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RESEARCH ARTICLE

Phytoplankton composition and physicochemical properties in Lake Swarzędzkie (midwestern Poland) during restoration: Preliminary results

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Abstract. This paper presents the preliminary results of a study of the phytoplankton structure and dynamics and physicochemical properties of Lake Swarzędzkie in 2011. The subject of the study is a shallow, elongated, post-glacial lake located in western Poland. The surface area is 93.7 ha with a maximum depth of 7.2 m. Its poor water quality led to the implementation of chemical and biological restoration procedures in an attempt to improve it. The highest concentration of total nitrogen was 13.07 mg l^{-1} N. Secchi depth (SD) was low in the summer with a minimum value of 0.5 m in September. The most abundant group of phytoplankton were cyanobacteria, and the maximum value of chlorophyll *a* concentration was 278.0 µg l^{-1}. The dominant species were *Pseudanabaena limnetica* and *Aphanizomenon gracile*. Cyanobacteria were the most abundant phytoplankton until November. Maximum diatom, cryptophyte, and chrysophyte density was noted in the spring, and the most abundant were *Nitzschia acicularis*, *Cryptomonas marssonii*, *Rhodomonas lacustris*, *Erkenia subaequiciliata*, and *Dinobryon sociale*. One-hundred and thirty-six phytoplankton taxa belonging to nine taxonomic groups were identified in Lake Swarzędzkie. The highest number of taxa was noted among chlorophytes (57 taxa), cyanobacteria (19), diatoms (16), and chrysophytes (12), while other taxonomic groups were represented by smaller number of taxa.

Keywords: phytoplankton abundance, water physicochemistry, cyanobacteria blooms, lake restoration

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Introduction

The Lake Swarzędzkie is a shallow, post-glacial water body located in the Wielkopolska region of midwestern Poland. The lake's water quality and phytoplankton have been studied in recent years by several authors (Kowalczewska-Madura et al. 2005, Kowalczewska-Madura and Gołdyn 2006, 2010, Stefaniak et al. 2007, Gołdyn and Kowalczewska-Madura 2008). Laboratory experiments have also been performed on bottom sediments to study the intensity of phosphorus release (Szyper et al. 1994, Kowalczewska-Madura and Gołdyn 2009). As a result of these investigations, it was shown that the highest rates of P release were observed in the deepest site under anaerobic conditions during the summer and autumn months, and that the process depended especially on water temperature. Despite the fact that P concentration in the surface water layer decreased clearly from 1.18 mg l^{-1} P in 1992 to 0.2 mg l^{-1} P in 2002 (Kowalczewska-Madura and Gołdyn 2006), the water blooms caused by cyanobacteria were still intense. The most numerous in September 2002 comprised *Aphanizomenon gracile* (Lemmermann) Lemmermann, *Limnothrix redekei* (Van Goor) Meffert, and *Planktothrix agardhii* (Gomont) Anagnostidis et Komárek (Stefaniak et al. 2007). The restoration program for the Cybina River catchment and Lake Swarzędzkie was initiated with the main goal of preventing water blooms and improving water quality. An aerator was placed in the lake in September 2011, and biomanipulation was planned to strengthen the efficiency of the whole process. In November 2011, 100 kg of pike, *Esox lucius* L., fry was released into the lake, and iron treatment using iron sulphate (PIX) was done in November 2011 to reduce phosphorus concentrations in the water. These measures will be repeated in subsequent years.

The main goal of the present study was to evaluate and thoroughly describe the state of the lake before restoration measures, as this will be very important for comparisons with the data from subsequent years and permit evaluating the influence of restoration measures on the state and functioning of this ecosystem.

Study area

Lake Swarzędzkie is a small, shallow post-glacial water body located in the town of Swarzędz (52°25'N, 17°04'E). The lake is elongated with a surface area of 93.7 ha, a maximum depth of 7.2 m, and a mean depth of 2.6 m (Kowalczewska-Madura and Gołdyn 2010). The lake is located in the Cybina River catchment area (195.5 km^2), which mainly comprises agricultural lands (77%) and forests and inhabited areas (21%) (Gołdyn and Kowalczewska-Madura 2005). The lake has been subjected to strong human impact for many years. The Cybina River and Mielcuch Stream supply the lake with nutrients. Intense internal phosphorus loading from bottom sediments, especially in summer and autumn, have also been reported (Kowalczewska-Madura and Gołdyn 2009). The lake was hypertrophic and heavily polluted from the long-term impact of sewage inflows from the town of Swarzędz (Kowalczewska-Madura and Gołdyn 2012). Even though sewage was diverted from the lake in 1991, no improvement in water quality was observed. The restoration of the lake began in September 2011 with hypolimnion aeration. A pulverizing wind aerator was deployed in the center of the lake, which started to oxidize the bottom zone of the lake and contributed to eliminating phosphorus from the water column. Some other restoration measures, including biomanipulation, were undertaken later, which helped to improve water quality. Predatory fish fry, such as pike, was introduced into the lake, while, simultaneously, cyprinids, such as roach, *Rutilus rutilus* (L.), and bream, *Abramis brama* (L.), were removed in mass numbers.

