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Gonyostomum semen (Ehr.) Diesing bloom formation in nine lakes of Polesie region (Central–Eastern Poland)

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Abstract – Using data from nine lakes, sampled between 2002 and 2010, as well as literature we have analysed blooms of *Gonyostomum semen* (Ehr.) Diesing in a new spreading area (Polesie region, Central–Eastern Poland). We tried to determine habitat suitability for high biomass of the species, including both physico-chemical and morphometric features. High biomass of *Gonyostomum* (>1.4 mg.L^{-1}) was found in three groups of coloured water bodies: (a) very small (<0.002 km^2) peat pits with low pH values and mineral content; (b) larger ponds with neutral pH values and intermediate conductivity; (c) natural lakes with intermediate parameters in terms of area, pH and mineral content. There were no statistical differences regarding the values of the species biomass among the groups of lakes. *Gonyostomum* biomass was closely positively correlated with water colour, whereas it was weakly negatively correlated with lake area and depth. The results show that *G. semen* in a new spreading area bloomed in a broad spectrum of freshwater habitats.

Key words: *Gonyostomum semen* / phytoplankton / algal blooms / habitats / humic waters

Introduction

The number of reports on mass development of the flagellate alga *Gonyostomum semen* (Ehr.) Diesing in freshwaters has been increased during the last three decades and currently the species is claimed to be common phytoplankton dominant in many brown-coloured lakes (Cronberg *et al*., 1988; Lepistö *et al*., 1994; Willén, 2003; Laugaste and Nõges, 2005). The species blooms were sometimes followed by the reports on skin problems in people who had bathed in such lakes (Cronberg *et al*., 1988; Hongve *et al*., 1988; Lepistö *et al*., 1994).

The first reports about the species' occurrence come from European freshwaters (peat bogs, humic lakes and fish ponds) including Germany, Sweden and former Czechoslovakia (Ehrenberg, 1853; Levander, 1894; Fott, 1952; Sörensen, 1954 after Hassdenteufelová, 1955; Lepistö *et al*., 1994). Nowadays, *Gonyostomum* is known to be found in an increasing number of habitats in different parts of continental Europe. It has been recorded in a peat bog in Hungary (Grigorszky *et al*., 2010), in very small lakes on the islands of Lake Ladoga, Russia (Voyakina, 2010), highly humic lakes in Latvia (Druvietis *et al*., 2010) and small lakes in Lithuania (Koreivienė *et al*., 2012). It has been also found in other types of water bodies, including floodplain pools (Pithart *et al*., 1997) and large artificial reservoirs (Le Cohu *et al*., 1989; Negro *et al*., 2000), as well as in a highly eutrophic tropical lake (Njine *et al*., 2007).

Some hypotheses have been developed to explain the worldwide spread of G. *semen* during the last decades. It was suggested that an intensive development of the alga is an effect of the acidification (Cronberg *et al*., 1988; Hansson, 1996), the increased phosphorus and ammonium loading (Lepistö and Saura, 1998; Hehmann *et al*., 2001), the increased dissolved organic carbon or fulvic acid concentrations (Findlay *et al*., 2005; Rengefors *et al*., 2008) and the extension of the growing season due to the global warming (Rengefors *et al*., 2012).

In Poland, *Gonyostomum* occurs in northern glacial lakelands. The first record comes from humic Lake Smolak (Masurian Lake District) and dates back to the early 1980s (Hutorowicz, 2001). During the following decades, new observations from 92 lakes in the same region were recorded – species' density was low and exceeded one hundred thousands cells per litre in only

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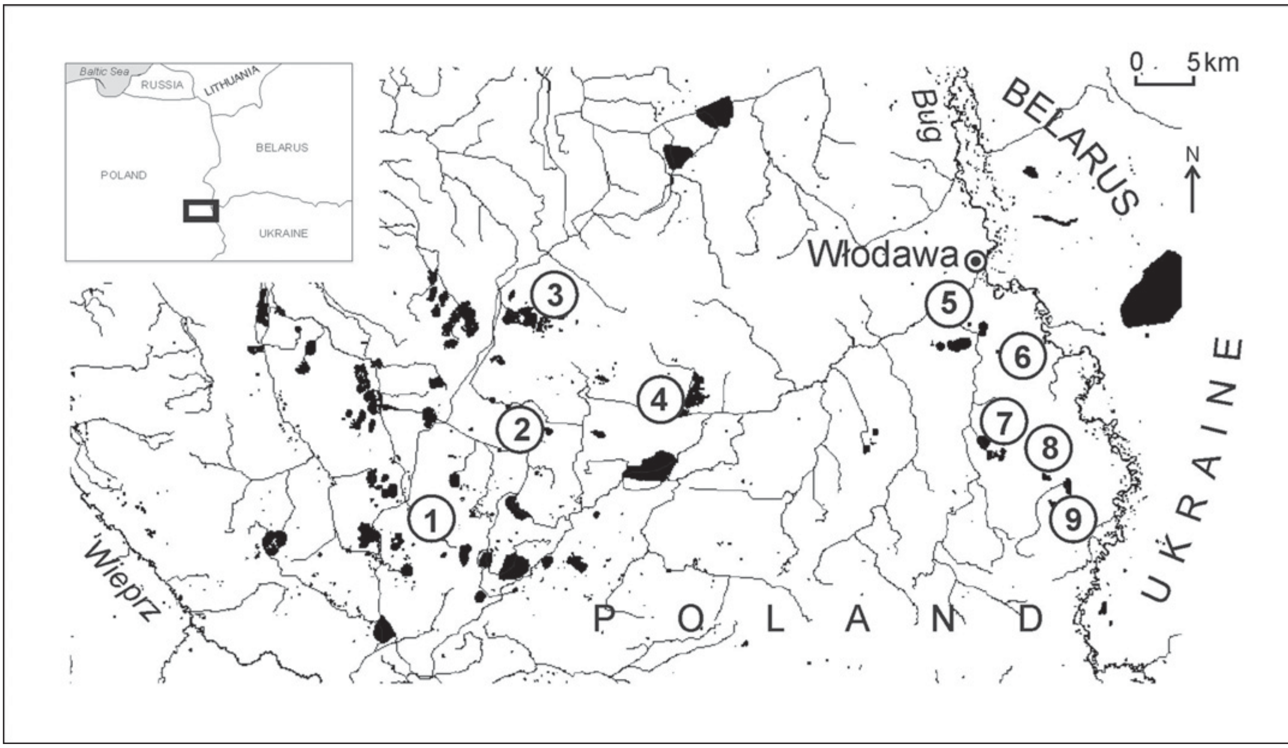

