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Cyanobacteria and cyanotoxins in Polish freshwater bodies

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Key words: cyanobacterial blooms, cyanotoxins, freshwater cyanobacteria

Abstract

In this work, the authors examined the presence of cyanobacteria and cyanotoxins in 21 samples collected from fresh water bodies located in 5 provinces in Poland: Lublin (2), Podlasie (1), Pomerania (6), Warmia-Masuria (1) and Wielkopolska (11). In addition, to determine the general pattern of geographical distribution, frequency of cyanobacteria occurrence, and cyanotoxins production, the published data from 238 fresh water bodies in Poland were reviewed. On the basis of these collected results, we concluded that *Planktothrix, Aphanizomenon, Microcystis* and *Dolichospermum* were dominant. The general pattern in geographical distribution of the identified cyanobacterial genera was typical of other eutrophic waters in Europe. The production of cyanotoxins was revealed in 18 (86%) of the 21 samples analyzed in the present work and in 74 (75%) of the 98 total water bodies for which the presence of toxins had been examined. Among the 24 detected microcystin variants, [Asp^3]MC-RR was most common. These results can be verified when more data from the less explored water bodies in the southern and eastern parts of Poland are available.

INTRODUCTION

In Europe, there are over 1500 species of cyanobacteria belonging to the orders *Chroococcales* (92 genera), *Oscillatoriales* (52 genera) and *Nostocales* (83 genera) (Komárek 2010; Komárek & Anagnostidis 1999, 2005). They occur in many geographical regions, in fresh, brackish, and marine environments (Mur et al. 1999). The mass development of cyanobacteria is stimulated by anthropogenic eutrophication and increased water temperature (O'Neil et al. 2012). For the growth and development of cyanobacteria, the ability to effectively utilize the available resources at minimal losses is also crucial. The formation of visible surface accumulates is restricted to gas vesicle (aerotop) containing species, including the filamentous genera *Dolichospermum*

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(*Anabaena*), *Planktothrix*, *Nodularia*, *Aphanizomenon* and *Cylindrospermopsis*, as well as the colony forming genera *Microcystis* and *Woronichinia* (Mur et al. 1999, Walsby et al. 1997, Walsby 2005). Gas vesicles make cyanobacteria buoyant and enable them to adjust position to take advantage of optimal light and nutrient conditions (Walsby et al. 1997, Walsby 2005).

Among the harmful effects of the blooms, the reduction in biological diversity, oxygen depletion and general deterioration of water quality, accompanied by unpleasant smell and change in water color, can be observed. The blooms in drinking water sources and at recreational sites are of special concern and pose a threat to humans and animals (Dittmann et al. 2012, Kardinaal 2007, Kuiper-Goodman et al. 1999, Sychrova et al. 2012). Some species of cyanobacteria produce metabolites that show hepatotoxic, neurotoxic, cytotoxic or dermatotoxic activities. Hepatotoxic cyclic peptides, microcystins (MCs) belong to the most frequently studied cyanobacterial metabolites in fresh water ecosystems. The general structure of MCs is: cyclo-(D-Ala^1-X^2-D-MeAsp^3-Z^4-Adda^5-D-Glu^6-Mdha^7) where X^2 and Z^4 stand for variable L amino acids, MeAsp – methylaspartic acid, Adda – (2S,3S,8S,9S)-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid, and Mdha-N-methyldehydroalanine (Reinehart et al. 1988). Microcystins have been reported mainly from planktonic cyanobacteria belonging to *Microcystis*, *Dolichospermum* and *Planktothrix* genera (Dittmann et al. 2012, Kardinaal 2007). They were also detected in *Anabaenopsis*, *Nostoc*, *Radiocystis*, *Gloeotrichia*, *Arthrospira*, *Fischerella*, *Phormidium*, *Pseudanabaena* and *Synechocystis* (Carey et al. 2007, Domingos et al. 1999, Fiore et al. 2009, Sivonen & Börner 2008). The group of cyanobacterial neurotoxins includes the nonproteogenic amino acid β-N-methylamino-L-alanine (BMAA) (Cox et al. 2005, Jonasson et al. 2010), alkaloid compounds such as anatoxin-a, homoanatoxin-a, anatoxin-a(s) and saxitoxins (Aráoz et al. 2010). They were less frequently reported than cyanobacterial hepatotoxins. Anatoxin-a is produced by freshwater species of the genera *Dolichospermum*, *Aphanizomenon*, *Cylindrospermum*, *Oscillatoria*, *Planktothrix* and *Phormidium* (Ballot et al. 2010, Cadel-Six et al. 2007, Sivonen & Börner 2008). The carbamate alkaloid, saxitoxin and their derivatives, have been found in filamentous species of cyanobacteria, such as *Aph. flos-aquae*, *D. circinalis*, *Oscillatoria mougeotti*, *Lyngbya wollei*, *Cylindrospermopsis raciborskii, Scytonema* and *Planktothrix* sp. (Al-Tebrineh et al. 2010, Sivonen & Jones 1999). In Australia and some other subtropical geographical regions, the cytotoxic cyclic alkaloid cylindrospermopsin (CYN) poses serious health problems. The production of the compound was reported from *C. raciborski*, *Aph. ovalisporum*, *Aph. flos-aquae*, *Umezakia natans*, *Anabaena bergii* and *Raphidiopsis curvata* (Falconer 2005). In European waters, mainly in Germany, France, Hungary and Poland, CYN was detected in *Aph. ovalisporum, Aph. flos-aquae* and *Aph. gracile* (Fastner et al. 2007, Kokociński et al. 2013).

Cyanobacteria, including *Lyngbya*, *Schizothrix* and *Oscillatoria*, are also known sources of dermatotoxic metabolites such as lyngbyatoxin, aplysiatoxins and debromoaplysiatoxins (Sivonen & Börner 2008). They are often responsible for skin irritation and blistering dermatitis among swimmers in Hawaii. Cyanobacteria also produce lipopolysacharides (LPS). These endotoxins constitute integral elements of their cell wall and belong to irritant and allergic agents (Stewart et al. 2006).

In European waters, cyanobacteria belonging mainly to the *Chroococcales*, *Oscillatoriales* and *Nostocales* orders have been reported. As in aquatic ecosystems, the cyanobacterial community is usually composed of several species represented by both toxin-producing and non-toxic strains, the correlation between cyanobacterial biomass and toxin concentration can rarely be observed.

It was also proved that environmental conditions have only minor and indirect effects on toxin production (Repka et al. 2004). The toxicity of the bloom depends on the genetic diversity of the cyanobacterial species and the contribution of the toxin-producing strains (Kurmayer et al. 2002, Rohrlack et al. 2001). Therefore, only the factors that favor the growth of the toxic strains can have an effect on sanitary conditions of water bodies (Hesse & Kohl 2001).

The structure and dynamics of cyanobacteria in 238 Polish water bodies have been described in numerous papers published in the last two decades. Most of the studies were carried out in the waters of Wielkopolska and Pomerania Provinces. Some of the lakes were subjected to sampling and analyses on regular bases; in other lakes samples were collected sporadically or just once.

Despite numerous reports on cyanobacterial structure and abundance in Polish water bodies, the data on toxin production by cyanobacteria are limited.

Table 1

Structure of cyanobacteria and the detected microcystin variants in samples collected from different water bodies in Poland in 2009 (n.d. – not detected; n.a. – not analyzed, % - percentage in total phytoplankton biomass, MC – microcystin; total MCs concentration was measured by HPLC-DAD)

