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THE PHYSICOCHEMICAL BACKGROUND FOR THE DEVELOPMENT OF POTENTIALLY HARMFUL CYANOBACTERIUM *GLOEOTRICHIA ECHINULATA* J. S. SMITH EX RICHT

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Abstract

This study focused on site-specific preferences of potentially harmful cyanobacterium *Gloeotrichia echinulata* to occur in lakes with different ecological and trophic conditions. Its pelagic growth was studied in six lakes from June to September in 1986-1988, 2000-2001 and 2009. In total, 78 samples were taken from the epilimnion (stratified lakes) or the whole water column (non-stratified lakes). Analyses of phytoplankton and environmental variables were performed according to standard methods.

During summer, a distinct maximum of the *Gloeotrichia* growth was observed in July or August (the warmest period). Bloom events of *G. echinulata* occurred in lakes where the light and oxygen conditions were significantly inferior while the phosphorus content remained on a slightly elevated level. The distinct domination of this cyanobacterium (above 40% of the total phytoplankton biomass) was limited to lakes with a high, moderate or even poor ecological status, and to the meso-eutrophic or eutrophic state of lakes. However, *G. echinulata* occurred in a broader range of ecological and trophic conditions of lakes. The historical approach to mass occurrence of *G. echinulata*, with its possible contribution to phosphorus translocation from sediment to the pelagic zone, suggested its importance as an indicator of progressive ecological and trophic deterioration of lakes. This indication should be very useful for establishment of main targets in water management.

Key words: algal blooms, cyanobacteria, ecological status assessment, *Gloeotrichia echinulata*, trophy.

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INTRODUCTION

The planktonic cyanobacterium *Gloeotrichia echinulata* J. S. Smith ex Richt (Nostocales) generally occurs in oligo- and mesotrophic waters, and is described as one of typical representatives of such conditions in the functional classification of freshwater phytoplankton (Reynolds et al. 2002). Mass development of *G. echinulata* has been frequently observed not only in nutrient-poor lakes in Sweden and the USA (Karlsson-Elfgren et al. 2005, Carey et al. 2008, 2012), but also in more eutrophic lakes in Denmark (Jacobsen 1994), Estonia or Russia (Nõges et al. 2004). Additionally, *G. echinulata* may negatively affect human health or disrupt food webs in a lake ecosystem because of its responsibility for producing toxins such as microcystin-LR, which can be harmful to humans and whole aquatic ecosystems (Carey et al. 2012). In Poland, there are only some preliminary data on the toxicity of *G. echinulata* (Kobos et al. 2013), or its ability to form surface blooms in lakes in the northern part of Poland (Napiórkowska-Krzebietke, Hutorowicz 2007).

In the benthic phase of *Gleotrichia echinulata* life cycle, the akinetes germinate, grow on or in the nutrient-rich sediment, form a large colony (up to 3 mm) containing gas vacuoles and then migrate up to the pelagic waters (Karlsson-Elfgren et al. 2004). The pelagic colonies are mainly positive buoyant and large amounts of these organisms can be also found at several water depths due to their translocation to more nutrient-rich waters (Karlsson-Elfgren et al. 2005). During the first phase, they take up nutrients, especially phosphorus, from the nutrient-rich sediment, which is sometimes used by pelagic colonies as the only source of the mentioned element (Tymowski, Duthie 2000). The recruitment of *Gloeotrichia* colonies enables effective transport of phosphorus from lake sediments to upper layers of a lake (Jacobsen 1994, Pitois et al. 1997, Nõges et al. 2004). According to Istvanovics et al. (1993), such transport can involve up to 3.8 mg P m^{-2} d^{-1}, i.e. as much as up to 66% to a lake's total annual internal P load. Recently, in a composition metric for the phytoplankton-based ecological status assessment of European lakes for the Water Framework Directive (WFD), the genus *Gloeotrichia* has been described as a taxon with high optima, which should reflect a high phosphorus concentration in lakes (Phillips et al. 2013).

Despite various reports on bloom-forming *G. echinulata* occurring in a rather broad range of nutrient concentrations, the data on its ecological and trophic requirements are still scanty. We have hypothesized that the habitat-specific preference of this cyanobacterium allows it to occur and bloom in lakes with different ecological and trophic states. Shoould this hypothesis be verified, it would facilitate the identification of main targets in the water management policy, including decisions to restore lakes which do not meet the good ecological status required by the WFD.

MATERIAL AND METHODS

Phytoplankton data were collected from 6 lowland lakes (4 stratified, 2 non-stratified) in 1986-1988, 2000-2001, 2009. The lakes lie in north-eastern Poland (the Western and Eastern Europe Units) – Figure 1, Table 1. This