Material and methods

To evaluate the state of the lake ecosystem before restoration measures, we decided to check the usefulness of a few popular parameters used in monitoring of lakes, especially those that describe trophic state and other features of lakes used for recreational purposes. We took into consideration phytoplankton abundance and taxonomic composition with a focus on dominant species and the share of cyanobacteria in the total phytoplankton composition, chlorophyll *a* concentration, and a few physicochemical variables used for evaluating the ecological status of lakes (Regulation of the Minister of the Environment, 2011), as well as Carlson's Trophic State Index (Carlson 1977) based on total phosphorus concentrations (TP), chlorophyll *a* (Chl), and Secchi depth (SD). The mean values from the period from March to December were used.

The water for phytoplankton and chemical analyses of Lake Swarzędzkie was sampled monthly from April (and from March for phytoplankton) to December in 2011 from the water surface layer and at depths of 1, 2, 3, 4, 5, and 6 m. The samples were collected at the deepest place in the lake (Fig. 1) using a 5 l sampler. Samples for phycological analyses were collected without concentration and fixed with Lugol's solution using the Utermöhl modification. The phytoplankton was counted using a Sedgwick-Rafter chamber with a volume of 0.65 ml. The taxonomic composition and number of phytoplankton were analyzed under an Olympus light microscope at a magnification of 400×. Secchi depth measurements were performed in the field. Water temperature, conductivity, dissolved

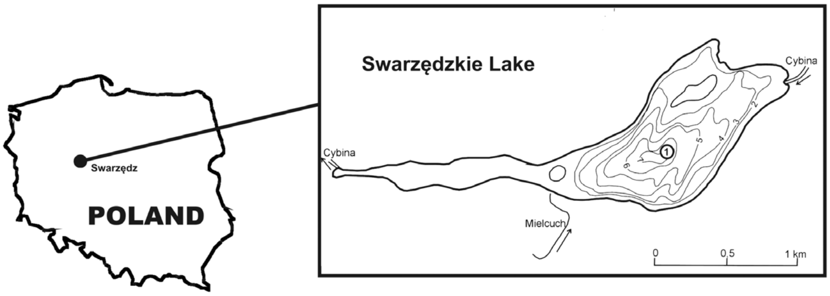

Figure 1. Location of sampling station (1) in Lake Swarzędzkie (Kowalczewska-Madura and Gołdyn (2006), modified).

oxygen, and pH were measured with a WTW 350 instrument. Concentrations of nitrogen, total phosphorus, and chlorophyll *a* were analyzed spectrophotometrically in the laboratory, and these parameters for seston dry mass were analyzed according to Polish standards (Elbanowska et al. 1999).

Results

Lake Swarzędzkie is partially stratified, and water temperature in the surface layer in summer 2011 reached 21.9°C, while in the near bottom it was 16.5°C (Table 1, Fig. 2). Water pH was the same throughout the water column (7.5-7.6) in spring, but in the summer months it decreased along the depth profile of the lake. A maximum pH value of 8.9 was noted in August in the surface layer and the lowest of 7.0 in the same month at a depth of 6 m. Conductivity in the water column was more or less the same in spring at about 780 μS cm^{-1} (Fig. 3), but in summer it started to increase from the surface to the bottom reaching a maximum value of 835 μS cm^{-1} in June at the bottom. The greatest difference between the surface and the bottom values of 238 μS cm^{-1} was recorded in August. In autumn and at the beginning of winter, the lake water began to be mixed, so the values from the surface to the bottom were very similar.

The dissolved oxygen concentration in depth profiles varied from zero in August in the hypolimnion to 17.96 mg l^{-1} (181% saturation) in September at a depth of 1 m (Fig. 4). During the study, the highest dissolved oxygen concentrations were recorded in September. During thermal stratification in the late spring and summer, oxygen deficits

Table 1
Minimum and maximum values of physicochemical variables in Lake Swarzędzkie

Variable	Unit	Min.	Max.
Temperature	°C	0.2	21.9
pH	pH	7.0	8.9
Conductivity	μS cm^{-1}	540	835
Dissolved oxygen	mg l^{-1}	0.00	17.96
Secchi depth	m	0.5	2.7
Seston	mg l^{-1}	1.1	37.5
Chlorophyll *a*	mg l^{-1}	1.2	278.0
Ammonium nitrogen	mg l^{-1} NH_4-N	0.53	7.44
Nitrite nitrogen	mg l^{-1} NO_2-N	0.00	0.02
Nitrate nitrogen	mg l^{-1} NO_3-N	0.00	9.96
Mineral nitrogen	mg l^{-1} N	0.90	10.57
Organic nitrogen	mg l^{-1} N	0.55	5.08
Total nitrogen	mg l^{-1} N	2.76	13.07
Phosphate phosphorus	mg l^{-1} P	0.02	0.71
Total phosphorus	mg l^{-1} P	0.04	0.85