No.	Lakes/Reservoirs	Date of sampling DD.MM (T_w [°C])	Total biomass [mg dm^{-3}]	Cyanobacteria	Cyanotoxins by LC-MS/MS (total concentrations of MCs by HPLC [µg dm^{-3}])
Pomerania Province					
1	Brodno Małe	19.08 (18.7)	2.38	*Cuspidothrix issatschenkoi* (2.7%), *Dolichospermum* spp. (0.03%)	n.d.
2	Raduńskie Dolne	19.08 (20.1)	0.68	*Dolichospermum* sp. (2.4%), *C. issatschenkoi* (2.2%)	n.d.
3	Raduńskie Górne	19.08 (21.1)	0.86	*Dolichospermum* spp. (17.0%), *Aphanizomenon* sp. (7.0%)	[Asp^3]MC-RR, [Asp^3]MC-RY, MC-RR, MC-YR, [Ser^7]MC-RR, MC-VR
4	Karczemne	19.08 (18.4)	41.80	*Microcystis* spp. (49.2%), *M. wesenbergii* (9.8%), *M. aeruginosa*, (8.7%), *C.issatschenkoi* (1.6%), *Woronichinia naegeliana* (<1%)	MC-RR, MC-LR, MC-YR, [D-Asp^3]MC-LR, MC-WR, MC-(H$_4$)YR
5	Klasztorne Małe	19.08 (19.7)	26.70	*Planktothrix agardhii* (65.0%), *Dolichospermum* spp. (23.0%)	MC-RR, MC-LR, MC-YR, [D-Asp^3]MC-LR, [D-Asp^3]MC-RR, [Asp^3,DMAdda^5]MC-HarW
6	Klasztorne Duże	19.08 (20.2)	34.10	*Pl. agardhii* (75.0%), *C. issatschenkoi* (4.9%), *Dolichospermum* spp. (2.5%), *Microcystis* spp. (0.3%)	MC-RR, MC-LR, MC-YR, [D-Asp^3]MC-LR, [D-Asp^3]MC-RR, MC-LY, MC-LF, MC-AR, [Asp^3,DMAdda^5]MC-HarW, MC-LW
Wielkopolska Province					
7	Góreckie	14.08 (21.5)	19.10	*Pl. agardhii* (38.0%), *Limnothrix redeckei* (32.4%), *Apha. flos-aquae* (10.6%), *M. flos-aquae* (1.8%), *Pseudanabaena limnetica* (0.8%), *Cylindrospermopsis raciborskii* (0.3%)	[Asp^3]MC-HtyR, [DMAdda^{5}MeDha^7]MC-YR **(2.7 µg dm^{-3})**
8	Jarosławieckie	14.08 (21.7)	9.31	*Ps. catenata* (54.5%), *M. aeruginosa* (<1%), *M. flos-aquae* (<1%), *Pl. agardhii* (<1%), *W. naegeliana* (<1%)	n.d.
9	Łęknińskie	30.08 (21.9)	31.80	*Pl. agardhii* (63.2%), *Apha. flos-aquae* (4.1%), *Aphanizomenon* sp. (3.4%), *Cyl. raciborskii* (3.1%)	[Asp^3]MC-RR, [Asp^3,MeDhb^7]MC-LW, [Asp^3,Dhb^7]MC-RR, [Asp^3]MC-RY, MC-YM **(25.0 µg dm^{-3})**
10	Maltańskie	30.08 (21.8)	15.80	*Apha. flos-aquae* (94.3%), *Apha. gracile* (1.4%), *Cyl. raciborskii* (0.4%), *M. aeruginosa* (<1%), *M. wesenbergii* (<1%), *Pl. agardhii* (<1%)	[Dha^7]MC-RR, [Asp^3]MC-HarR, MC-LR
11	Warta River, Poznań	30.08 (20.8)	23.50	*Apha. flos-aquae* (80.3%), *Pl. agardhii* (4.3%), *M. aeruginosa* (0.7%)	MC-YM, [Asp^3]MC-RR, MC-LW, MC-LR, [Asp^3]MC-HarR
12	Bnińskie	04.09 (19.9)	48.80	*Pl. agardhii* (37.5%), *W. naegeliana* (7.2%), *M. aeruginosa* (6.8%), *Microcystis* spp. (1.5%), *Cyl. raciborskii* (0.02%)	[Asp^3]MC-RR
13	Kórnickie	21.09 (n.d.)	no data	*Pl. agardhii*, *Cyl. raciborskii*	MC-RR, MC-YR, [Asp^3,ADMAdda^5,Dhb^7]MC-HtyR
14	Kierskie Małe	23.09 (18.7)	21.20	*Apha. gracile* (25.3%), *Pl. agardhii* (10.0%), *Cyl. raciborskii* (3.6%)	[Asp^3]MC-RR
15	Lubosińskie	23.09 (17.7)	79.10	*Pl. agardhii* (96.3%), *Apha. gracile* (0.2%)	[Asp^3]MC-RR, [Asp^3]MC-YR, MC-LR, MC-YR, [Asp^3]MC-LR **(40.0 µg dm^{-3})**
16	Buszewskie	23.09 (18.8)	20.60	*Pl. agardhii* (16.6%), *M. aeruginosa* (11.6%), *Aphanizomenon* spp. (3.5%), *Cyl. raciborskii* (1.4%)	[Asp^3]MC-HtyR, [Asp^3]MC-RR
17	Borusa	26.09 (17.9)	15.80	*M. aeruginosa* (7.4%), *Microcystis* spp. (4.2%) *Apha. flos-aquae* (6.5%), *Cyl. raciborskii* (<1%), *Pl. agardhii* (<1%)	[Asp^3]MC-HarR, MC-YR, MC-LR
Warmia-Masuria Province					
18	Zwiniarz	27.08 (19.9)	61.00	*Apha. gracile* (29.2%), *Pl. agardhii* (20.6%) , *M. aeruginosa* (11.8%), *M. wesenbergii* (0.8%), *Dolichospermum* spp. (<1%), *W. naegeliana* (0.2%)	[Asp^3]MC-RR
Lublin Province					
19	Syczyńskie	27.08 (22.1)	35.40	*Pl. agardhii* (82.0%), *Planktolyngbya limnetica* (0.4%), *M. aeruginosa* (0.3%), *Apha. gracile* (0.2 %)	[Asp^3]MC-RR **(4.0 µg dm^{-3})**
20	Zemborzycki	10.08 (22.0)	no data	*Apha. flos-aquae*, *D. flos-aquae*, *D. circinalis*, *D. spiroides*, *D. planctonicum*, *Pl. agardhii*, *M. wesenbergii*, *M. aeruginosa*	MC-LR, MC-YR **(trace amount)** (LC-MS/MS n.a.)
Podlasie Province					
21	Siemianówka	22.09 (17.3)	65.50	*Pl. agardhii* (95.0%)	[Asp^3]MC-RR, [Asp^3]MC-RY, MC-VR, [Asp^3]MC-LR, [DMAdda^5,MeGlu^6,Dhb^7]MC-YR **(10.0 µg dm^{-3})**

The aim of this work was to determine the distribution of cyanobacterial genera and species in Polish fresh water bodies and to assess the frequency of toxins production by the microorganisms. For this purpose, the previously published data on the occurrence of cyanobacteria and cyanotoxins in Polish waters were reviewed. In addition, the analyses of phytoplankton samples collected in 2009 from different water bodies in the country were conducted during a workshop organized by the Laboratory of Biochemical Ecology of Microorganisms at the Institute of Oceanography, University of Gdańsk. During the workshop, the performance of HPLC with a dioda array detector was compared with that of HPLC with a tandem mass spectrometer.

MATERIALS AND METHODS

Analysis of cyanobacteria

Water samples were collected in summer 2009 from 21 lakes and other water bodies in Poland (Table 1). The sub-samples for microscopic analyses of cyanobacteria were preserved with Lugol's solution (1%) and stored under cool and dark conditions. A light microscope (Nikon Eclipse E600, Tokyo, Japan) was used for qualitative analyses of cyanobacterial genera and species. Their biomass was determined according to the Utermöhl method (Edler 1979) using an inverted microscope (Nikon TMS, Tokyo, Japan) with 200×, 400× and 600× magnification. The size of the counting chambers (10, 20, or 50 cm^3) and the sedimentation time (24 or 48 h) depended on the abundance of cyanobacteria. The counting units (N) were cells, coenobia, or trichomes 100 µm in length. The biovolume of cyanobacteria was calculated using species-specific geometric formulas and standardized size classes (Olenina et al. 2006).

Analysis of cyanotoxins

The water sub-samples for cyanotoxins analyses were passed through Whatman GF/C glass microfiber filter discs. Filters with cyanobacterial material were placed in 2 cm^3 microcentrifuge tubes and 1 cm^3 of 90% methanol in water was added. The extracts were prepared by a 10-min bath sonication (Sonorex, Bandeline, Berlin, Germany) followed by a 1-min probe sonication with an HD 2070 Sonopuls ultrasonic disrupter (Bandeline, Berlin, Germany) equipped with an MS 72 probe. After centrifugation at 10,000×g for 15 min, the samples were analyzed with high performance liquid chromatography (HPLC).

The Waters HPLC system (Milford, MA, USA) equipped with a model 996 diode array detector (DAD) was used; the absorbance at 227, 238 and 261 nm were monitored. The separation was performed on a Waters Symmetry RP-18 column (3.9 mm × 150 mm; 5 µm) kept at a temperature of 20°C. Gradient elution with the mobile phase A (5% acetonitrile in MilliQ water with 0.05% trifluoroacetic acid TFA) and B (100% acetonitrile with 0.05% TFA) was used. The mobile phase was delivered at a flow rate of 1 cm^3 min^{-1}. Phase B was linearly increased from 1% to 70% in 15 min and held for one minute. Then a further increase in phase B content to 100% was performed in 2 min. The column was washed with 100% phase B for 7 min, then the mobile phase composition was brought back to the initial conditions (1% B) in 5 min. During the HPLC-DAD analysis of cyanobacterial extract we obtained a limit of detection (LOD) of 0.1 µg cm^{-3}.

Cyanotoxin structures were characterized with HPLC (Agilent 1200, Agilent Technologies, Waldboronn, Germany) coupled online to a hybrid triple quadrupole/linear ion trap mass spectrometer (QTRAP5500, Applied Biosystems, Sciex, Concorde, ON, Canada). As a mobile phase a mixture of A (5% acetonitrile in water containing 0.1% formic acid FA) and B (100% acetonitrile containing 0.1% FA) was used. Separation was performed on a Zorbax Eclipse XDB-C18 column (4.6 × 150 mm; 5 µm) (Agilent Technologies, Santa Clara, California, USA). Phase B was linearly increased from 15% to 75% in 5 min and then to 90% in the next 5 min. This composition of the mobile phase was held for 5 min and brought back to 15% B in 1 min. The column oven temperature was 35°C with the flow rate of 0.6 cm^3 min^{-1} and an injection volume of 0.05 cm^3. Turbo ion spray (550°C) voltage was 5.5 kV, with the nebulizer gas pressure and curtain gas pressures set at 60 p.s.i. and 20 p.s.i., respectively.

The MS/MS experiments were run using the information dependent acquisition method (IDA) and in enhanced ion product mode (EIP). In EIP mode, the ions fragmented in the collision cell (Q2) were captured in the ion trap and then scanned. In the IDA method, Q3 survey scans were used to automatically trigger an EIP scan if the signal was above a threshold of 100,000 cps. EPI spectra were acquired from 50 to 1000 Da with a scan speed of 2000 Da s^{-1} and a collision energy (CE) of 45 V with collision energy spread (CES) of 20 V. Data acquisition and processing were accomplished using Analyst QS 1.5.1 software. In the LC-ESI-MS analysis of cyanobacterial crude extract, using the IDA method, the limit of detection was 0.005 μg cm^{-3}.

RESULTS AND DISCUSSION

Potentially toxic cyanobacteria

The structure of the phytoplankton community is determined by the ability of individual species to adapt to such physical and chemical factors as temperature, nutrient concentrations, pH, water dynamics and light intensity. In the case of cyanobacteria, the physiological benefits of possessing heterocytes, aerotopes or accessory pigments make them more competitive than eukaryotic microalgae. In response to environmental conditions, and also due to their adaptive strategies, some cyanobacterial species occur only in a specific geographical location or climate zone while others are present worldwide (Hoffmann 1999, Sukenik et al. 2012).