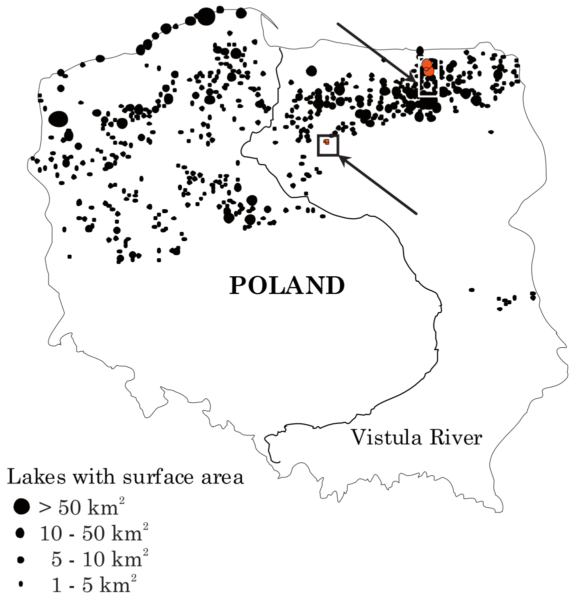

Fig. 1. Location of the surveyed lakes (red circles) in north-eastern Poland - Western and Eastern Europe Units

Table 1

Morphometric parameters of the surveyed lakes (north-eastern Poland)

Lake	Geographic coordinates	Surface area (km^2)	Max. depth (m)	Mean depth (m)	Type of stratification	CB lake's type*
Niegocin	54.00152N 21.78041E	26.00	39.7	9.9	stratified	L-CB1
Mamry Północne	54.17509N 21.68967E	25.04	43.8	11.7	stratified	L-CB1
Dąbrowa Wielka	53.43642N 20.05513E	6.15	34.7	8.2	stratified	L-CB1
Dąbrowa Mała	53.44303N 20.02052E	1.73	34.5	10.0	stratified	L-CB1
Kirsajty	54.14462N 21.70836E	2.07	7.0	3.2	non-stratified	L-CB2
Hartowieckie	53.39568N 19.83721E	0.70	5.2	2.9	non-stratified	L-CB2

* according to the *Commission Decision* (2013) Central/Baltic types: L-CB1 – lowland, stratified, shallow calcareous with retention time 1-10 years, L-CB2 – lowland, very shallow calcareous with retention time 1-12 months

paper reports data gathered in summer (June – September), when *G. echinulata* occurred in pelagic waters. In total, 78 samples were collected from the epilimnion (stratified lakes L-CB1) or the whole depth (non-stratified lakes L-CB2) at one-meter intervals and were then integrated. The quantitative and qualitative analyses of phytoplankton were conducted according to the Utermöhl method (CEN 2006) with calculations of total biomass based on cell volume measurements. Some data on phytoplankton biomass and structure in these lakes have been published to date (Napiórkowska-Krzebietke, Hutorowicz 2005, 2006, 2007, Napiórkowska-Krzebietke et al. 2009, Hutorowicz et al. 2011). Data on physicochemical parameters were obtained from literature (Napiórkowska-Krzebietke, Hutorowicz 2005, 2006, 2007, Napiórkowska-Krzebietke et al. 2007, 2009, Wołos et al. 2009, Zdanowski et al. 2009, Hutorowicz et al. 2011) or from unpublished IFI data. These included Secchi disk visibility, temperature, dissolved oxygen, pH, electrolytic conductivity, which were measured with a Secchi disk, a model 58 YSI oxygen probe, a pH-meter by Hanna Instruments HI 22 and a Digitalmeter DIGI 610 conductometer, respectively. Concentrations of total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, phosphates and chlorophyll *a* were analyzed according to the standard methods (*Standard Methods* ... 1999, PN-86/C-05560.02).

The ecological status of the lakes was assessed according to the composition metric Phytoplankton Trophic Index – PTI (Phillips et al. 2013). For comparison, the national method Phytoplankton Metric for Polish Lakes (Phillips et al. 2014) in modification ($PMPL_{MOD}$) was used to cover the similar PTI technique (MTB – Metric Total Biomass, MBC – Metric Biomass of Cyanobacteria, equation 1 for L-CB1, equation 2 for L-CB2):

(1) $PMPL_{MOD} = (MTB + MBC)/2$,

where $MTB = k + m \times \ln (TB)$; $MBC = [m \times \ln (BC + BC \times BC/TB)/2] + k$;

(2) $PMPL_{MOD} = (MTB + 0.5 \times MBC)/1.5$,

where $MTB = k + m \times \ln (TB) + z \times TB + o \times \sqrt{TB}$; $MBC = m \times \ln BC + k$

and *k, z, m, o* are specific coefficients for a lake's type.

The Trophic State Index (Carlson 1977, Kratzer, Brezonik 1981) and Trophic Level Index (Burns et al. 2005) were calculated based on the Secchi disk visibility and concentrations of chlorophyll *a*, total phosphorus and total nitrogen, using datasets from summer.

The biological and environmental variables were correlated using the Spearman's coefficient and principal component analysis (PCA) with a correlation matrix (StatSoft, Inc.), and incorporating the data obtained when *G. echinulata* occurred in pelagic waters. The linear regression was used to indicate the relationships within and/or between ecological and trophic approaches to assess water quality, as well the *G. echinulata* biomass versus ecological and trophic assessments. It was assumed that relationships were statistically significant at the 0.05 significance level.