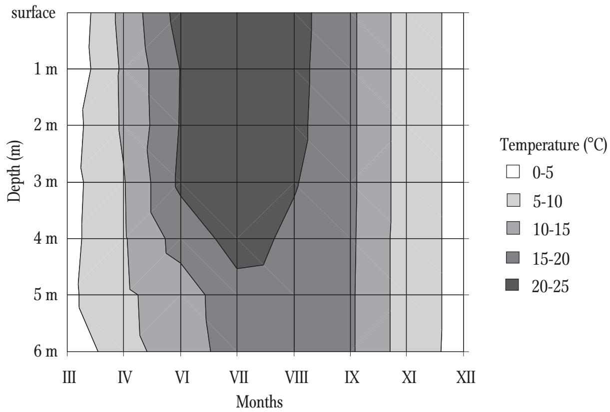

Figure 2. Vertical distribution of temperature (°C) in Lake Swarzędzkie in 2011.

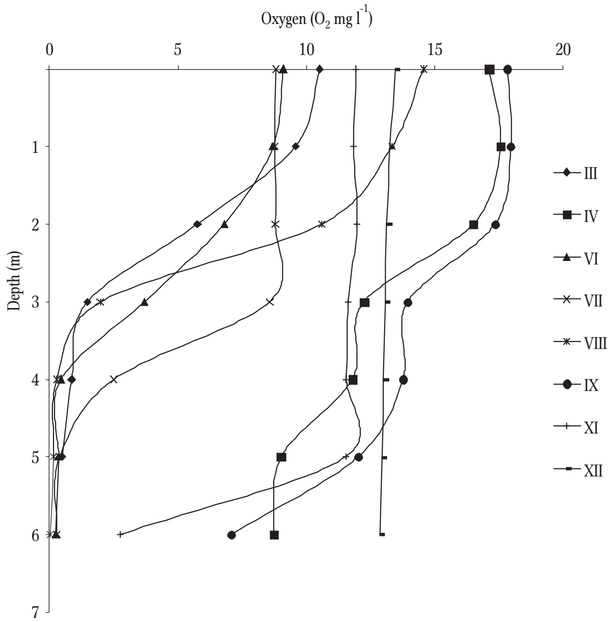

Figure 4. Vertical distribution of dissolved oxygen concentrations (mg l^{-1}) measured in Lake Swarzędzkie by month in 2011.

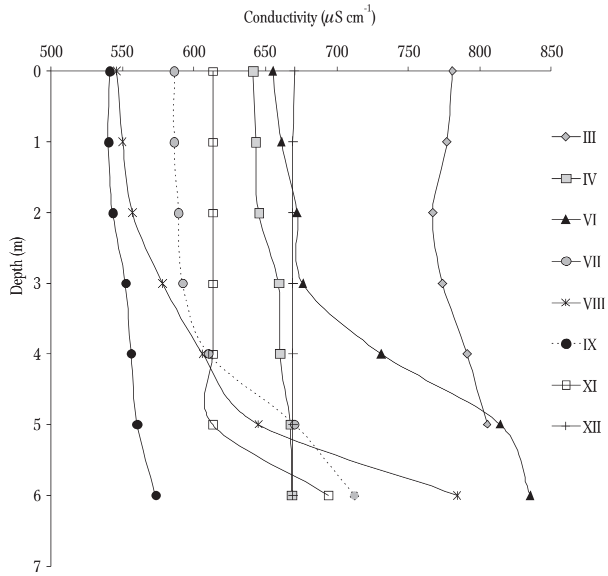

Figure 3. Vertical distribution of conductivity in Lake Swarzędzkie by month in 2011.

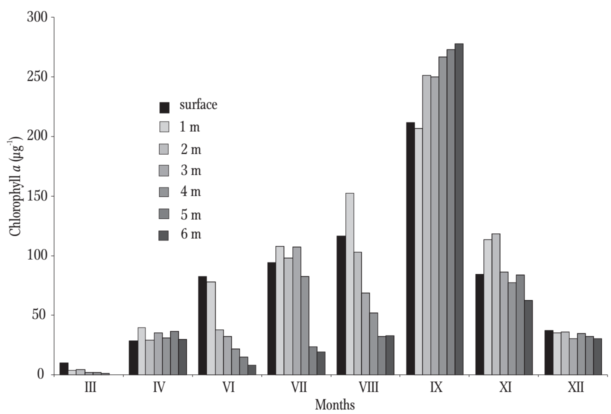

Figure 5. Concentrations of chlorophyll *a* in depth profiles in Lake Swarzędzkie by month in 2011.

were noted below 3 m in the depth profiles, while it was equal in all the water layers during the autumn in November and December.