The cyanobacteria belonging to the genus *Microcystis* are the most commonly occurring ones. Under field conditions, they form colonies of different shape, size and cell density. In eutrophic and hypertrophic waters, this genus tends to form thick surface accumulates. The presence of *Microcystis* was documented among others from lakes in Finland (Sivonen et al. 1990), Germany (Via-Ordorika et al. 2004), Spain (Ouahid et al. 2005), Belgium, Luxembourg (Williame et al. 2005) and Czech Republic (Znachor et al. 2006). Among the different *Microcystis* morphospecies, the highest number of toxic strains were classified as *M. botrys* Teiling (90%), *M. aeruginosa* (Kütz.) Kütz. (72%) and *M. flos-aquae* (Wittr.) Kirch. (50%) (Kurmayer & Kutzenberger 2003, Via-Odorika et al. 2004). In European waters, the production of microcystins by *M. ichthyoblabe* Kütz (20%), and *M. viridis* (Braun in Raben.) Lemm. (17%) are less frequently reported, and no records of toxic *M. wesenbergii* (Kom.) Kom. in Kond. have been published.

In the summer, different *Microcystis* morphospecies also constitute a significant phytoplankton component of many freshwater ecosystems in Poland. During our studies in 2009, *Microcystis* species, mainly *M. aeruginosa*, were present in 57% of the 21 analyzed samples. However, the contribution of the genus was significant only in Lake Karczemne where it constituted 49.2% of the total phytoplankton biomass (Table 1). When the previously published data from 238 Polish water bodies were taken into account, *Microcystis* was recorded in 43% of the analyzed samples (Fig. 1A, Table 2). In 33% of them, it belonged to the dominating or co-dominating phytoplankton organism (Table 3), e.g. in the Sulejow Reservoir and Lake Karczemne (Mankiewicz-Boczek et al. 2006a, b; Mazur-Marzec et al. 2008). The review of all the

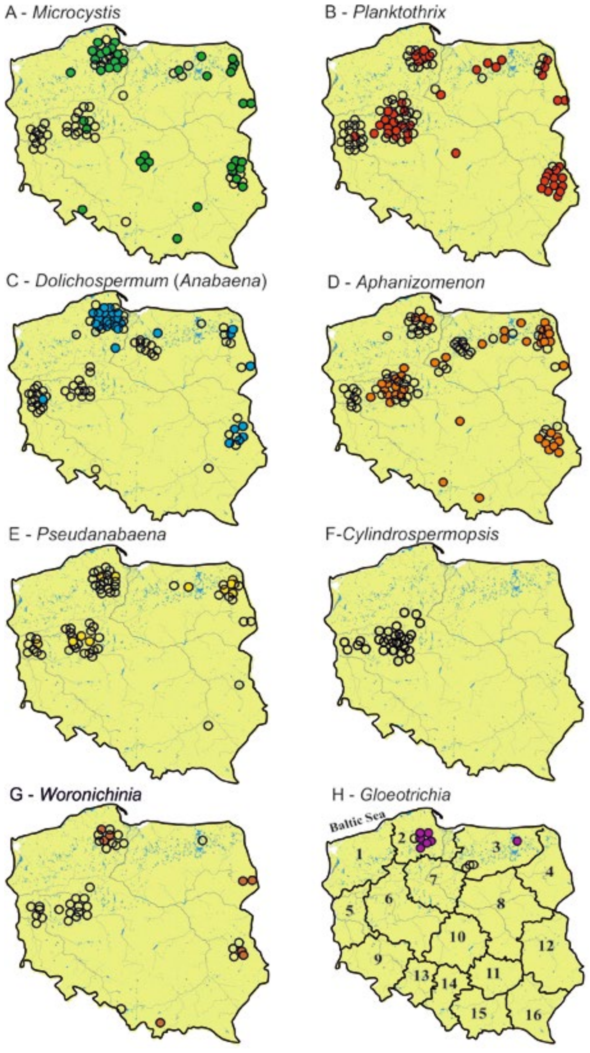

Fig. 1. Distribution of the cyanobacteria in Polish water bodies (full circles - dominance or co-dominance of given genus, empty circles – occurrence of the genus in the phytoplankton); H - Provinces in Poland: 1 – West Pomerania, 2 – Pomerania, 3 – Warmia-Masuria, 4 – Podlasie, 5 – Lubuskie, 6 – Wielkopolska, 7 – Kujawy-Pomerania, 8 – Mazowia, 9 – Lower Silesia, 10 – Łódź, 11 – Świętokrzyskie, 12 – Lublin, 13 – Opole, 14 – Silesia, 15 – Małopolska, 16 – Podkarpacie

available data on the occurrence of *Microcystis* in Polish waters concluded that *M. aeruginosa*, *M. flos-aque*, *M. wesenbergii*, *M. viridis* and *M. ichthoblabe* belonged to the most commonly occurring morphospecies.

The phycocyanin-rich *Planktothrix agardhii* (Gom.) Anagn. et Kom. can usually be found in shallow, polymictic and eutrophicated reservoirs, while the phycoerythrin-rich *Pl. rubescens* (De Cand. ex Gom.) Anagn. et Kom. lives in deep, oligo- or mesotrophic lakes. The presence of *Pl. rubescens* was among others reported from the metalimnic layer of deep alpine lakes (Cerasino & Salmaso 2012, Jacquet et al. 2005).

In waters of north Germany, *Planktothrix* is the most frequently encountered cyanobacterium (Fastner et al. 1999). It also occurred in Austria, the Netherlands and Denmark (Kurmayer et al. 2011), Belgium, Luxembourg (Williame et al. 2005), France (Yépremian et al. 2007), Norway, Sweden and Finland (Rantala et al. 2006, Rohrlack et al. 2008, Sivonen et al. 1990, Willén & Mattsson 1997). However, in Scandinavian waters, *Planktothrix* rarely dominated in phytoplankton communities. *Planktothrix* is considered to be a more effective producer of microcystins than *Microcystis* (Fastner et al. 1999). The lakes dominated by this cyanobacterium are usually characterized by elevated MC concentrations (Fastner et al. 1999). However, within the *Planktothrix* community, both toxic and non-toxic strains can be found. As documented by Kurmayer et al. (2011), the proportion of microcystin encoding genes (*mcy*) to the abundance of *Planktothrix* populations in several European lakes was stable, regardless of the season and the density of the total population. Therefore, in *Planktothrix* dominated lakes, the microcystin concentration can be estimated based on the size of the *Planktothrix* population.

The results of published studies and those obtained during the experiments conducted in 2009 showed that *Pl. agardhii* occurred more frequently in eutrophicated waters in Poland than *Pl. rubescence*. The latter species was previously found in lakes Białe, Piaseczno and Rogóźno in Lublin Province (Table 2). In the current work, *Pl. agardhii* was present in 81% of the 21 samples (Table 1). In 9 of them (collected from lakes Klasztorne Małe, Klasztorne Duże, Zwiniarz, Syczyńskie, Łękniński, Bnińskie, Kórnickie, Siemianówka, and Lubosińskie) the species constituted from 37.5% to 96.3% of the total phytoplankton biomass (Table 1). The mass occurrences of the species in lakes Buszewskie, Zwiniarz, Łękińskie and Kórnickie was documented here for the first time. During the sampling campagne in 2009, *Pl. agardhii* was not detected in 4 Kashubian lakes (Pomerania), including 3 mesotrophic lakes (Brodno Małe, Raduńskie Dolne and Raduńskie Górne), and one hypertrophic lake (Karczemne). According to the previously published results from Kashubian lakes, the share of *Planktothrix* in cyanobacterial biomass varied significantly from 5% to 80%, depending on the water body and season (Mazur-Marzec et al. 2008) (Fig. 1B, Table 2). The cyanobacterium was reported to be more abundant in the lakes of Wielkopolska, Lubuskie and Lublin Provinces (Fig. 1B, Table 2). Since 2006, it has replaced other cyanobacterial species in the Siemianówka Dam Reservoir (Podlasie) (Grabowska & Pawlik-Skowrońska 2008).

The heterocytes-containing *Dolichospermum* is another genus of cyanobacteria that frequently occurs in eutrophicated freshwater ecosystems. The species classified to *Dolichospermum* were previously considered to be planktonic forms of *Anabaena*. However, it has been proposed that due to the genetic, ultrastructural and ecological differences, *Dolichospermum* should be separated from the benthic and mat-forming *Anabaena* (Wacklin et al. 2009). The presence of *Dolichospermum* was reported from Scandinavia (Sivonen et al. 1990), Italy (Cerasino & Salmaso 2012, Messineo et al. 2009), Belgium, Luxembourg (Willame et al. 2005), Czech Republic (Zapomělová et al. 2012) and many other countries worldwide (Sivonen & Jones 1999).

So far, *Dolichospermum* has been found in 44% of the examined waters in Poland and it dominated or co-dominated in 24.5% of the 110 described bloom events (Fig. 1C, Table 3). Among others, *Dolichospermum* was detected in the Zemborzycki Reservoir where the genera *Aphanizomenon* and *Planktothrix* were also present (Pawlik-Skowrońska et al. 2004, Sierosławska et al. 2010). In northern Poland, the toxic blooms composed of *Dolichospermum*, *Microcystis* and *Planktothrix* were recorded in 10 lakes (Table 2). In two other lakes, the blooms of *Dolichospermum* were monospecies: Lake Orle (*D. planctonicum*) and Lake Białe (*D. lemmermannii*). In samples from both lakes, anatoxin-a was detected (Błaszczyk 2011, Kobos 2007).

