features of mesotrophic lake, the evaluation of trophic status based on TSI and TLI indicated the meso-eutrophic or slightly eutrophic profile of the lake. In addition, the partial assessments of TSI_{TP}, TLI_{TP}, and TLI_{TN}, and the domination of filamentous blue-green algae suggested a more advanced degree of eutrophication.

References

1. CARLSON R.E. A trophic state index for lakes. Limnol. Oceanogr. **22**, 361, **1977**.
2. KRATZER C.R., BREZONIK P.L. A Carlson-type trophic state index for nitrogen in Florida lakes. Water. Res. Bull., **17**, 713, **1981**.
3. BURNS N.M., RUTHERFORD C.R., CLAYTON J.S. A monitoring and classification system for New Zealand lakes and reservoirs. Lake and reservoir management **14**, (4), 255, **1999**.
4. The Regulation of the Minister of the Environment of November 9, 2011 for the status classification of surface water bodies and environmental quality standards for priority substances. The Official Journal of the Laws, No. 257, Item 1545, **2011**.
5. European Commision. Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of water policy. Official Journal 2000 L 327/1, European Commission, Brussels, **2000**.
6. PADISÁK J., BORICS G., GRIGORSZKY I., SORÓCZKI-PINTÉR E. Use of phytoplankton assemblages for monitoring ecological status of lakes within the Water Framework Directive: the assemblage index. Hydrobiologia **553**, 1, **2006**.
7. MISCHKE U., RIEDMÜLLER U., HOEHN E., SCHÖNFELDER I., NIXDORF B. Description of the German system for phytoplankton-based assessment of lakes for implementation of the EU Water Framework Directive (WFD). In: Mischke U and Nixdorf B. (Eds), Bewertung von Seen mittels Phytoplankton zur Umsetzung der EU-Wasserrahmenrichtlinie. Aktuelle Reihe 2/2008, Bad Saarow, Freiburg, Berlin. University of Cottbus, pp. 117-146, **2008**.
8. KAIBLINGER C. ANNEVILLE O., TADONLEKE R., RIMET F., DRUART J.C., GUILLARD J., DOKULIL M.T. Central European water quality indices applied to long-term data from peri-alpine lakes: test and possible improvements. Hydrobiologia **633**, 67, **2009**.
9. NAPIÓRKOWSKA-KRZEBIETKE A., PASZTALENIEC A., HUTOROWICZ A. Phytoplankton metrics response to the increasing phosphorus and nitrogen gradient in shallow lakes. J. Elem. **17**, (2), 289, **2012**.
10. TUNOWSKI J. Pelagic zooplankton of Lake Dejguny with a population of marine relict *Limnocalanus macrurus* G.O. Sars, 1888. XXII Zjazd Hydrobiologów Polskich, Kraków, 19-22 IX 2012, pp. 187, **2012** [In Polish].
11. FISZER M., PRZYBYŁ A., ANDRZEJEWSKI W., MAZURKIEWICZ J., GOLSKI J., PRZYBYLSKA K., RUNOWSKI S. Effects of eutrophication on vendace, *Coregonus albula* (L.). II. Biological characteristics of vendace from selected lakes in Wielkopolska. Arch. Pol. Fish. **20**, 97, **2012**.
12. PYKA J.P., ZDANOWSKI B., STAWECKI K., PRUSIK S. Trends in environmental changes in the selected lakes of the Mazury and Suwałki Lakelands. Limnol. Rev. **7**, (2), 101, **2007**.
13. DUNALSKA J., BRZOZOWSKA R., ZDANOWSKI B., STAWECKI K., PYKA J. Variability of organic carbon, nitrogen and phosphorus in the context of Lake Dejguny eutrophication (Mazurskie Lakes District). Limnol. Rev. **6**, 79, **2006**.
14. DOMSKA D., RACZKOWSKI M., STANKIEWICZ K. Influence of different areal pollution sources on some compounds content in water of Dejguny Lake. Pol. J. Natur. Sc. **25**, (4), 369, **2010**.
15. UTERMÖHL H. The improvement to the quantitative phytoplankton methods. Mitt. internat. Verein. Limnol. **9**, 1, **1958** [In German].