The highest Secchi depth values in Lake Swarzędzkie (2.7 m) were noted in March. Visibility then decreased to a minimum of 0.5 m in September as a result of intense phytoplankton growth. The chlorophyll *a* concentration reached a maximum value of 278.0 µg l^{-1} at this time. In November its concentration was still high at 118.1 µg l^{-1} (Fig. 5). The seston dry mass concentration in Lake Swarzędzkie increased distinctly from March to September 2011 (Fig. 6).

High concentrations of both nitrogen and phosphorus were measured in Lake Swarzędzkie (Table 1). The highest concentration of mineral nitrogen (10.57 mg l^{-1} N) was noted in spring, but it decreased in summer in the surface water layer while it exceeded 7.0 mg l^{-1} N in the hypolimnion. From May to December most of the mineral nitrogen was in the form of ammonium, and in early spring and in winter nitrates were observed to increase. The highest concentration of ammonium nitrogen was recorded from June to

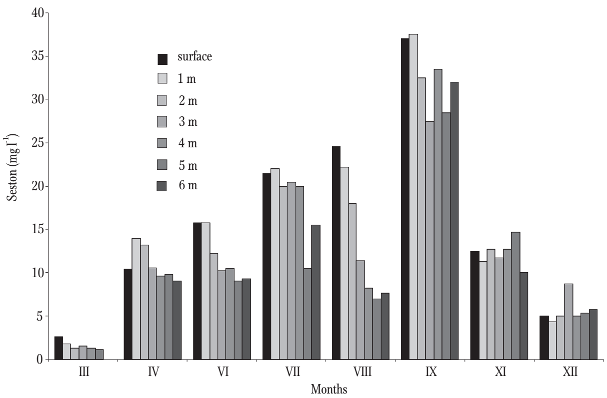

Figure 6. Vertical concentrations of seston dry mass in Lake Swarzędzkie by month in 2011.

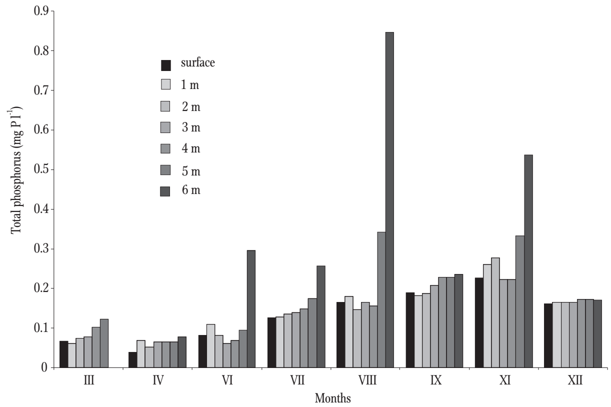

Figure 7. Vertical concentrations of total phosphorus in Lake Swarzędzkie by month in 2011.

August, particularly in the hypolimnion, and the maximum value was noted in August at 7.44 mg l^{-1} NH_4-N. The content of this form of nitrogen was lower and almost equal throughout in the vertical profiles and ranged from 0.53 to 1.40 mg l^{-1} NH_4-N in the periods of March-April and September-December.

Nitrite nitrogen concentrations were low at 0.02 mg l^{-1} NO_2-N in the hypolimnion, and this form of nitrogen was not detected in August and September. The maximum nitrate nitrogen concentration was noted in March (9.96 mg l^{-1} NO_3-N). In subsequent months it decreased rapidly, and in August this form of nitrogen was not detected in the lake water. The nitrate nitrogen concentration in autumn was low not exceeding 0.82 mg l^{-1} NO_3-N. The highest organic nitrogen concentration was noted in September at 5.08 mg l^{-1} N. During summer stagnation, organic nitrogen decreased from the surface to the near bottom water layer. The lowest organic N concentration (0.55 mg l^{-1} N) was noted in August at a depth of 5 m.

The highest total nitrogen concentration of 13.07 mg l^{-1} N was noted in March at a depth of 2 m (Table 1), which was from the strong impact of external loading from the catchment area. The concentration of total nitrogen fluctuated from 2.92 to 4.73 mg l^{-1} N in November and December and was quite similar throughout the vertical profile. Minerals forms of nitrogen dominated in total nitrogen in winter and early spring, while at the end of the summer and in autumn organic nitrogen prevailed.

Dissolved phosphates and total phosphorus were noted in the lake waters throughout the research period, and concentrations increased with depth. The highest concentrations of both forms of phosphorus were observed in summer, especially in the hypolimnion where they reached 0.71 mg l^{-1} P for phosphates and 0.85 mg l^{-1} P for total phosphorus. The lowest values were noted in April (Fig. 7). The TN:TP ratios in the lake fluctuated from 2.4 to 184, with higher values observed in spring and lower ones in summer. According to the OECD criteria, these total nitrogen and phosphorus data mean this lake is hypertrophic (Table 2).