The analyses carried out in this work (2009) confirmed the presence of *Dolichospermum* in lakes Brodno Małe, Raduńskie Górne, Raduńskie Dolne, Klasztorne Małe, Klasztorne Duże (Pomerania Province), Zwiniarz (Warmia-Masuria Province) and in the Zemborzycki Reservoir (Lublin Province)

Table 2

Cyanobacteria and cyanotoxins occurring in Polish water bodies (based on published data) *Plankt. – Planktothrix, Dolich. – Dolichospermum (Anabaena), Apha. – Aphanizomenon (including Cuspidothrix issatschenkoi), Micro. – Microcystis, Woron. – Woronichinia, Pseudan. – Pseudanabaena, Gloeo. – Gloeotrichia, Cylind. – Cylindrospermopsis, Lyng. – Lyngbya*, **bold** – dominated genera of cyanobacteria, MCs – microcystins, CYN – cylindrospermopsin, Atx-a – anatoxin-a, n.d. – not detected , n.a. – not analyzed

No.	Water body	Cyanobacteria	Toxins	References
Pomerania Province				
1	Bagienny	n.d.	n.a.	Gąbka et al. 2004
2	Barlewickie	***Plankt., Dolich., Micro.*** *Pseudan.*	MCs	Błaszczyk 2011, Jurczak et al. 2004, Mazur-Marzec et al. 2010
3	Białe	***Dolich.***, *Plankt., Apha., Micro.*	MCs	Błaszczyk 2011, Kobos 2007, Luścińska & Witek 2007, Mazur-Marzec et al. 2010
4	Bobiecińskie Małe	n.d.	n.a.	Szeląg-Wasielewska 1997
5	Borzytuchom III	***Woron.***	n.a.	Szeląg-Wasielewska 1997
6	Brodno Małe	***Gloeo.***, *Apha., Micro., Pseudan.*	-	Błaszczyk 2011, Luścińska & Witek 2007, **current work**
7	Brodno Wielkie	***Gloeo., Dolich.***, *Micro., Pseudan., Apha.*	MCs	Błaszczyk 2011, Luścińska & Witek 2007
8	Bukrzyno Duże	*Micro., Woron., Pseudan., Plankt., Dolich.*	n.a.	Luścińska & Witek 2007
9	Bukrzyno Duże	*Micro., Pseudan., Dolich.*	n.a.	Luścińska & Witek 2007
10	Ciemniak	n.d.	n.a.	Szeląg-Wasielewska 1997
11	Cietrzewie-Małe	n.d.	n.a.	Szeląg-Wasielewska 1997
12	Czarne	n.d.	n.a.	Gąbka et al. 2004
13	Czarne Południowe	*Plankt., Micro., Dolich., Woron., Pseudan.*	MCs	Kobos et al. 2005, Mazur-Marzec et al. 2010
14	Damaszka	***Dolich.***	-	Błaszczyk 2011
15	Dąbrowskie	*Micro., Plankt., Apha., Dolich.*	n.a.	Luścińska & Witek 2007
16	Dobre	***Dolich.***	-	Błaszczyk 2011, Mazur-Marzec et al. 2010
17	Dzierzgoń	***Micro.***	MCs	Błaszczyk 2011
18	Godziszewskie	***Micro.***	MCs	Błaszczyk 2011
19	Goszyńskie	*Plankt., Micro., Dolich.*	MCs	Błaszczyk 2011, Głowacka et al. 2011, Kobos 2007, Mazur-Marzec et al. 2010
20	Jasień	***Micro, Dolich.***, *Apha.*	MCs	Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010
21	Kałębie	***Micro., Dolich.***, *Apha., Woron., Pseudan.*	MCs	Błaszczyk 2011, Kobos et al. 2005, Mazur-Marzec et al. 2010
22	Kamień	*Micro.*	-	Błaszczyk 2011
23	Karczemne	***Micro.***, *Dolich., Plankt., Apha., Woron., Pseudan.*	MCs	Błaszczyk 2011, Kobos 2007, Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010, **current work**
24	Karlikowskie	***Micro., Dolich., Woron.***	MCs	Błaszczyk 2011, Głowacka et al. 2011, Kobos 2007, Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010, Pliński et al. 1998
25	Kielno	***Micro.***	n.a.	Głowacka et al. 2011, Pliński et al. 1998
26	Klasztorne	***Micro., Dolich.***	-	Błaszczyk 2011
27	Klasztorne Duże	***Plankt., Dolich.***, *Apha., Micro., Woron., Pseudan.*	MCs	Błaszczyk 2011, Głowacka et al. 2011, Kobos 2007, Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010, **current work**
28	Klasztorne Małe	***Plankt., Dolich.***, *Apha., Micro., Woron.*	MCs	Błaszczyk 2011, Kobos 2007, Mazur-Marzec et al. 2010, **current work**
29	Kłodno	***Gloeo.***, *Micro., Dolich., Pseudan., Apha.*	-	Błaszczyk 2011, Luścińska & Witek 2007
30	Krasne	n.d.	n.a.	Szeląg-Wasielewska 1997
31	Krąg	*Micro., Dolich.*	n.a.	Głowacka et al. 2011
32	Kuźniczek	n.d.	n.a.	Gąbka et al. 2004
33	Kuźnik	n.d.	n.a.	Gąbka et al. 2004
34	Kuźnik Olsowy	n.d.	n.a.	Gąbka et al 2004
35	Leśniówek Mały	n.d.	n.a.	Szeląg-Wasielewska 1997
36	Linowskie	***Woron.***	n.a.	Szeląg-Wasielewska 1997
37	Lubienieckie Duże	n.d.	n.a.	Szeląg-Wasielewska 1997
38	Lubienieckie Małe	n.d.	n.a.	Szeląg-Wasielewska 1997
39	Lubowisko	*Micro., Woron., Pseudan., Apha., Dolich.*	n.a.	Luścińska & Witek 2007
40	Łapińskie	*Micro., Dolich.*	-	Kobos unpublished
41	Mały Smólsk	n.d.	n.a.	Gąbka et al. 2004
42	Mausz	*Micro., Dolich.*	n.a.	Głowacka et al. 2011
43	Mergiel Duży	***Apha.***	MCs	Błaszczyk 2011
44	Modre	n.d.	n.a.	Gąbka et al. 2004
45	Nierybno	n.d.	n.a.	Szeląg-Wasielewska 1997
46	Nowoparszczenieckie	n.d.	n.a.	Szeląg-Wasielewska 1997
47	Okoniowe	n.d.	n.a.	Gąbka et al. 2004
48	Orle	***Dolich.***	MCs Atx-a	Błaszczyk 2011, Mazur-Marzec et al. 2010
49	Osowa	***Micro.***	-	Pliński et al. 1998
50	Ostrzyckie	***Plankt., Apha., Gloeo., Pseudan.***, *Micro., Dolich.*	MCs	Błaszczyk 2011, Głowacka et al. 2011, Luścińska & Witek 2007, Mazur et al. 2003, Mazur-Marzec et al. 2010
51	Patulskie	*Micro., Woron., Pseudan., Plankt., Apha., Dolich.*	n.a.	Luścińska & Witek 2007
52	Półwieś	***Plankt.***	-	Błaszczyk 2011
53	Przywidzkie	*Micro., Dolich.*	MCs	Mazur et al. 2003
54	Raduńskie Dolne	*Micro., Dolich.,* ***Gloeo.***, *Apha., Pseudan.*	MCs	Błaszczyk 2011, Głowacka et al. 2011, Luścińska & Witek 2007, **current work**
55	Raduńskie Górne	*Micro., Dolich.,* ***Gloeo.,*** *Apha.*	MCs	Błaszczyk 2011, Głowacka et al. 2011, Luścińska & Witek 2007, **current work**
56	Rakowieckie	*Plankt.*	-	Błaszczyk 2011
57	Rekowo	*Micro., Woron., Apha., Dolich.*	n.a.	Luścińska & Witek 2007
58	Sekacz	n.d.	n.a.	Szeląg-Wasielewska 1997
59	Sarbsko	*Apha.*	-	Kokociński et al. 2013