RESULTS AND DISCUSSION

In summer (June – September), the mean temperature in the epiliminon (stratified lakes) and in the whole water column (non-stratified lakes) ranged from 11.5 to 22.5°C. The pH and electrolytic conductivity were approximately 8.4 and 323.7 µS cm^{-1}, respectively, whereas the mean dissolved oxygen content fluctuated between 5.5 and 12.4 mg dm^{-3} (Figure 2). The total nitrogen concentration ranged from 0.7 to 2.2 mg dm^{-3}, and higher values were noted in the lakes called Mamry Północne, Niegocin and Kirsajty. The concentrations of ammonium nitrogen and nitrate nitrogen were relatively low (on average 0.08 and 0.04 mg dm^{-3}, respectively). The total phosphorus content reached the highest level of 0.14 mg dm^{-3} in Lake Niegocin, whereas the lowest TP content (on average 0.05 mg dm^{-3}) was recorded in Lake Dąbrowa Wielka and Lake Dąbrowa Mała. Analogously, the highest and lowest concentrations of phosphates were recorded in the same lakes. The mean summer Secchi disk visibility changed between 4.5 and 1.2 m (with the highest value in Lake Mamry Północne and lowest in Lake Hartowieckie). Chlorophyll *a* reached at the most 40 µg dm^{-3} in Lake Niegocin and 50 µg dm^{-3} in Lake Hartowieckie, when the Secchi disk visibility was relatively low. The lowest chlorophyll *a* concentrations (on average 3.7 µg dm^{-3}) were noted in lakes with high visibility. The mean summer content of total nitrogen and total phosphorus was comparable with the mean seasonal concentrations typical of lakes in at least the second quality class, corresponding to at least a good ecological status (*Regulation* ... 2011), analogously to the Secchi disk visibility or electrolytic conductivity. In Lake Niegocin, the TP content was exceptionally much higher. Furthermore, the mean summer chlorophyll *a* content could indicate that Lake Mamry Północne and Lake Kirsajty belonged to quality class I (high ecological status), whereas the other lakes were classified as class III or IV.

The pelagic phase of *Gloeotrichia echinulata*, as one of its two-stage life cycles after recruitment from sediments (Karlsson-Elfgren et al. 2004), was associated with the summer season, most often in July or August and sporadically in June and September. In this, the Polish lakes were similar to other European lakes, e.g. Lake Erken or Lake Peipsi (Nõges et al. 2004). The biomass of *G. echinulata* varied from <0.1 to 7.0 mg dm^{-3} in stratified, and to 4.0 mg dm^{-3} in non-stratified lakes (Table 2). The average total biomass of phytoplankton ranged then from 0.5 to 16.3 mg dm^{-3}, whereas the average biomass of Cyanobacteria fluctuated between less than 0.1 and 8.8 mg dm^{-3} in all the lakes. During long-term studies of Lake Mamry Północne, significant contribution (40% of total biomass in the epilimnion) of *G. echinulata* was noted only at the end of August 2000, when surface blooms were observed for the first time (Napiórkowska-Krzebietke, Hutorowicz 2005). This phenomenon indicated considerable changes in phytoplankton assemblages, with a clear tendency towards eutrophy of this lake, prob-