Carlson's Trophic State Index indicated that Lake Swarzędzkie was in the hypertrophic class (Table 3). The one exception was with regard to TSI_{SD}, according to which the lake was classified as eutrophic. Based on the mean chlorophyll *a* concentration of 76.4 μg l^{-1} from April to September, Lake Swarzędzkie was designated to the fifth class (limiting values >68 μg l^{-1}), which corresponds to bad ecological status. According to supporting physicochemical aspects of the water that were also considered in the evaluation of its ecological status, Lake Swarzędzkie was not within the range of good quality. The water quality aspects with the worst scores were conductivity, TN, and TP (Table 4).

A total of 136 phytoplankton taxa belonging to nine taxonomic groups were identified in Lake Swarzędzkie. The most taxa were represented by the following: green algae with 57 taxa or 42% of all

Table 2
Evaluation of Lake Swarzędzkie trophic state according to OECD (1982) criteria

		Data from Lake Swarzędzkie		
Variable (unit)	Limit value	2002*	2011	Trophic state
Mean TP (μg l^{-1})	>100	151	175.8	Hypertrophy
Mean ChL (μg l^{-1})	>25	33.7	75.9	Hypertrophy
Max. ChL (μg l^{-1})	>75	97.1	278.0	Hypertrophy
Mean Secchi depth (m)	<1.5	1.2	1.1	Hypertrophy
Min. Secchi depth (m)	<0.7	0.6	0.5	Hypertrophy

*Data from 2002 – according to Kowalczewska-Madura (2005)

Table 3
Mean values of the Carlson's Trophic State Index for Lake Swarzędzkie (mean values from March-December period)

Indicator (unit)	Mean value	TSI
Secchi depth (m)	1.06	59.16
TP (μg l^{-1})	175.8	78.73
Chl *a* (μg l^{-1})	75.86	73.04

phytoplankton taxa (Fig. 8); cyanobacteria – 19 taxa and 14%; diatoms – 16 taxa and 12%; chrysophytes – 12 taxa and 9%. The remaining taxonomic groups were represented by smaller numbers of taxa of three to nine. The most abundant among green algae were *Tetraedron minimum* (A. Braun) Hansgirg and *Phacotus lenticularis* (Ehrenberg) Stein. Their abundance exceeded 6×10^3 specimens ml^{-1} in July or September. Less numerous at approximately 4×10^3 spec. ml^{-1} were *Closteriopsis longissima* (Lemmermann) Lemmermann, *Elakatothrix biplex* (Nygaard) Hindák, *Koliella spiculiformis* (Vischer) Hindák, and *Monoraphidium contortum* (Thuret) Komárková-Legnerová.

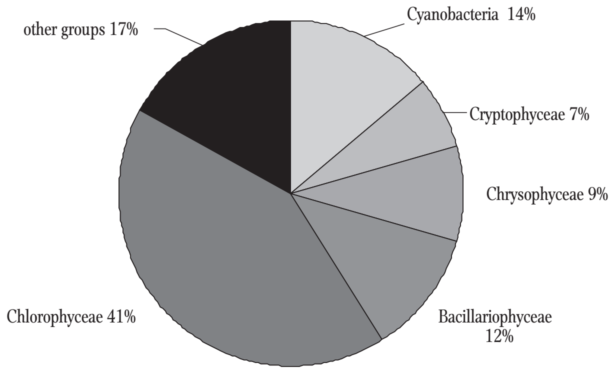

Figure 8. Relative numbers of phytoplankton taxa belonging to the main algal groups identified in Lake Swarzędzkie in 2011 (total number of taxa 136).

The phytoplankton was characterized by high seasonal variability among both the months and the depths studied. Diatoms, cryptophytes, and chrysophytes were the most abundant in spring, and the most important were *Nitzschia acicularis* W. Smith, *Cryptomonas marssonii* Skuja, *Rhodomonas lacustris* Pascher et Ruttner, *Erkenia subaequiciliata* Skuja, and *Dinobryon sociale* Ehrenberg.