No.	Water body	Cyanobacteria	Toxins	References
60	Sianowskie	***Dolich.***, *Micro.*	MCs	Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010
61	Siecino	*Dolich.*	MCs	Mankiewicz et al. 2005
62	Sitno	***Micro., Dolich.***	-	Pliński et al. 1998
63	Słone	***Dolich.***, *Pseudan., Plankt.*	MCs	Kobos et al. 2005, Mazur-Marzec et al. 2010
64	Smolary	n.d.	n.a.	Gąbka et al. 2004
65	Stężyckie	*Plankt.*	-	Błaszczyk 2011
66	Sudomie	***Apha., Micro., Dolich.***	Atx-a	Błaszczyk 2011
67	Trzęsiecko	*Micro.*	MCs	Głowacka et al. 2011, Mankiewicz et al. 2005
68	Tuchomskie	***Micro., Dolich.***	MCs Atx-a	Błaszczyk 2011, Głowacka i in. 2011, Kobos 2007, Mazur et al. 2003, Mazur-Marzec et al. 2008, Mazur-Marzec et al. 2010
69	Wandowo	*Plankt.*	-	Błaszczyk 2011
70	Wdzydzkie	***Plankt.***	MCs	Błaszczyk 2011, Mazur-Marzec et al. 2010
71	Zajezierskie	*Dolich.*	-	Błaszczyk 2011
72	Żur (Wda River)	***Pseudan.***, *Plankt., Micro., Dolich.*	n.a.	Wiśniewska 2010
Wielkopolska Province				
73	Bierzyńskie	*Cylind.*	n.a.	Kokociński & Soinen 2012
74	Biezdruchowo	*Plankt., Apha., Micro., Dolich., Woron. Pseudan.,*	CYN MCs	Kokociński et al. 2013, Zagajewski et al. 2007, Zagajewski et al. 2009
75	Biskupieckie	*Plankt., Micro., Cylind.*	n.a.	Kokociński & Soinen 2012, Pełechata et al. 2006
76	Bnińskie	***Plankt.,*** *Apha., Pseudan., Woron., Cylind.*	MCs	Gągała et al. 2010, Głowacka et al. 2011, Kokociński et al. 2009, Kokociński et al. 2010, Kokociński & Soinen 2012, Mankiewicz-Boczek et al. 2012, Kokociński et al. 2013, Mankiewcz-Boczek et al. 2006a,c, Stefaniak & Kokociński 2005, Zagajewski et al. 2007, Zagajewski et al. 2009, **current work**
77	Borusa	***Micro.***, *Plankt., Apha., Pseudan., Cylind.*	MCs	Burchardt i in. 2006, **current work**
78	Budzyńskie	n.d.	n.a.	Celewicz et al. 2001
79	Buszewskie	***Plankt.***, *Apha., Micro., Cylind.*	MCs	Kokociński & Soinen 2012, Kokociński et. al. 2013, **current work**
80	Bytyńskie	***Plankt.***, *Apha., Cylind.*	CYN MCs	Głowacka et al. 2011, Kokociński et al. 2009, Kokociński et al 2010, Kokociński & Soinen 2012, Kokociński et al. 2013, Stefaniak & Kokociński 2005, Mankiewicz-Boczek et al. 2009, Mankiewicz-Boczek et al. 2011, Mankiewicz-Boczek et al. 2012
81	Chodzieckie	*Cylind.*	n.a.	Kokociński & Soinen 2012
82	Durowskie	***Plankt., Pseudan.***, *Apha.*	n.a.	Gołdyn & Messyasz 2008
83	Dymaczewo	*Plankt., Apha., Micro., Dolich., Woron., Pseudan., Cylind.*	MCs	Zagajewski et al. 2007, Zagajewski et al. 2009
84	Góreckie	***Plankt.,*** *Apha., Pseudan., Cylind.*	MCs	Pełechata et al. 2009, **current work**
85	Grylewskie	***Plankt.,*** *Apha., Cylind.*	-	Kokociński et al. 2013, Stefaniak & Kokociński 2005, Stefaniak et al. 2005
86	Jarosławieckie	*Pseudan., Micro., Plankt., Woron.*	**-**	**current work**
87	Jelonek	***Apha.***, *Cylind., Micro.*	-	Burchardt 1998, Głowacka et al. 2011, Kokociński & Soinen 2012, Kokociński et al. 2013
88	Jeziorak Mały	***Apha.***	n.a.	Zębek 2005, Zębek 2006
89	Kaliszany Duże	***Apha.***	n.a.	Burchardt 1998
90	Kamienieckie	*Micro.*	n.a.	Głowacka et al. 2011
91	Kierskie	*Plankt., Apha., Micro., Dolich., Woron., Pseudan.*	MCs	Kokociński et al. 2013, Zagajewski et al. 2007, Zagajewski et al. 2009
92	Kierskie Małe	***Apha.,*** *Plankt., Cylind.*	CYN MCs	Kokociński & Soinen 2012, Kokociński et al. 2013, **current work**
93	Kowalskie	*Cylind., Apha.*	CYN	Kokociński & Soinen 2012, Kokociński et al. 2013
94	Kórnickie	*Plankt., Cylind.*	MCs	**current work**
95	Kursko	*Cylind.*	n.a.	Kokociński & Soinen 2012
96	Laskownickie	***Plankt., Apha***, *Pseudan.*	n.a.	Messyasz 1998, Stefaniak et al. 2005
97	Lednica	*Plankt., Apha., Micro., Dolich., Woron., Pseudan.*	n.a.	Messyasz 2011
98	Lipno	*Plankt., Apha., Micro., Dolich., Woron., Pseudan.*	MCs	Zagajewski et al. 2007, Zagajewski et al. 2009
99	Lubaskie Duże	*Plankt., Micro.*	n.a.	Kuczyńska-Kipper et al. 2004
100	Lubosińskie	***Plankt.,*** *Apha.*	MCs	Kokociński et al. 2013, Mankiewicz-Boczek et al. 2009, Mankiewicz-Boczek et al. 2011, **current work**
101	Lusowskie	*Plankt., Apha., Micro., Dolich., Woron., Pseudan.*	MCs	Zagajewski et al. 2007, Zagajewski et al. 2009
102	Łęknińskie	***Plankt.,*** *Apha., Cylind.*	MCs	**current work**
103	Malta	***Apha., Pseudan.***, *Micro., Dolich., Cylind.*	MCs	Kozak 2005, Kozak 2006, Zagajewski et al. 2009, **current work**
104	Moczydło	n.d.	n.a.	Gąbka et al. 2004
105	Niepruszewskie	*Plankt., Apha., Micro., Dolich., Woron., Pseudan., Cylind.*	MCs	Kokociński & Soinen 2012, Zagajewski et al. 2007, Zagajewski et al. 2009
106	Perskie	n.d.	n.a.	Gąbka et al. 2004
107	Pniewskie	*Cylind.*	-	Kokociński & Soinen 2012, Kokociński et al. 2013
108	Pokraczyn	n.d.	n.a.	Gąbka et al. 2004
109	Pustelnik I	n.d.	n.a.	Gąbka et al. 2004
110	Pustelnik II	n.d.	n.a.	Gąbka et al. 2004
111	Rosnowskie Duże	*Plankt., Micro., Dolich.*	n.a.	Celewicz-Gołdyn 2005, Celewicz-Gołdyn 2006
112	Rusałka	*Plankt., Micro., Woron., Apha., Cylind., Dolich., Pseudan.,*	-	Zagajewski et al. 2009
113	Warta River, Poznań	***Apha., Micro., Pseudan.,*** *Plankt.*	MCs	Szeląg-Wasielewska 2009, **current work**
114	Strykowskie	*Plankt., Apha., Micro., Dolich., Woron., Pseudan., Cylind.*	CYN MCs	Kokociński & Soinen 2012, Kokociński et al. 2013, Zagajewski et al. 2007, Zagajewski et al. 2009
115	Strzeszyńskie	*Apha., Micro., Dolich.*	n.a.	Szeląg-Wasielewska 2006, Szeląg-Wasielewska 2007
116	Strzyżewskie	*Apha.*	CYN	Kokociński et al. 2013
117	Szydłowskie	*Apha.*	n.a.	Kokociński et al. 2013
118	Święte	n.d.	n.a.	Gąbka et al. 2004
119	Świętokrzyskie	***Apha.***, *Cylind.*	-	Burchardt 1998, Burchardt et al. 2007, Kokociński et al. 2013
120	Tomickie	*Cylind.*	-	Kokociński & Soinen 2012, Kokociński et al. 2013
121	Uzarzewskie	***Plankt.***, *Apha., Pseud., Dolich.*	MCs	Budzyńska et al. 2009
122	Wilcze Błoto	n.d.	n.a.	Gąbka et al. 2004
123	Witobelskie	*Cylind., Apha.*	-	Kokociński & Soinen 2012, Kokociński et al. 2013
124	Zbąszyńskie	***Plankt.,*** *Apha., Cylind.*	CYN	Kokociński et al. 2013, Stefaniak & Kokociński 2005
125	Żurawin	n.d.	n.a.	Gąbka et al. 2004
Lubuskie Province				
126	No name	*Plankt., Micro., Pseudan.*	n.a.	Pełechata et al. 2006
127	Bielawa	*Plankt., Apha., Dolich.*	n.a.	Pełechata et al. 2006