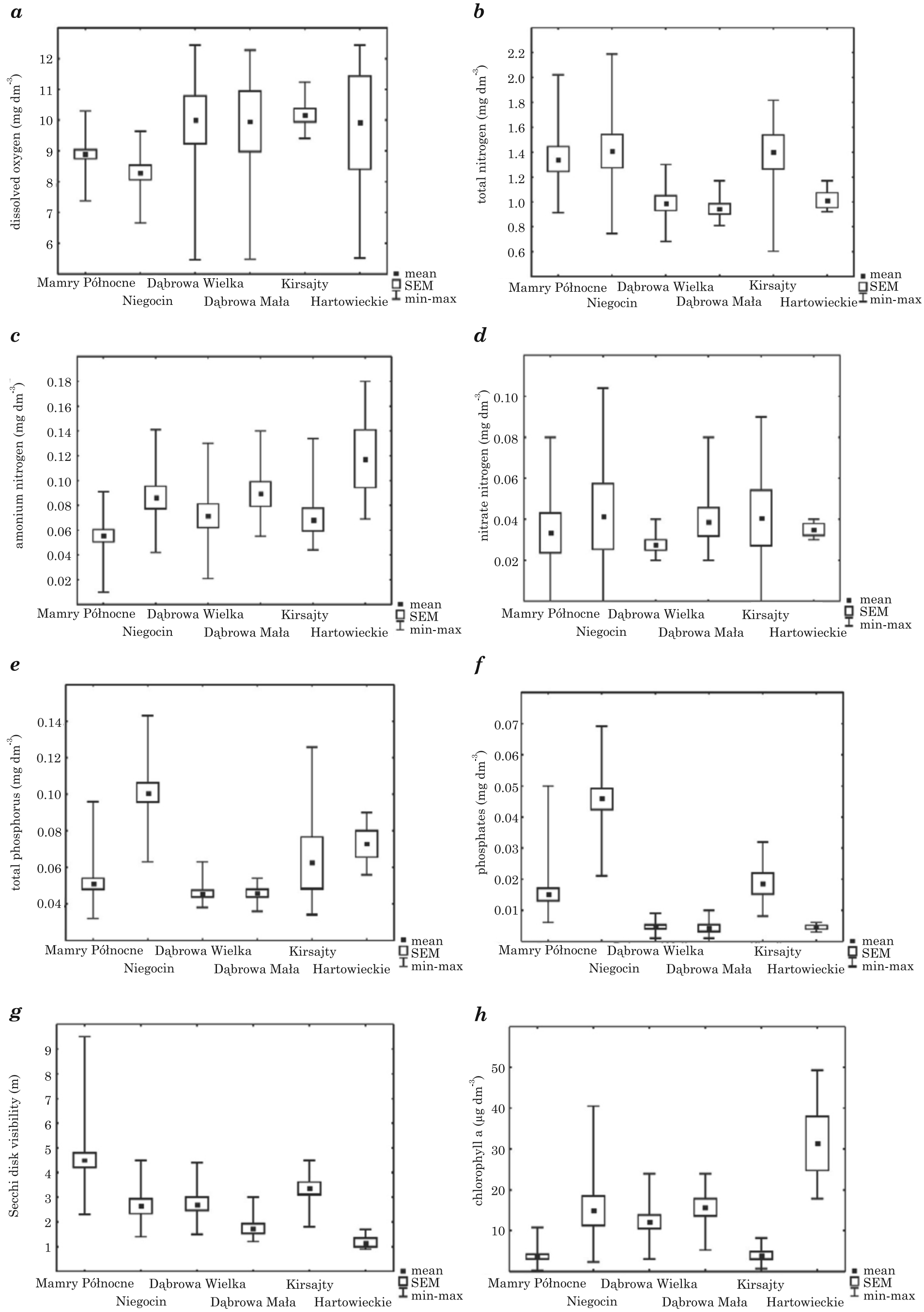

Fig. 2. The selected physicochemical parameters during summer in 1986-1988, 2000-2001, 2009 when *G. echinulata* occurred in pelagic waters, SEM – standard error of the mean

Table 2

Total biomass of phytoplankton, biomass of Cyanobacteria (mean) and biomass of *Gloeotrichia echinulata* in summer (June-September) 1986-1988, 2000-2001 and 2009 in the surveyed lakes

Lake	Year of study	Total biomass*** (mg dm^{-3})	Cyanobacteria biomass*** (mg dm^{-3})	*Gloeotrichia echinulata* biomass (mg dm^{-3}, % of total biomass in brackets)			
				June	July	August	September
Mamry Północne#*	1986	0.5	0.1	no	-	<0.1 (<1)	-
	1987	0.6	<0.1	no	no	<0.1 (<1)	no
	1988	0.8	0.1	no	<0.1 (<1)	<0.1 (<1)	-
	2000	1.5	0.7	no	no	1.0 (39)	-
	2001	1.8	1.3	no	-	<0.1 (<1)	no
Niegocin#*	2001	3.6	2.4	no	<0.1 (<1)	-	<0.1 (<1)
Dąbrowa Wielka#*	2009	5.4	2.4	no	6.6 (55)	<0.1 (<1)	no
Dąbrowa Mała#*	2009	8.1	4.8	no	0.8 (11)	no	no
Kirsajty**	1986	1.0	<0.1	<0.1 (<1)	-	<0.1 (<1)	<0.1 (<1)
	1987	1.1	<0.1	no	<0.1 (<1)	no	no
	2000	1.7	0.4	no	<0.1 (3)	no	-
Hartowieckie**	2009	16.3	8.8	no	3.7 (19)	no	no

epilimnion layer, * maximum from two or more stations, ** the whole water column, ***according to Napiórkowska-Krzebietke, Hutorowicz 2005, 2006, 2007, Hutorowicz et al. 2011, no – not observed, - – no data

ably resulting from the strong anthropopressure and internal enrichment (Zdanowski et al. 2009). However, in Lake Kirsajty both the summer total and *G. echinulata* biomasses in 1986-1987 were not too abundant, but there was an increase in 2000. Evident changes in phytoplankton assemblages were observed not only in summer but throughout the growth season in 2000-2001 (Napiórkowska-Krzebietke, Hutorowicz 2007). A similarly low contribution of *G. echinulata* into the total phytoplankton was observed in Lake Niegocin. Its presence in assemblages was connected with Cyanobacteria re-domination and indicated a relatively low stability of the lake's ecosystem, with pollution deposits collected over many years (Napiórkowska-Krzebietke, Hutorowicz 2006, Napiórkowska-Krzebietke et al. 2007). The study of Jakubowska et al. (2013) showed subsequent domination of Cyanobacteria in summer 2007 (mainly potentially toxic *Microcystis*), when the content of microcystins reached 0.16 µg dm^{-3}.

During the whole period of the *Gloeotrichia* pelagic growth, the nutrient concentration in these lakes was relatively low. The relationships between selected phytoplankton features and environmental variables were revealed by the Spearman's rank correlation (Table 3). Cyanobacteria and *G. echinulata* biomasses had a significant impact on the total biomass. The total biomass and Cyanobacteria biomass significantly and positively correlated with the chlorophyll *a* content, temperature and pH of water. Significantly negative correlations were found with dissolved oxygen and Secchi disk visibility. Regarding the relationships between *Gloeotrichia echinulata* and environmental variables, its biomass significantly and negatively correlated with electrolytic conductivity and the content of phosphates. However, the rela-

Table 3

The Spearman's rank correlation coefficient (r_s)* between phytoplankton and environment