The phytoplankton was the most abundant in September at 130.0×10^3 spec. ml^{-1} (Fig. 9a), and, of these, the most numerous were cyanobacteria

Table 4
Lake Swarzędzkie ecological status evaluated using physicochemical variables that support biological variables

Indicator (unit)	Physicochemical variable limits for good ecological status*	Mean values for April-September in Lake Swarzędzkie
Secchi depth (m)	≥1	0.74
Oxygen (mg l^{-1})	≥4	1.68
Conductivity (μS cm^{-1})	≤600	638.7
TN (mg l^{-1})	≤2.5	6.63
TP (mg l^{-1})	≤0.12	0.27

*according to the Regulation of the Minister of the Environment (2011) dominated by the species *Pseudanabaena limnetica* (Lemmermann) Komárek at 125.4×10^3 spec. ml^{-1} noted in September at a depth of 6 m. Consequently, a high chlorophyll *a* concentration was noted at up to 278 µg l^{-1}. *Aphanizomenon gracile* (Lemmermann) Lemmermann (2.5×10^3 spec. ml^{-1}) and *Aph. flos-aquae* (Linnaeus) Ralfs (3.5×10^3 spec. ml^{-1}) were less abundant. Other taxa like *Anabaenopsis circularis* (G. S. West) Wołoszyńska et Miller in Miller and *Cuspidothrix issatschenkoi* (Usačev) Rajaniemi et al. were noted in July. In summer, dinophytes were also quite abundant, especially *Ceratium hirundinella* (O. F. Müller) Bergh and *C. furcoides* (Levander) Langhans at 5.7×10^3 spec. ml^{-1}. Cyanobacteria were the most numerous until November, and following their decrease in December, cryptophytes increased in number (Fig. 9 b) and taxa such as *Cryptomonas marssonii*, *Rhodomonas lens* Pascher et Ruttner, and *Rh. lacustris* dominated.

Discussion

In most cases, the application of various indicators of ecological status produced similar results, namely that Lake Swarzędzkie is of bad water quality and is of the very high trophic status of hypertrophy. This unambiguous classification of a hypertrophic state was determined using the OECD (1980) criteria; however, some other variables were not so unequivocal, such as Secchi depth in Carlson's (1977) TSI (Table 3). Both TSI_{TP} and TSI_{Chl} were typical of hypertrophy, but TSI_{SD} was much lower and indicated a eutrophic status (Kratzer and Brezonik, 1981). Chlorophyll *a* in the EU ecological status classification for lakes according to the Water Framework Directive (WFD) (Regulation 2011) designate the status of the lake as bad. However, the mean value used for evaluating ecological status of 75.86 µg l^{-1} is very close to the limit value of this class, which is 68 µg l^{-1}. Physicochemical variables used to evaluate the ecological status of the lake indicated that it was worse than good (Table 4). Unfortunately, according to the WFD, no limit values are provided for moderate, poor, or bad ecological status, so a classification of worse than good is of limited use in comparisons and for designating differences. However, values of individual variables used in this estimation can be used in comparisons. The question is whether all of these variables are sensitive indicators of changes in ecosystems. Variables connected with phytoplankton primary production in the lake, like Secchi depth, total N and P, chlorophyll *a* or seston dry mass, should be rather good indicators. However, oxygen content near the bottom sediments will be probably still close to zero regardless of restoration since this lake has a metalimnion that is not frequently mixed in summer. Conductivity is the next variable which is not expected to improve as a result of restoration. Decreases in these values during summer happen through the use of free ions in primary production and the increased formation and precipitation of calcium carbonate crystals as a result of increased pH during strong algal blooms in the water. Anticipated decreases of algal growth will maintain conductivity at a constant level depending on the impact of the catchment area.

Phytoplankton indices will be probably of limited use for comparing changes in lake ecosystem functioning resulting from restoration measures. Estimating phytoplankton biomass, especially that of cyanobacteria, is subject to significant error of as much as ±25% (Hutorowicz et al. 2011); thus, slight differences in phytoplankton composition can be omitted. A better indicator of phytoplankton community restoration will be species domination analyses and abundance in subsequent years.

The phytoplankton structure in the studied lake in 2011 was highly dynamic. In April, phytoplankton abundance reached 16.1×10^3 specimens ml^{-1} and the chlorophyll *a* concentration was 40 µg l^{-1}. The most abundant taxa were *Nitzschia acicularis, Cryptomonas marssonii, Rhodomonas lacustris, Erkenia subaequicilia*, and *Dinobryon sociale*, which all belong to a group that prefers lower temperatures and are usually noted in colder months (Kozak et al. 2007). Later in the warmer season, the phytoplankton was completely restructured and cyanobacteria was the dominant group. These