16. KELLY M. International and European standards for algal-based monitoring. Oceanol. Hydrobiol. Stud. **33**, 77, **2004** [In German with English Summary].

17. PLIŃSKI M., PICIŃSKA J., TARGOŃSKI L. Method defining the biomass of marine phytoplankton by means of computers. Zesz. Nauk. WBiNoZ Gdansk University **10**, 129, **1984** [In Polish].
18. KAWECKA B., ELORANTA P.V. Outline of the ecology of algae in freshwater and terrestrial habitats. PWN, Warsaw, pp. 1-252, **1994** [In Polish].
19. LORENZEN C.J. Determination of chlorophyll and pheopigments: Spectrophotometric equations. Limnol. Oceanogr. 12, 343, **1967**.
20. HERMANOWICZ W., DOJLIDO J., DOŻAŃSKA W., KOZIOROWSKI B., ZERBE J. The physico-chemical analyses of water and wastewater. Arkady Press, Warsaw, pp. 1-555, **1999** [In Polish].
21. STANDARD METHODS for Examination of Water & Wastewater. Am. Publ. Health ASN., New York, pp. 1325, **1999**.
22. STATISTICA FOR WINDOWS [Computer program manual]. 1984-2009, v. 9; StatSoft, Inc. Tulsa, OK: StatSoft, Inc., 2300 East 14th Street, Tulsa, OK 74104, http://www.statsoft.com.
23. KREEGER D.A., GOULDEN C.E., KILHAM S.S., LYNN S.G., DATTA S., INTERLANDI S.J. Seasonal changes in the biochemistry of lake seston. Freshwater Biol. **38**, 539, **1997**.
24. BERTONI R., PISCIA R., CALLIERI C. Horizontal heterogeneity of seston, organic carbon and picoplankton in the photic zone of Lago Maggiore, Northern Italy. J. Limnol. **63**, (2), 244, **2004**.
25. ZDANOWSKI B. Eutrophication of lakes in Wigry National Park: threats and their assessment. In: Zdanowski B., Kamiński M. and Martyniak A. (Eds), Functioning and protection of aquatic ecosystems in protected areas. IRS, Olsztyn, pp. 261-278, **1999** [In Polish].
26. HÅKANSON L., BOULION V.V. Regularities in primary production, Secchi depth and fish yield and a new system to define trophic and humic state indices for lake ecosystems. Internat. Rev. Hydrobiol. **86**, 23, **2001**.
27. BURNS N, MC INTOSH J., SCHOLES P. Strategies for managing the lakes of the Rotorua District, New Zealand. Lake and reservoir management **21**, (11), 61, **2005**.
28. PARPAROV A., GAL G., HAMILTON D., KASPRZAK P., OSTAPENIA A. Water quality assessment, trophic classification and water resources management. J. Water Resource and Protection **2**, 907, **2012**.
29. HILLBRICHT-ILKOWSKA A., WIŚNIEWSKI R.J. Trophic diversity of the lakes of SLP and its buffer zone – current state, long-term variability and place in the trophic classification of lakes. In: Hillbricht-Ilkowska A. and Wiśniewski R.J. (Eds) Lakes of SLP. Relationships with landscape, eutrophication state and protection policy. Zesz. Nauk. Kom. „Człowiek i Środowisko" **7**, 181, **1994** [In Polish].
30. TOLOTTI M. Phytoplankton and littoral epilithic diatoms in high mountain lakes of the Adamello-Brenta Regional Park (Trentino, Italy) and their relation to trophic status and acidification risk. J. Limnol. **60**, (2), 171, **2001**.
31. SZELĄG-WASIELEWSKA E. Trophic status of lake water ewaluated using phytoplankton community structure – change after two decades. Pol. J. Environ. Stud. **15**, (1), 139, **2006**.
32. GRABOWSKA M. Cyanoprokaryota blooms in the polyhumic Siemianówka dam reservoir in 1992-2003. Ocean. Hydrob. Stud. **34**, (1), 73, **2005**.