Parameters		Total biomass	Cyanobacteria biomass	*G. echinulata* biomass
Phytoplankton features	total biomass	-	0.829*	0.497*
	cyanobacteria biomass	0.829*	-	0.379
	G. echinulata biomass	0.497*	0.379	-
Environmental variables	chlorophyll *a*, Chl-*a*	0.857*	0.891*	0.379
	temperature, T	0.591*	0.682*	0.213
	dissolved oxygen, DO	-0.667*	-0.751*	-0.218
	Secchi disk visibility, SDV	-0.631*	-0.728*	-0.265
	pH	0.635*	0.578*	0.267
	electrolytic conductivity, EC	-0.275	-0.030	-0.537*
	phosphates, Phos	-0.299	-0.197	-0.673*
	total phosphorus, TP	-0.129	-0.069	-0.261
	total nitrogen, TN	-0.371	0.126	-0.123

* statistically significant difference, $p < 0.05$ ($n = 24$)

tionship with total nitrogen was not significant statistically. Such close relationships were confirmed by the PCA analysis (Figure 3). Similar findings of a low oxygen concentration but not low visibility during the domination of *G. echinulata* have been reported from a eutrophic Danish lake (Jacobsen 1994). In contrast to Jacobsen's observations (1994), the light conditions during the *G. echinulata* blooms in lakes Dąbrowa Wielka, Dąbrowa Mała, Hartowieckie and Mamry Północne were rather worse than in the other sum-

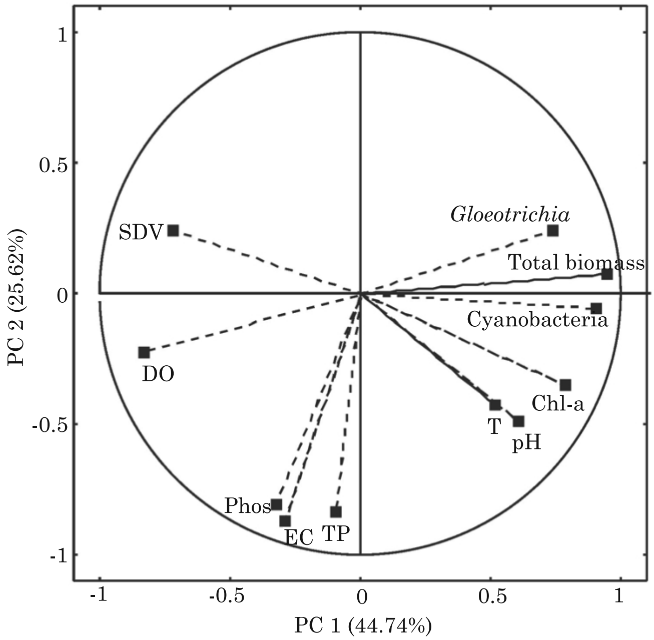

Fig. 3. Phytoplankton-environment relations (PCA ordination diagram), the abbreviations of the parameters are given in Table 3

mer months. However, the total phosphorus and phosphate concentrations were relatively low in the surface but high in the bottom layers; besides, negative correlations were found between the epilimnion total phosphorus and *Gloeotrichia* biomass. Nutrient-rich sediments are very important for the *G. echinulata* recruitment and consequently for its bloom forming in pelagic waters, and phosphorus absorbed from sediments can fulfil its nutritional requirements (Forsell, Pettersson 1995, Tymowski, Duthie 2000, Karlsson-Elfgren et al. 2005, Carey et al. 2008). Whereas the P uptake by pelagic colonies may be insignificant, *Gloeotrichia* can also cover its nutritional needs by N_2-fixation or TN uptake in the pelagial zone (Szász, Pettersson 2000). The relationships between the biomass of this species or even the whole Cyanobacteria group with total nitrogen proved to be non-significant. Generally, phytoplankton including Cyanobacteria showed statistically significant correlations with TN in other lakes, more or less eutrophied (Napiórkowska-Krzebietke et al. 2013, Grabowska et al. 2014, Zębek 2015).

The PTI classified 4 lake-years as having a high ecological status and 2 lake-years as the ones with a good status (lakes Mamry Północne and Kirsajty) – Figure 4. The remaining lake-years, including lakes with high *Gloeotrichia* biomass, had a moderate status. The $PMPL_{MOD}$ classified 7 lake-