No.	Water body	Cyanobacteria	Toxins	References
128	Błędno	*Apha., Micro., Dolich.*	n.a.	Pełechata et al. 2006
129	Boczowskie	*Apha., Cylind.*	CYN	Kokociński et al. 2013
130	Busko	***Plankt., Dolich.****, Apha., Pseudan., Cylind.*	n.a.	Kokociński & Soinen 2012, Kokociński et al. 2013, Pełechata et al. 2006
131	Czyste Małe	*Dolich., Woron.*	n.a.	Pełechata et al. 2006
132	Długie	*Plankt., Pseudan.*	n.a.	Pełechata et al. 2006
133	Głębiniec	*Plankt., Micro., Dolich.*	n.a.	Pełechata et al. 2006
134	Głębokie	*Plankt., Dolich., Woron.*	n.a.	Pełechata et al. 2006
135	Głębokie (Koziczyn)	*Plankt., Dolich.*	n.a.	Pełechata et al. 2006
136	Gnilec	*Plankt., Micro., Dolich.*	n.a.	Pełechata et al. 2006
137	Ilno	*Apha.*	CYN	Kokociński et al. 2013
138	Imielno	*Plankt., Apha., Dolich.*	n.a.	Pełechata et al. 2006
139	Kocioł	*Plankt., Apha., Dolich.*	n.a.	Pełechata et al. 2006
140	Kursko	*Apha., Cylind.*	CYN	Kokociński et al. 2013
141	Linie	*Plankt., Dolich., Pseudan.*	n.a.	Pełechata et al. 2006
142	Mościenko	*Plankt., Woron.*	n.a.	Pełechata et al. 2006
143	Niwa	n.d.	n.a.	Pełechata et al. 2006
144	Oczko	*Micro., Dolich.*	n.a.	Pełechata et al. 2006
145	Odrzygoszcz	*Plankt., Micro., Dolich.*	n.a.	Pełechata et al. 2006
146	Ostrowicko	*Apha., Micro., Dolich., Pseudan.*	n.a.	Pełechata et al. 2006
147	Pierwsze	*Plankt., Dolich., Woron., Pseudan.*	n.a.	Pełechata et al. 2006
148	Płytkie	n.d.	n.a.	Pełechata et al. 2006
149	Popienko	*Micro., Dolich., Woron., Pseudan.*	n.a.	Pełechata et al. 2006
150	Rzepinka	*Plankt., Micro., Dolicho., Cylindro.*	n.a.	Kokociński & Soinen 2012, Pełechata et al. 2006
151	Rzepsko	*Plankt., Apha., Woron.*	n.a.	Pełechata et al. 2006
152	Żabiniec	***Pseudan.****, Plankt., Apha., Micro., Cylindr.*	n.a.	Kokociński & Soinen 2012, Pełechata et al. 2006
Warmia-Masuria Province				
153	Dąbrowa Mała	*Apha., Dolich., Gloeo.*	n.a.	Napiórkowska-Krzebietke et al. 2009
154	Dąbrowa Wielka	*Apha., Dolich., Gloeo.*	n.a.	Napiórkowska-Krzebietke et al. 2009
155	Dejguny	***Plankt****., Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke & Hutorowicz 2013
156	Grądy	*Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
157	Hańcza	n.d.	n.a.	Napiórkowska-Krzebietke & Hutorowicz 2013
158	Hartowieckie	*Apha., Dolich., Gloeo.*	n.a.	Napiórkowska-Krzebietke et al. 2009
159	Jagodne	***Plankt.****, Apha., Micro., Woron.*	MCs	Mankiewcz et al. 2005
160	Jeziorak	***Plankt., Apha., Micro., Pseudan.***	MCs	Mankiewcz et al. 2005, Mankiewicz-Boczek et al. 2006a,c
161	Kiełpińskie	*Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
162	Kirsajty	***Apha., Micro.***	n.a.	Napiórkowska-Krzebietke & Hutorowicz 2007
163	Lidzbarskie	*Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
164	Mamry Północne	***Apha., Micro., Gloeo.****, Dolich.*	n.a.	Napiórkowska-Krzebietke & Hutorowicz 2005
165	Niegocin	***Plankt., Apha., Dolich****., Micro.*	n.a.	Napiórkowska-Krzebietke & Hutorowicz 2006
166	Rumian	*Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
167	Szymon	***Apha.***	MCs	Mankiewcz et al. 2005
168	Szymoneckie	***Apha.***	MCs	Mankiewcz et al. 2005
169	Tałtowisko	*Plankt., Apha., Micro., Pseudan.*	MCs	Mankiewcz et al. 2005
170	Tarczyńskie	*Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
171	Zarybinek	*Apha., Dolich.*	n.a.	Napiórkowska-Krzebietke et al. 2009
172	Zwiniarz	*Apha., Dolich.*	MCs	Napiórkowska-Krzebietke et al. 2009, **current work**
Lublin Province				
173	Białe	***Plankt.***	n.a.	Szczurowska et. al. 2009
174	Białe Sosnowickie	***Micro., Apha.,*** *Dolich., Woron.*	MCs	Pawlik-Skowrońska & Toporowska 2013
175	Czarne Uścimowskie	***Apha.***	n.a.	Wojciechowska & Solis 2009
176	Czarne Włodawskie	***Apha.***	n.a.	Wojciechowska & Solis 2009
177	Domaszne	***Plankt.****, Apha, Micro, Dolich, Woron.*	MCs	Pawlik-Skowrońska & Toporowska 2013, Solis et al. 2009
178	Dratów	***Micro.****, Apha., Dolich., Woron*	MCs	Pawlik-Skowrońska & Toporowska 2013, Solis et al. 2009
179	Głębokie	***Plankt., Micro., Dolich.***	MCs	Pawlik-Skowrońska et al. 2010, Wojciechowska & Solis 2009
180	Koseniec	***Plankt.***	n.a.	Solis et al. 2010
181	Konstantynów	***Dolich., Plank.,*** *Micro., Apha., Woron., Lyng.*	Atx-a MCs	Pawlik-Skowrońska & Toporowska 2011
182	Krasne	***Plankt.***	n.a.	Wojciechowska et al. 2004
183	Kraśnik	***Apha., Micro.,*** *Plankt., Dolich.*	Atx-a MCs	Pawlik-Skowrońska & Toporowska 2011
184	Krzczeń	***Micro., Apha.,*** *Dolich., Woron.*	Atx-a MCs	Pawlik-Skowrońska & Toporowska 2013, Solis et al. 2009
185	Maśluchowskie	***Plankt. Apha.***	n.a.	Wojciechowska & Solis 2009
186	Mytycze	***Micro, Dolich. Apha., Plankt.***	MCs	Pawlik-Skowrońska (personal communication), Solis 2010
187	Nadrybie	***Micro., Dolich.***	n.a.	Krupa & Czernaś 2003a, Solis et al. 2009
188	Piaseczno	***Plankt.***	n.a.	Krupa & Czernaś 2003b
189	Płotycze k. Urszulina	***Woron****., Micro.*	n.a.	Krupa & Czernaś 2003c, Solis et al. 2010
190	Syczyńskie	***Plankt.,*** *Apha., Micro., Dolich., Woron., Pseudan.*	Atx-a MCs	Pawlik-Skowrońska et al. 2008, Pawlik-Skowrońska et al. 2010, Toporowska et al. 2010, Pawlik-Skowrońska et al., 2012, Toporowska et al., 2013 (in press), Wiśniewska et al. 2007, **current work**
191	Rogóźno	***Plankt.***	n.a	Lenard 2009
192	Uścimowskie	***Plankt., Apha.***	n.a.	Wojciechowska & Solis 2009
193	Wereszczyńskie	n.d.	n.a.	Krupa & Czernaś 2003c
194	Zagłębocze	***Woron.***	n.a.	Solis 2005
195	Zemborzycki	***Plankt., Apha, Micro, Dolich.***	MCs Atx-a	Głowacka et al. 2011, Kalinowska et al. 2012, Pawlik-Skowrońska et al. 2004, Pawlik-Skowrońska et al. 2011, Sierosławska et al. 2010, **current work**
Małopolska Province				
196	Dobczyce	***Woron.,*** *Micro.*	n.a.	Bucka & Wilk-Woźniak 1999, Pociecha & Wilk-Woźniak 2003, Pociecha & Wilk-Woźniak 2005, Pociecha & Wilk-Woźniak 2006, Wilk-Woźniak 1998, Wilk-Woźniak & Bucka 1998, Wilk-Woźniak & Mazurkiewicz-Boroń 2003, Wilk-Woźniak et al. 2006
197	Czorsztyn	n.d.	n.a.	Pociecha & Wilk-Woźniak 2005

No.	Water body	Cyanobacteria	Toxins	References
198	Rożnów	***Apha.***, *Micro., Plankt., Dolich.*	n.a.	Bucka & Wilk-Woźniak 1999, Pociecha & Wilk-Woźniak 2005, Wilk-Woźniak & Bucka 2000
199	Wisła-Czarne	n.d.	n.a.	Wilk-Woźniak & Bucka 1998
Silesia Province				
200	Goczałkowickie	***Apha.***, *Micro., Dolich., Woron.*	n.a.	Bucka & Żurek 1992, Bucka & Wilk-Woźniak 1999, Bucka & Wilk-Woźniak 2005a
Łódź Province				
201	Biała Rawska	***Micro.***	MCs	Jurczak et al. 2004
202	Biały Bór	***Micro.***	MCs	Jurczak et al. 2004
203	Sulejowski	***Micro., Apha., Plankt.,*** *Dolich.*	MCs	Galicka et al. 1998, Gągała et al. 2010, Głowacka et al. 2011, Izydorczyk et al. 2005, Izydorczyk et al. 2008, Jurczak et al. 2004, Jurczak et al. 2005, Kabziński et al. 2000, Mankiewicz et al. 2002, Mankiewicz-Boczek et al. 2006a,b,c, Mankiewicz-Boczek et al. 2011, Rakowska et al. 2005, Tarczyńska et al. 2001
204	Jeziorsko	***Micro.***, *Apha.*	MCs	Jurczak et al. 2004, Kabziński et al. 2000, Mankiewicz et al. 2002, Mankiewicz-Boczek et al. 2011
205	Włocławek	No data	MCs	Kabziński et al. 2000
Kujawy - Pomerania Province				
206	Mogileńskie	*Cylind., Apha.*	CYN	Kokociński & Soinen 2012; Kokociński et al. 2013
207	Pniewskie	*Cylind., Apha.*	n.a.	Kokociński & Soinen 2012; Kokociński et al. 2013
208	Szydłowskie	*Cylind., Apha*	n.a.	Kokociński & Soinen 2012; Kokociński et al. 2013
209	Toruń – city pound	***Apha.,*** *Plankt., Micro.*	n.a.	Komarzewska & Głogowska 2005
210	Koronowski	***Plankt., Apha., Dolich.***	n.a.	Wiśniewska 1998
West Pomerania Province				
211	Trzęsiecko	***Micro.***	MCs	Głowacka et al. 2011, Mankiewicz et al. 2005, Mazur-Marzec unpublished
Podlasie Province				
212	Siemianówka	***Plankt., Apha., Micro., Dolich***., ***Woron***. *Pseudan.,*	MCs	Górniak et al. 2002, Górniak et al. 2006, Grabowska 1998, Grabowska et al. 2003, Grabowska 2005, Grabowska & Pawlik-Skowrońska 2008, Grabowska & Mazur-Marzec 2011, Jurczak et al. 2004, **current work**
213	Narew River	***Plankt., Micro***., ***Woron***., *Dolich., Apha., Pseudan.*	MCs	Grabowska & Mazur-Marzec 2011, Grabowska 2012
214	Jaczno	*Apha.*	n.a.	Grabowska et al. 2006
215	Kopane	***Apha., Plankt.,*** *Pseudan.*	n.a.	Grabowska et al. 2006
216	Kameduł	*Apha., Dolich.,* ***Pseudan.***	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
217	Kluczysko	***Apha., Pseudan., Plankt.***	n.a.	Grabowska et al. 2006
218	Kojle	*Dolich., Plankt.*	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
219	Krejwelek	***Apha., Dolich.***, *Plankt.*	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
220	Pogorzałek	***Apha., Dolich.***	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
221	Postawelek	***Apha***., *Dolich., Plankt., Pseudan.*	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
222	Przechodnie	***Apha.***	n.a.	Jekatierynczuk-Rudczyk & Grabowska (personal communication)
223	Grauże	***Pseudan.***	n.a.	Grabowska et al. 2013
224	Jałówek	***Micro.***	n.a.	Grabowska et al. 2013
225	Jodel	***Pseudan.***	n.a.	Grabowska et al. 2013
226	Kupowo	***Pseudan.***	n.a.	Grabowska et al. 2013
227	Pejcze	***Apha.***	n.a.	Grabowska et al. 2013
228	Gielucha	***Micro.***	n.a.	Grabowska et al. 2013
229	Sumowo	***Micro.***	n.a.	Grabowska et al. 2013
230	Szelment Mały	***Micro.***	n.a.	Grabowska et al. 2013
231	Udziejek	***Apha.***	n.a.	Jekatierynczuk-Rudczyk & Grabowska (personal communication)
232	Hańcza	*Dolich., Pseudan.*	n.a.	Jekatierynczuk-Rudczyk et al. 2012
233	Linówek	*Apha., Dolich.*	n.a.	Jekatierynczuk-Rudczyk et al. 2012
234	Okrągłe	*Apha., Dolich., Woron., Pseudan.,*	n.a.	Jekatierynczuk-Rudczyk et al. 2012, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
235	Szurpiły	*Apha., Pseudan.*	n.a.	Grabowska et al. 2006, Jekatierynczuk-Rudczyk & Grabowska (personal communication)
Podkarpacie Province				
236	Piaseczno	*Anabaena minderi*	n.a.	Bucka & Wilk-Woźniak 2005b, Mazurkiewcz-Boroń et al. 2008
Opole Province				
237	Turawskie	***Micro***.	MCs	Kobos, Błaszczyk & Studnik, unpublished
Świętokrzyskie Province				
238	Brody Iłżeckie	***Micro.***	n.a.	Prus et al. 2007