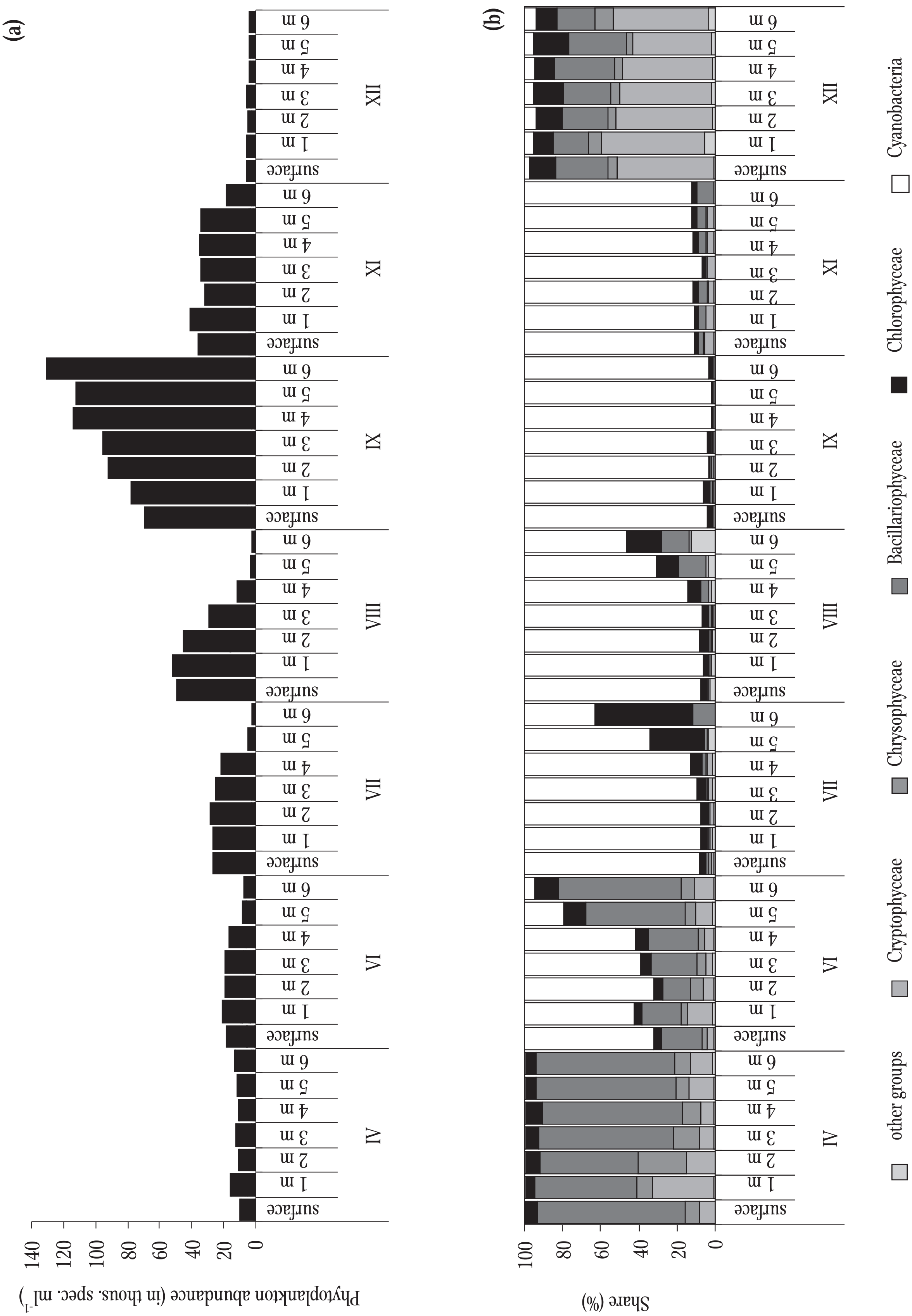

Figure 9. Phytoplankton abundance (a) and shares of main groups (b) in Lake Swarzędzkie by depth and month in 2011.

organisms grew intensively from July until November with maximum density in September, and the most abundant was *Pseudanabaena limnetica*, which was not noted in Lake Swarzędzkie previously in the summer period of July to September in 2000-2003 (Gołdyn and Kowalczewska-Madura 2007, Stefaniak et al. 2007). This is a common species, and it can cause water blooms in lakes and reservoirs. It has been identified in both deep dimictic lakes (Nixdorf et al. 2003) and in shallow lakes such as the ten lakes of the Lubuskie Lakeland (Pełechata et al. 2006), the Siemianówka Reservoir (Grabowska and Mazur-Marzec 2011), and the Maltański Reservoir (Kozak 2005). In addition to *P. limnetica*, other cyanobacteria species such as *Anabaena smithii* (J. Komárek) M. Watanabe, and *Aphanizomenon gracile* were recorded. *A. gracile* was also noted in the 2000-2003 summer period (Stefaniak et. al. 2007) when the summer phytoplankton was dominated by the non-N_2-fixing cyanobacteria *Limnothrix redekei* (Van Goor) Meff. and *Planktothrix agardhii* (Gom.) Anagnostidis & Komarek. In 2011, these two species were the most numerous at year's end in deep water layers (6 m). These species can cause water blooms even at low water temperatures since they were noted at temperatures of < 2°C (Toporowska et al. 2010). Potentially toxic species were noted among the cyanobacteria (Pawlik-Skowrońska and Toporowska 2011); however, the factors that control toxin amounts produced during blooms are still not well understood. Cyanobacteria also dominated at the low N:P ratios (Sommer 1989) recorded in the summer in September.