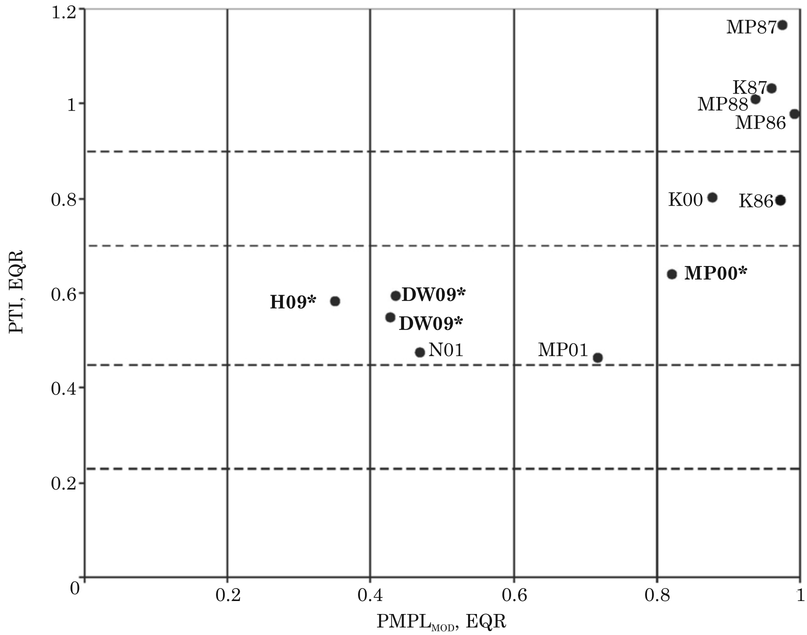

Fig. 4. Ecological status assessment of lakes according to PTI and $PMPL_{MOD}$. The codes of the lakes are given in Fig. 3, *the domination of *G. echinulata*. The class boundaries are as follows: 0.89, 0.70, 0.45 and 0.23 (for PTI-EQR, according to Phillips et al. 2013) and 0.80, 0.60, 0.40, 0.20 (for PMPL-EQR, according to Napiórkowska-Krzebietke et al. 2012) for the high/good, good/moderate, moderate/poor, poor/bad ecological status, respectively

-years as having a high ecological status, including Lake Mamry Północne with *Gloeotrichia* blooms in 2000, and one with a good status. The remaining lakes had a moderate or poor status. The trophic state assessment using TSI (on average 51) indicated a meso-eutrophic state in most lakes (Figure 5), except for the waters of Lake Mamry Północne in 1987 and Lake Hartowieckie in 2009, which were classified as mesotrophic and eutrophic, respectively. The mean TLI values ranged between 3.4 and 5.5 (Figure 5), and confirmed the meso-eutrophic conditions of lakes Kirsajty and Mamry Północne in 1986-1988, and 2000-2001 with the exception of MP87 and MP88 (mesotrophic). The TLI values in the other lakes usually exceeded the boundary value of the eutrophic state. Regarding the assessment-impact aspect, the role of *G. echinulata* biomass was significant only in the $PMPL_{MOD}$-based ecological status assessment (Table 4).

Thus, the occurrence of *Gloeotrichia echinulata* was connected with the lakes being classified from a high to poor ecological status and from

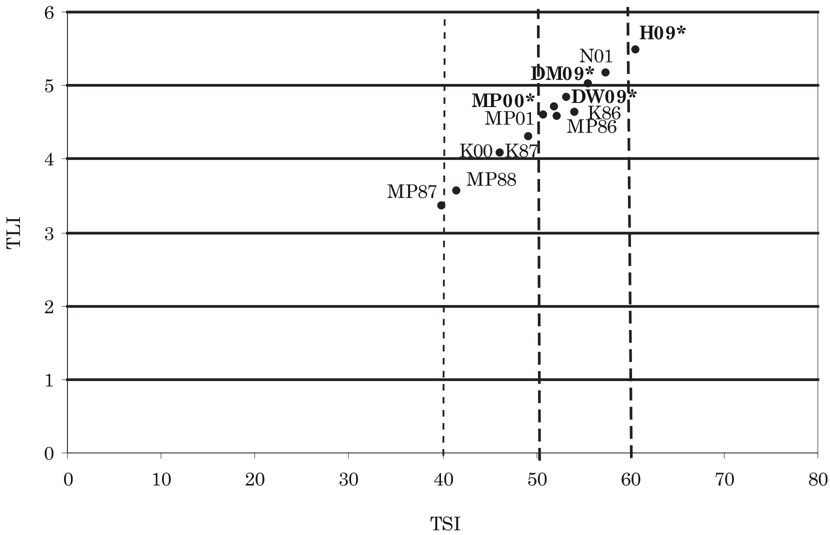

Fig. 5. Trophic state assessment of lakes according to TLI and TSI. The codes of the lakes are given in Fig. 3, *the domination of *G. echinulata*. The trophic state boundaries are as follows: 3, 4, 5 and 6 (for TLI, according to BURNS et al. 2005) for the oligo-/meso-, meso-/eu-, eu-/super- super-/hypertrophic trophic state and 40, 50, 60 (for TSI, according to CARLSON 1977) for the meso-, meso-eu-, eutrophic trophic state, respectively

Table 4

Relationships between *G. echinulata* biomass and ecological and trophic assessments of the lakes

Specification	Regression formula	R^2	r	p
B*Ge* vs. PTI	B*Ge* = −3.109 × PTI + 3.356	0.133	−0.365	0.243
B*Ge* vs. $PMPL_{MOD}$	B*Ge* = −5.209 × $PMPL_{MOD}$ + 4.882	0.412*	−0.642*	0.025
B*Ge* vs. TSI	B*Ge* = 0.132 × TSI − 5.734	0.153	0.392	0.208
B*Ge* vs. TLI	B*Ge* = 1.433 × TLI − 5.486	0.189	0.435	0.158

PTI – Phytoplankton Trophic Index, $PMPL_{MOD}$ – modified Phytoplankton Metric for Polish Lakes, TSI – Trophic State Index, TLI – Trophic Level Index, B*Ge* – *G. echinulata* biomass * statistically significant difference, $p < 0.05$

the mesotrophic to eutrophic state. Its mass development was observed in lakes representing a moderate (using PTI) or even high and poor ecological status (using $PMPL_{MOD}$), and the meso-eutrophic and eutrophic conditions. According to CAREY et al. (2008), this taxon could significantly affect the phosphorus translocation from sediments to an entire lake, thus accelerating the eutrophication process, and it can represent a significant element in the benthic-pelagic coupling of biogeochemical cycling (i.e. the turnover of nutrients in the form of living matter). Moreover, such phenomena seen in the ecological or trophic context could improve our understanding of biotic-abiotic relations in lake management strategies.