Table 3

Summary: Presence of cyanobacteria and cyanotoxins in Polish water bodies (*Micro. – Microcystis, Plankt. – Planktothrix, Dolich. – Dolichospermum (Anabaena), Apha. – Aphanizomenon (including Cuspidothrix issatschenkoi), Cylind. - Cylindrospermopsis, Woron. – Woronichinia, Gloeo. – Gloeotrichia)*

	Micro.	*Plankt.*	*Dolich.*	*Apha.*	*Pseud.*	*Cylind.*	*Woron.*	*Gloeo.*
Total number of the examined water bodies	**238**							
Total number of water bodies in which cyanobacteria were present	**204**							
Total number of water bodies in which cyanobacteria dominated	**110**							
Number of water bodies in which cyanotoxins were detected **(out of the 97 analyzed for cyanotoxins)**	**74**							
Number of water bodies (out of **204**) in which the cyanobacterial genus was observed	103	90	104	119	57	33	41	11
Percentage [%] of water bodies (out of **204**) in which the cyanobacterial genus was observed	50.5	44.1	51.0	58.3	27.9	16.2	20.1	5.4
Number of water bodies (out of **110**) in which the dominance or co-dominance of the genus was observed	37	40	28	38	12	0	8	7
Percentage [%] of water bodies (out of **110**) where the cyanobacterial genus dominated or co-dominated	33.6	36.4	26.9	34.5	10.9	0.0	7.3	6.4

(Table 1). The following species of the genus *Dolichospermum* were recorded most frequently: *D. flos-aquae* (Brébisson ex Bornet et Flahault) Wacklin, Hoffmann et Komárek, *D. lemmermmannii* (Richt. in Lemm.) Wacklin, Hoffmann et Komarek, *D. planctonicum* (Brunn.) Wacklin, Hoffmann et Komarek, *D. spiroides* (Kleb.) Wacklin, Hoffmann et Komarek. Mass development of *Dolichospermum* was observed occasionally, mainly in the northern part of Poland (e.g. Lake Białe and Orle) and in Lublin Province (Zemborzycki Reservoir) (Fig. 1C, Table 2). The studies conducted in other European countries also showed that in the northern latitudes, e.g. in Norway (Skulberg et al. 1994), Finland and Sweden (Sivonen et al. 1990, Willén & Mattsson 1997), the presence of *Dolichospermum* was more common.

Dolichospermum can produce different types of toxins: hepatotoxic microcystins (*Dolichospermum* sp.), cylindrospermopsin (*D. lapponica*), neurotoxic anatoxin-a (*D. flos-aquae*) and saxitoxin (*D. circinalis*) (Dittmann et al. 2013, Rapala et al. 1993, Rapala & Sivonen 1998, Sivonen & Jones 1999, Willén & Mattsson 1997). In Belgium and Luxembourg only 12% of the bloom events dominated by these cyanobacteria were toxic (Willame et al. 2005). In Finland, Rantala et al. (2006) detected the *mcy*E-containing *Dolichospermum* in 37% of the lakes.

Aphanizomenon, a planktonic cyanobacterium, is most abundant in the metalimnion of lakes in temperate climates. Species belonging to this genus were found in lakes in Denmark (Jacobsen 1994), Belgium and Luxembourg (Willame et al. 2006), Portugal (De Figueiredo et al. 2010), Spain, Slovakia and Germany (Stüken et al. 2009), among others.

The presence of *Aphanizomenon* has been reported from nearly 50% of the 238 examined water bodies in Poland (Fig. 1D, Table 2). Therefore, it is one of the most commonly occurring cyanobacterium in Polish fresh waters. In previous studies, the following species of the genus were found most frequently: *Apha. flos-aquae* Ralfs ex Born. et Flah, *Apha. klebahnii* (Elenk.) Pechar et Kalina and *Apha. gracile* (Lemm.) Lemm. *Apha. issatschenkoi* (Usač), which was common but not abundant in the Polish lakes, has been recently classified as *Cuspidothrix issatschenkoi* (Usač) Rajan (Komarek & Komarkova 2006). *Aphanizomenon* was observed in Lake Świętokrzyskie (Burchardt et al. 2007), Lake Malta and in the Warta River near Poznań (Kozak 2005; 2006, Szeląg-Wasielewska et al. 2009). It also occurred frequently in lakes in Warmia-Masuria Province (Table 2). In the current study, the dominance of the cyanobacterium in the phytoplankton of Lake Malta and the Warta River was confirmed (Table 1). Generally, in Polish waters, *Aphanizomenon* tends to occur in association with *Dolichospermum* species.

Some strains of *Aphanizomenon* produce cylindrospermopsin (*Apha. ovalisporum, Apha. flos-aquae, Apha. gracile*) and neurotoxic compounds such as saxitoxins (*Apha. gracile*), anatoxin-a (*Apha. issatschenkoi*) and homoanatoxin-a (Dittmann et al. 2013, Ferriera et al. 2001, Pereira et al. 2000, Preußel et al. 2006, Sivonen & Jones 1999). In Polish lakes, the production of cylindrospermopsin by *Apha. gracile* was documented by Kokocinski et al. (2013).

Cylindrospermopsis raciborskii (Woloszynska) Seenaya et Subba Raju, one of the main producers of cylindrospermopsin (CYN), was originally observed only in waters of tropical and subtropical regions. Recently, however, it has become more and more common in European waters as well. Specifically, it has been observed in Germany (Fastner et al. 2007), Austria, Spain, France, Greece, Hungary (Padisák 1992, 1997) and Poland (Kokociński & Soinien 2012). So far, the production of CYN by the European strains of *C. raciborskii* has not been revealed.

In Poland, *C. raciborskii* was found in the lakes in Lubuskie, Wielkopolska and Kujawy-Pomerania Provinces (Fig 1F, Table 2). In the current work we also confirmed the presence of the species in lakes located in Wielkopolska Province: Kierskie Małe, Buszewskie, Kórnickie, Bnińskie, Łękníńskie, Malta and Borusa (Table 1).

According to Sukenik et al. (2012), the two cyanobacteria belonging to the Nostocales order, *Cylindrospermopsis* and *Aphanizomenon,* show the tendency to expand to new habitats and proliferate there, outcompeting the native species. This expansion to new geographical regions is mainly attributed to global warming and changes in nutrient regimes.

Woronichinia naegeliana (Ung.) Elenk., rarely dominates in the phytoplankton community of European countries. This species was more abundant in the lakes of central Belgium (Willame et al. 2005), Portugal (Santos et al. 2012) and some water bodies of northern and southern Poland (Fig. 1G, Table 2). In our studies, small numbers of *W. naegeliana* colonies were observed in samples from four lakes: Jarosławieckie, Karczemne, Zwiniarz and Bnińskie. According to the published data, *W. naegeliana* was detected only in 41 out of the 238 examined water bodies in Poland (Table 3). This species has been a stable and dominating component of the cyanobacterial community in Lake Dobczyce since 1995 (Wilk-Woźniak & Mazurkiewicz-Boroń 2003).

W. naegeliana was sometimes associated with the presence of microcystins (Santos et al. 2012, Willame et al. 2005). However, due to the difficulties in isolation of *W. naegeliana* and maintenance in culture, the production of the toxins by isolated strain was not well documented (Bober et al. 2011, Lara et al. 2013).

The occurrence of *Pseudanabaena limnetica* (Lemm) Kom. was described from freshwater bodies in Spain (Rojo & Cobelas 1994), Germany (Mischke & Nixdorf 2003), Hungary (Padisák et al. 2003), Czech Republic (Maršálek et al. 2003) and France (Willame et al. 2006). So far, *Ps. limnetica* has been observed in 57 water bodies in Poland, but only in 12 of them it was quite abundant (Fig. 1E, Table 2). Among others, this species dominated in the summer phytoplankton community of Lake Żabiniec (Pełechata et al. 2006). In autumn and winter it constituted up to 81-95% of phytoplankton biomass in Lake Durowskie (Gołdyn & Messyasz 2008). Other *Pseudanabaena* species recorded in Polish lakes include *Ps. mucicola* (Naumann et Hub.-Pest.) Schwabe (Szeląg-Wasielewska et al. 2009) and *Ps. galeata* Böcher (Pełechata et al. 2006) or *Ps. catenata* Lauternborn (Czerwik-Marcinkowska & Uher 2011). In our study *Ps. limnetica* was found in minor amounts in Lake Góreckie, while the *Ps. catenata* dominated in Lake Jarosławieckie (Table 1).