33. NAPIÓRKOWSKA-KRZEBIETKE A., HUTOROWICZ A. Long-term changes of phytoplankton in Lake Niegocin, in the Masurian Lake Region, Poland. Ocean. Hydrob. Stud. **35**, (3), 209, **2006**.
34. PAWLIK-SKOWROŃSKA B., PIRSZEL J., KORNIJÓW R. Spatial and temporal variation in microcystin concentrations during perennial bloom of *Planktothrix agardhii* in a hypertrophic lake. Ann. Limnol. – Int. J. Lim. **44**, 145, **2008**.
35. PIONTEK M., CZYŻEWSKA W. Efficiency of drinking water treatment processes. Removal of phytoplankton with special consideration for Cyanobacteria and improving physical and chemical parameters. Pol. J. Environ. Stud. **21**, (6), 273, **2012**.
36. TREVISAN R., POGGI C., SQUARTINI A. Factors affecting diatom dynamics in the alpine lakes of Colbricon (Northern Italy): a 10-year survey. J. Limnol. **69**, (2), 199, **2010**.
37. HUTOROWICZ A., NAPIÓRKOWSKA-KRZEBIETKE A. Phytoplankton assemblages in Lake Hańcza. In: Kozłowski J., Poczyczyński P. and Zdanowski B. (Eds) Environment and ichtyofauna of Lake Hańcza. IRS, Olsztyn, pp. 93-102, **2008** [In Polish].
38. NAVARRO J.M., THOMPSON R.J. Seasonal fluctuations in the size spectra, biochemical composition and nutritive value of the seston available to a suspension-feeding bivalve in a subarctic environment. Mar. Ecol. Prog. Ser. **125**, 95, **1995**.
39. OLEKSOWICZ A.S. The dynamics of algal communities in the Kashubian Lakes of different trophy. Rozprawy UMK, Toruń, pp. 1-84, **1988** [In Polish].
40. GUILDFORD S.J., HECKY R.E., SMITH R.E.H., TAYLOR W.D., CHARLTON M.N., BARLOW-BUSCH L., NORTH R.L. Phytoplankton nutrient status in Lake Erie in 1997. J. Gt. Lakes Res. **31**, (2), 72, **2005**.
41. KOZAK A. Seasonal Changes Occurring Over Four Years in a Reservoir's Phytoplankton Composition. Pol. J. Environ. Stud. **14**, (4), 451, **2005**.
42. LEWIS W.M., WURTSBAUGH W.A. Control of lacustrine phytoplankton by nutrients: erosion of the phosphorus paradigm. Int. Rev. Hydrobiol. **93**, (4-5), 446, **2008**.
43. BRZOZOWSKA R., DUNALSKA J., ZDANOWSKI B. Preliminary characteristics of the chemical composition of the toplayer bottom deposits in Lake Dejguny (Mazurskie Lake District). Limnol. Rev. **5**, 11, **2005**.
44. ZDANOWSKI B. Variability of nitrogen and phosphorus contents and lake eutrophication. Pol. Arch. Hydrobiol. **29**, 541, **1982**.
45. NORTH R.L., GUILDFORD S.J., SMITH R.E.H., HAVENS S.M., TWISS M.R. Evidence for phosphorus, nitrogen, and iron colimitation of phytoplankton communities in Lake Erie. Limnol. Oceanogr. **52**, (1), 315, **2007**.
46. DOLMAN A.M., RÜCKER J., PICK F.R., FASTNER J., ROHRLACK T., MISCHKE U., WIEDNERET C. Cyanobacteria and cyanotoxins: the influence of nitrogen versus phosphorus. PLoS ONE **7**, (6), e38757, **2012**.
47. DOKULIL M.T., TEUBNER K. Cyanobacterial dominance in lakes. Hydrobiologia **438**, 1, **2000**.
48. WIŚNIEWSKA M., KRUPA D., PAWLIK-SKOWROŃSKA B., KORNIJÓW R. Development of toxic *Planktothrix agardhii* (Gom.) Anagn. et Kom. and potentially toxic algae in the hypertrophic Lake Syczyńskie (Eastern Poland). Ocean. Hydrob. Stud. **36**, (1), 173, **2007**.