CONCLUSIONS

In the lakes of north-eastern Poland, the pelagic growth of *Gloeotrichia echinulata* was connected with the warmest period of summer. During its mass development, including bloom events, the light and oxygen conditions decreased significantly. The phosphorus content then remained on a rather low level, although the concept developed for the PTI in assessing an ecological status implies that the genus *Gloeotrichia* should reflect a high TP concentration assigned to very tolerant or tolerant taxa. *G. echinulata* tends to occur in a broad range of lakes, from a high to poor ecological status, although – with respect to trophy – it can occur in mesotrophic to eutrophic lakes. Additionally, with its ability affect phosphorus translocation from sediments to an entire lake, thus contributing to the benthic-pelagic coupling of biogeochemical cycling, *G. echinulata* could accelerate eutrophication. Therefore, it may be a very important indicator of progressive deterioration of a lake's ecological and trophic conditions, providing useful information to the lake's management strategies.

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REFERENCES

Burns N., McIntosh J., Scholes P. 2005. *Strategies for Managing the Lakes of the Rotorua District, New Zealand*. Lake Reserv. Manage., 21(11): 61-72.

Carey C.C., Ewing H.E., Cottingham K.L., Weathers K.C., Thomas R.Q., Haney J.F. 2012. *Occurrence and toxicity of the cyanobacterium Gloeotrichia echinulata in low-nutrient lakes in the northeastern United States*. Aquat. Ecol., 46: 395-409.

Carey C.C., Weathers K.C., Cottingham K.L. 2008. *Gloeotrichia echinulata bloom in an oligotrophic lake: helpful insights from eutrophic lakes*. J. Plankton Res., 30(8): 893-904.

Carlson R.E. 1977. *A trophic state index for lakes*. Limnol. Oceanogr., 22: 361-369.

CEN 2006. EN 15204: *Water quality – Guidance standard for the routine analysis of phytoplankton abundance and composition using inverted microscopy (Utermöhl technique)*. European Committee for Standardization, Brussels.

Commission Decision of 20 September 2013 establishing, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Decision 2008/915/EC. Official Journal of the European Union 2013/480/EU.

Forsell L., Pettersson K. 1995. *On the seasonal migration of the cyanobacterium Gloeotrichia echinulata in Lake Erken, Sweden, and its influence on the pelagic population*. Mar. Freshwat. Res., 46(1): 287-293.

Grabowska M., Glińska-Lewczuk K., Obolewski K., Burandt P., Kobus Sz., Dunalska J., Kujawa R., Goździejewska A., Skrzypczak A. 2014. *Effect of hydrological and hydrochemical factors on the qualitative and quantitative structure of phytoplankton communities in selected floodplain lakes in the Middle Basin of the Biebrza River, NE Poland*. Pol. J. Environ. Stud., 23(3): 713-725.

Hutorowicz A., Napiórkowska-Krzebietke A., Pasztaleniec A., Hutorowicz J., Lyche Solheim A., Skjelbred B. 2011. *Phytoplankton*. In: *Ecological status assessment of the waters in the Wel river catchment. Guidelines for integrated assessment of ecological status of rivers and lakes to support river basin management plans*. Soszka H. (ed.). IFI Olsztyn, 143-168. (in Polish with English summary)

Istvanovics V., Pettersson K., Rodrigo M.A., Pierson D., Padisák J., Colom W. 1993. *Gloeotrichia echinulata, a colonial cyanobacterium with a unique P uptake and life strategy*. J. Plankton Res., 15: 531-552.

Jacobsen B.A. 1994. *Bloom formation of Gloeotrichia echinulata and Aphanizomenon flos-aquae in a shallow, eutrophic, Danish lake*. Hydrobiologia, 289: 193-197. DOI: 10.1007/BF00007420

Jakubowska N., Zagajewski P., Gołdyn R. 2013. *Water blooms an cyanobacterial toxins in lakes*. Pol. J. Environ. Stud., 22(4): 1077-1082.

Karlsson-Elfgren I., Hyenstrand P., Riydin E. 2005. *Pelagic growth and colony division of Gloeotrichia echinulata in Lake Erken*. J. Plankton Res., 27(2): 145-151. DOI: 10.1093/plankt/fbh165

Karlsson-Elfgren I., Rengefors K., Gustafsson S. 2004. *Factors regulating recruitment from the sediment to the water column in the bloom-forming cyanobacterium Gloeotrichia echinulata*. Freshwater Biol., 49(3): 265-273.

Kobos J., Błaszczyk A., Hohlfeld N., Toruńska-Sitarz A., Krakowiak A., Hebel A., Stryk K., Grabowska M., Toporowska M., Kokociński M., Messyasz B., Rybak A., Napiórkowska-Krzebietke A., Nawrocka L., Pełechata A., Budzyńska A., Zagajewski P., Mazur-Marzec H. 2013. *Cyanobacteria and cyanotoxins in Polish freshwater bodies*. Oceanol. Hydrobiol. St., 42(4): 358-378. DOI: 10.2478/s13545-013-0093-8

Kratzer C.R., Brezonik P.L. 1981. *A Carlson-type trophic state index for nitrogen in Florida lakes*. Water Res. Bull., 17: 713-715.