In Europe, the planktonic species *Gloeotrichia echinulata* (Smith) P. Richter occurs mainly in oligo- and beta-mesotrophic waters of the northern part of the continent (Jacobsen 1994, Karlsson-Elfgren et al. 2005). Its mass development was also observed in non-stratified eutrophic water bodies in Estonia and Russia (Alikas et al. 2010, Nõges et al. 2004). *G. echinulata* is known to cause serious skin problems (Cronberg et al. 1999). Skin irritations were observed in humans after exposure to *G. echinulata* blooms in Lake Ringsjön, Sweden (Cronberg at al. 1999) and in Lake Ostrzyckie, Poland (Kobos unpublished). According to Carey at al. (2007), this cyanobacterium can produce microcystins. In Poland, *G. echinulata* was found only in lakes located in the northern part of the country (Fig. 1H, Table 2). However, it was not found in samples collected in this work.

Our studies (Table 1) and the review of the published data on cyanobacterial occurrence in Polish freshwaters (Fig. 1, Table 2) showed that in individual reservoirs the structure of the cyanobacterial community can change significantly from year to year. For example, in Lake Bninskie and Sulejów Reservoir the high contribution of *Pl. agardhii* and *M. aeruginosa* has been recently recorded (Gągała et al. 2010). In the same water bodies, *Apha. flos-aquae* was more common in the past (Burchardt 1998, Galicka et al. 1998). In Siemianówka Dam Reservoir, *Pl. agardhii* has totally dominated the cyanobacterial community since 2006 (Grabowska & Mazur-Marzec 2011). In previous years, the Dam had been characterized by significant contributions of species from the *Chroococcales* and *Nostocales* orders (Grabowska & Pawlik-Skowrońska 2008). In Lake Klasztorne Duże, which usually experiences blooms of *Pl. agardhii*, the cyanobacterial community was occasionally dominated by *Dolichospermum* (Mazur-Marzec et al. 2010).

The collected data from freshwaters in Poland confirmed the general pattern in the geographical distribution of different cyanobacterial species reported by other authors. As in many other European countries, the highest biomass was usually formed by *Planktothrix, Microcystis, Aphanizomenon* and *Dolichospermum.* According to Rantala et al. (2006), the three genera, *Planktothrix, Microcystis* and *Dolichospermum,* co-existed in 24% of the lakes in Finland, usually those characterized by higher trophic level. The same frequency of their co-occurrence (24%) was recorded in our studies conducted in Poland in 2009.

Cyanotoxins in Polish water bodies

Although the potentially toxic cyanobacteria were found in all water bodies examined in this study, the HPLC analyses with dioda array detector revealed the presence of MCs only in 24% of the samples. They were collected from Zemborzycki Reservoir and lakes Góreckie, Syczyńskie, Łękinińskie, Lubosińskie and Siemianówka. The measured concentrations of the toxins ranged from traces in Zemborzycki Reservoir to 40 μg dm^{-3} in Lake Lubosińskie (Table 1). According to Mankiewicz et al. (2005), the average concentration of MCs in the lakes of northern Poland were in the range of 4-5 μg dm^{-3} (max. 12.14 μg dm^{-3}). However, the research carried out for many years in the Kashubian Lake District (northern Poland), showed that the total concentration of microcystins can temporarily reach hundreds of micrograms per dm^3. Such extreme situations were recorded in highly eutrophicated Lake Karczemne in 2005 and 2006, during bloom events dominated by *Microcystis* spp. (Mazur-Marzec et al. 2008). Also in Lake Białe, an exceptionally high concentration of MCs was measured (26,180.8±76.5 μg dm^{-3}) during a monospecies bloom of *D. lemmermannii* (Mazur-Marzec et al. 2010). The different values of MCs concentrations reported in studies from the same area can be explained by the dynamic character of cyanobacterial blooms. The changes in the structure, intensity and toxicity of cyanobacterial blooms can be sometimes observed within several days or even hours.

The analyses performed in this study with the application of LC-MS/MS revealed the presence of MCs in a higher number of lakes (85%) (Table 1) than HPLC-DAD. This was possibly due to the lower limit of detection of the MS/MS detector. At the time of the sampling (August 2009), the toxins were found in all but three lakes: Jarosławieckie, Brodno Małe and Raduńskie Dolne. Another important advantage of using LC-MS/MS is that it provides the possibility to elucidate the structure of the individual MCs variants present in the samples. On the basis of the fragmentation spectra, altogether 24 MC variants were identified. The highest number of variants (10) was detected in Lake Klasztorne Duże, characterized by high cyanobacterial biomass (34.1 mg dm^{-3}) and the dominance of *Pl. agardhii*. In this respect, similar conditions were observed in lakes Zwiniarz and Bnińskie, but in these lakes only one microcystin [Asp^3]MC-RR was found. As cyanobacterial populations can be either clonal or formed by several distinct chemotypes, including MC producers and non-MC producers (Rohrlack et al. 2008), the discovery of various types and numbers of microcystin variants in waters dominated by the same species is not unexpected.

In our study, [Asp^3]MC-RR belonged to the most commonly occurring microcystin. It was found in 11 water bodies in Poland that were usually dominated by *Pl. agardhii* – a known producer of demethylated MCs variants (Christiansen et al. 2003, Messineo et al. 2009). The group of four microcystins that were detected with lower frequency includes MC-LR (7/21), MC-YR (6/21), MC-RR (5/21), [Asp^3]MC-HtyR (3/21). Other microcystins were found in the analyzed water bodies only once or twice (Table 1). In waters dominated by *Microcystis*, MC-LR, MC-RR and MC-YR were usually detected.

Although potential producers of cylindrospermopsin and anatoxin-a were present in the analyzed samples, the toxins were not detected in any of them. In previous studies, the presence of CYN was revealed in 17 lakes in Poland. The concentrations of the toxin in seston ranged from trace amounts to 3.0 μg dm^{-3} (Kokociński et al. 2009, 2013) and were comparable to the concentrations determined in German water bodies during the bloom of *Aph. flos-aquae* (Preußel et al. 2006, Rücker et al. 2007). The production of anatoxin-a was reported from Zemborzycki Reservoir, lakes Syczyńskie, Krzczenie, Kraśnik and Konstatynowa in Lublin Province (Pawlik-Skowrońska et al. 2004, Pawlik-Skowrońska & Toporowska 2011, Pawlik-Skowrońska et al. 2012) and in lakes Orle, Sudomie and Tuchomskie in Pomerania Province (Błaszczyk 2011). The detection of anatoxin-a was most frequently associated with the presence of *Dolichospermum*. Production of anatoxin-a (ANTX-a) by *Dolichospermum* was confirmed by isolation of the cyanobacterium and subsequent identification of the neurotoxin in the isolated strains (Błaszczyk 2011). As in Lake Spino and Lake Mulargia in Italy (Messineo et al. 2009), *D. planctonicum* was also recognized as a producer of anatoxin-a in Lake Orle (Błaszczyk 2011).

In the lakes of Pomerania Province the concentration of ANTX-a did not exceed 6 μg dm^{-3}. One of the highest concentrations of the toxin reported in the published papers was measured in Zemborzycki Reservoir (1,035.59 μg dm^{-3} of surface scum) (Sierosławska et al. 2010) and Lake Syczyńskie (5,880.00 μg dm^{-3} in scum) (Pawlik-Skowrońska et al. 2012).

It was assessed that on average 59% of freshwater cyanobacteria blooms can be toxic (Sivonen & Jones 1999). According to Rantala et al. (2006), eutrophication increases the risk of high cyanotoxin concentration. In our study, the LC-MS/MS analyses revealed the presence of cyanotoxins in 85% of the samples collected from 21 different water bodies that regularly experience the blooms of potentially toxic cyanobacteria. Głowacka et al. (2011) used genetic methods to detect MC encoding genes (*mcy*B and *mcy*E) in Polish waters. They detected the genes in over 69% of samples collected from freshwaters: lakes, ponds and rivers. In bloom material, the presence of the genes was more frequent (78%). The review of published data and the data included in this paper (Table 1 and 2) showed that only 97 fresh water bodies in Poland have been examined for the presence of cyanotoxins. Out of this, the toxins were detected in 73 (75%) of the lakes, reservoirs, ponds or rivers. It should be emphasized, however, that the relults of chemical analyses strongly depend on the methods that were used for toxin detection. As the current work demonstrates, the application of HPLC-DAD can lead to the underestimation of the frequency of toxic cyanobacteria occurrence in the examined water bodies. The low limit of detection of LC-MS/MS constitutes a significant advantage of the method. Using this method it is possible to check directly, without time consuming clean-up procedures, if the concentration of miocrocystins is within the guideline value of 1 μg dm^{-3} proposed by the World Health Organization (WHO). In addition, individual MC variants show different biological activity and are characterized by various LD_{50} values. Therefore, the elucidation of their chemical structure with tandem mass spectrometry can be helpful in assessing the toxicity of the microcystin producing cyanobacteria.

CONCLUSIONS

The results obtained in this work and the review of the published data showed the varying frequency and intensity in the occurrence of toxic cyanobacteria in Polish water bodies. In general, the presence of toxic cyanobacteria was mainly documented in the northern and central part of Poland. As presented in Fig. 1, the occurrence of cyanobacteria and cyanotoxins in the southern and eastern parts of the country has been underexplored. On the basis of the available data it was concluded that cyanobacterial communities in Poland are mainly composed of the genera *Planktothrix, Aphanizomenon, Microcystis* and *Dolichospermum*. This corresponds to the typical structure of a cyanobacterial community in many eutrophicated European waters. So far, the presence of cyanotoxins was documented in 75% of the examined freshwaters in Poland. In some cases, the concentration of toxins was extremely high. Due to the use of many surface waters in Poland as a source of drinking water or for recreation, the ecological and sanitary status of these reservoirs should be regularly controlled. According to the Directive of European Parliament (2006/7 EC) from 15 February 2006, the presence of cyanobacteria is to be taken into account in the assessment of the quality of swimming areas. On the other hand, to be in line with the WHO recommendations, the concentration of MC-LR equivalent in tap water should not exceed 1 μg dm^{-3} (WHO 1998). In view of the regulations and recommendations already in place, knowledge about the occurrence of cyanobacteria and cyanotoxins is also crucial for proper planning of water management strategy.

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