Some increases in dinoflagellate (*Ceratium hirundinella* and *C. furcoides*) abundance were also noted in summer. These organisms are noted quite often in mesotrophic and eutrophic lakes (Rosén 1981, Zębek 2009). In 2001 and 2002, *Ceratium* sp. were also noted in Lake Swarzędzkie (Stefaniak et al. 2007). *C. hirundinella* was also abundant in summer in many other bodies of water such as Lake Łuknajno (Jaworska and Kruk 2007), the restored Lake Głęboczek (Jaworska et al. 2009), and the Maltański Reservoir (Kozak 2005). *Ceratium* is commonly noted in moderately to highly enriched lakes during warm, dry conditions in summer months in the English Lake District (Reynolds et al. 2012).

The second numerous phytoplankton group was Chlorophyta, which comprised the largest share of the qualitative structure (42% of all taxa noted in 2011). Most of the species were cosmopolitan, and they were also noted in other reservoirs located on the Cybina River such as Lake Uzarzewskie (Kozak 2009) and the Maltański Reservoir (Kozak 2005). The domination of green algae of a number of species has also been reported in many other eutrophic and hypertrophic water bodies (Celewicz-Gołdyn 2005, Kozak and Kowalczewska-Madura 2010, Dembowska et al. 2012). The high number of chlorophyte taxa suggests the high trophic status of the lake (Kawecka and Eloranta 1994).

The high phytoplankton density resulted from high nitrogen and phosphorus concentrations; however, they were not a limiting factor for algal growth. Phosphorus loads were the highest at depths of 6 m, and it was demonstrated that the sediments were the most important source of this element in the deepest water layers (Kowalczewska-Madura and Gołdyn 2009). It has been shown that in Lake Swarzędzkie, as in many other lakes, phosphorus is released into the water above the sediments under anoxic conditions, and that it precipitates more intensely to the sediments when water is oxygenated (Kowalczewska-Madura 2003).

The high trophic state of the lake was the main influence on phytoplankton abundance. Cyanobacteria blooms in the lake during the summer and autumn were caused by intense external and internal loading, and it was demonstrated that most nutrients were transported from the lake's catchment area with the waters of the Cybina River and Mielcuch Stream primarily in spring (Kowalczewska-Madura and Gołdyn 2006, 2010). Internal loading, especially phosphorus from bottom sediments, also affected phytoplankton growth. The intense mineralization of organic matter was noted in the warmer seasons, and seasonal changes of pore water phosphorus content were measured in 2001-2003 (Kowalczewska-Madura and Gołdyn 2012) with higher values recorded especially in the warm summer months and lower values in winter. Intense cyanobacteria growth noted in summer and autumn was a consequence of high nutrient concentrations and the low number of grazers. Zooplankton was quite an important factor affecting phytoplankton biomass and abundance in lakes (Kawecka and Eloranta 1994), especially larger filtrating zooplankton, which can control phytoplankton abundance in lakes (Kozak and Gołdyn 2004, Sommer and Sommer 2006). However, a quite unexpected positive correlation between cladocerans and phytoplankton was noted in Lake Swarzędzkie in 2000-2002 (Gołdyn and Kowalczewska-Madura 2008). The positive influence of grazing was detected with simple regression analysis, and was explained by zooplankton nutrient release that stimulates algal growth. A weak correlation was reported between zooplankton phosphorus excretion and internal loading from the sediments and the phytoplankton community parameters of abundance, biomass, and chlorophyll *a* (Kowalczewska-Madura et al. 2007). Grazers appear to be less able to exert effective top-down control on phytoplankton dominated by large cyanobacteria; this was confirmed in biomanipulation experiments performed over several years in the Maltański Reservoir (Kozak and Gołdyn 2004). Following intense stocking with predatory pike and pikeperch fry, the abundance of the dominant herbivorous bream and roach in this reservoir was limited. Additionally, filtrating organisms such as *Daphnia similis* Claus and *D. longispina* O. F. Müller appeared and were able to limit effectively cyanobacteria growth. However, these effects were not sustained for the whole four-year period studied, which is why technical restoration methods were also applied to supplement biomanipulation and ensure the long-term stabilization of the desired ecosystem (Kozak et al. 2009).

The hypertrophic state of Lake Swarzędzkie has remained at stable level for many years. The comparison of a few variables from 2002 with the current data indicated that water quality has deteriorated over the past decade, and this was the impetus to initiate protection and restoration measures that focus on reducing external and internal nutrient loading. Since iron treatment was chosen for phosphorus immobilization, it was necessary to apply also deep water layer oxygenation.

It is expected that internal loading will be halted thus limiting phytoplankton growth. Biomanipulation was initiated in Lake Swarzędzkie in November 2011 with the aim of increasing the impact of these measures, and it should be continued in coming years. The water quality should be improved by these measures which means that the lake could be used for recreation.

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