Napiórkowska-Krzebietke A., Hutorowicz A. 2005. *Long-term changes of phytoplankton in Lake Mamry Północne*. Oceanol. Hydrobiol. St., 34(3): 217-228.

Napiórkowska-Krzebietke A., Hutorowicz A. 2006. *Long-term changes of phytoplankton in Lake Niegocin, in the Masurian Lake Region, Poland*. Oceanol. Hydrobiol. St., 35(3): 209-226.

Napiórkowska-Krzebietke A., Hutorowicz A. 2007. *Long-term changes in the biomass and composition of phytoplankton in a shallow, flow-through lake Kirsajty (Masurian Lakeland, Poland)*. Pol. J. Natur. Sci., 22: 512-524.

Napiórkowska-Krzebietke A., Pasztaleniec A., Hutorowicz A. 2009. *Phytoplankton – element in ecological status assessment for lakes of the Wel river catchment area*. Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 6: 200-205.

Napiórkowska-Krzebietke A., Pasztaleniec A., Hutorowicz A. 2012. *Phytoplankton metrics response to the increasing phosphorus and nitrogen gradient in shallow lakes*. J. Elem., 17(2): 289-303. DOI: 10.5601/jelem.2012.17.2.11

Napiórkowska-Krzebietke A., Wierzchowska M., Błocka B., Hutorowicz J., Hutorowicz A., Zdanowski B. 2007. *Changes in the trophic state of Lake Niegocin after the modernization of a local wastewater treatment plant*. Limnol. Rev., 7(3): 153-159.

Napiórkowska-Krzebietke A., Stawecki K., Pyka J.P., Hutorowicz J., Zdanowski B. 2013. *Phytoplankton in relation to water quality of a mesotrophic lake*. Pol. J. Environ. Stud., 22(3): 793-800.

Nõges T., Tõnno I., Laugaste R., Loigu E., Skakalski B. 2004. *The impact of changes in nutrient loading on cyanobacterial dominance in Lake Peipsi (Estonia/Russia)*. Arch. Hydrobiol., 160(2): 261-279. DOI: 10.1127/0003-9136/2004/0160-0261

Phillips G., Lyche-Solheim A., Skjelbred B., Mischke U., Drakare S., Free G., Järvinen M., de Hoyos C., Morabito G., Poikane S., Carvalho L. 2013. *A phytoplankton trophic index to assess the status of lakes for the Water Framework Directive*. Hydrobiologia, 704(1): 75-95.

PHILLIPS G., FREE G., KAROTTKI I., LAPLACE-TREYTURE C., MAILEHT K., MISCHKE U., OTT I., PASZTALENIEC A., PORTIELJE R., SØNDERGAARD M., TRODD W., VAN WICHELEN J. 2014. *Phytoplankton classification systems of Member States*. In: *Annex A of Water Framework Directive Intercalibration Technical Report – Central Baltic Lake Phytoplankton ecological assessment methods*. POIKANE S. (ed.) Publications Office of the European Union, Luxembourg. DOI:10.2788/73991

PITOIS S.G., JACKSON M.H., WOOD B.J.B. 1997. *Summer bloom of Gloeotrichia echinulata and Aphanizomenon flos-aquae and phosphorus levels in Antermony Loch, central Scotland*. Int. J. Environ. Heal. R., 7(2): 31-140.

Regulation of the Minister of the Environment of 9 November 2011 on status classification of surface water bodies and environmental quality standards for priority substances. Official Journal of the Laws of 2011, No. 257, Item 1545.

REYNOLDS C.S., HUSZAR V., KRUK C., NASELLI-FLORES L., MELO S. 2002. *Towards a functional classification of the freshwater phytoplankton*. J. Plankton Res., 5: 417-428.

Standard Methods for Examination of Water & Wastewater 1999. Am. Publ. Health ASN., New York.

SZÁSZ E., PETTERSSON K. 2000. *Nitrogen uptake and fixation by phytoplankton in Lake Erken (Sweden) during summer*. Verh. Internat. Verein. Limnol., 27: 1995-1999.

TYMOWSKI R., DUTHIE H.C. 2000. *Life strategy and phosphorus relations of the cyanobacterium Gloeotrichia echinulata in an oligotrophic Precambrian shield lake*. Arch. Hydrobiol., 148(3): 321-332.

WOŁOS A., ZDANOWSKI B., WIERZCHOWSKA M. 2009. *Long-term changes in commercial fish catches in Lake Mamry Północne (northeastern Poland) on the background of physical, chemical, and biological data*. Arch. Pol. Fish., 17: 195-210.

ZDANOWSKI B., WOŁOS A., WIERZCHOWSKA M. 2009. *Change patterns in the trophic state of Lake Mamry Północne and Lake Niegocin (Masurian Lake District, Poland)*. Limnol. Rev., 9(1): 39-60.

ZĘBEK E. 2015. *Response of planktonic cyanobacteria and periphyton assemblages to physicochemical properties of storm water in a shallow urban lake.* J. Elem., 20(1): 231-245. DOI: 10.5601/jelem.2014.19.2.679