Fig. 1. Location of the studied water bodies (1, Jelino peat pit; 2, Moszne peat pit, 3, pond Głęboki; 4, pond Perkoz; 5, lake Święte; 6, lake Orchowe; 7, lake Pereszpa; 8, lake Brudzieniec; and 9, lake Płotycze).

a few locations (Hutorowicz *et al.*, 2006). The only natural lake districts situated beyond the last glaciation area in Central–Eastern Europe are the lakes of Polesie region. A bloom of *G. semen* in this area was observed for the first time in 1997 (more than 10 years after the first report from northern Poland) by Pęczuła (2007). Since then, the presence of *G. semen* in these freshwaters has been observed several times (Wojciechowska and Solis, 2009).

Assuming that this is a new spreading area of *G. semen* in Central–Eastern Europe, we analyse the habitats where the species forms high biomass. We investigated *G. semen* in a set of water bodies (natural lakes, peat pits and fish ponds) located in the Polesie region. The lakes in this region are characterized by specific hydrochemical and morphological conditions (karstic lakes developed on chalk deposits), so we aimed at describing the characteristics of *Gonyostomum* habitats and compare our results with results from other studies in northern Europe.

Study area

The studied water bodies are situated in the Polesie region (the East European Plain) (Fig. 1). Although precipitation in the area is rather low (500–550 mm.year^{-1}), the water table is located shallowly beneath the ground surface and the plain is rich in wetlands as well as in numerous water bodies of different origin (natural lakes, fish ponds and peat pits). The river network is scarcely developed; therefore most of the lakes are endorheic. Several lakes are coloured due to high humic content coming from adjacent forests and wetlands (Chmiel, 2009). They often have a neutral pH, which is associated with the specific geological conditions: the whole area is situated on some limestone formation deposited at various depths under the ground level (Harasimiuk *et al.*, 1998).

From our phytoplankton dataset concerning freshwaters of the studied area we have selected nine water bodies in which *G. semen* reaches high biomass level. We have assumed 1.4 mg.L^{-1} as a threshold value of high biomass, following other *Gonyostomum* studies (Angeler *et al.*, 2010; Trigal *et al.*, 2011). We do not have enough data to determine whether the species is dominant in all the studied water bodies, but in some cases its dominance in the total phytoplankton biomass was higher than 50% (Poniewozik *et al.*, 2011, Pęczuła and Poniewozik, unpublished data).

The studied water bodies represent different types in terms of their origin (natural lakes, fish ponds and peat pits). The lakes, due to their karstic genesis, are small and have oval shapes. The fish ponds are situated in the protected area (Poleski National Park), thus they are excluded from fishery. The peat pits are very small water bodies of post-mining origin. All the studied water bodies are shallow and represent various mictic types (dimictic and polymictic) and hydrological regimes (open or closed) (Table 1). The area covered by emergent vegetation ranges from 0% in peat pits, through 6–16% in lakes to 30–80% in ponds (Table 1).

Table 1. Basic limnological data of studied water bodies.

	Localization	Genetic type	Hydrological regime	Mictic type	Area (ha)	Emergent vegetation[1] (%)	Max. depth (m)
Jelino (JEL)	N 51°25'10.8" E 23°01'52.4"	Peat pit	Closed	Polymictic	0.2	0	1.0
Moszne (TMO)	N 51°27'27" E 23°06'45"	Peat pit	Closed	Polymictic	0.1	0	0.8
Głęboki (GLE)	N 51°29'20" E 23°10'38"	Fish pond	Open	Polymictic	17.3	30	1.9
Perkoz (PRK)	N 51°28'02" E 23°14'52"	Fish pond	Open	Polymictic	44.1	80	1.2
Święte (SWI)	N 51°30'30.7" E 23°32'37.6"	Natural lake	Closed	Dimictic	5.7	14	9.6
Orchowe (ORC)	N 51°29'23" E23°34'27"	Natural lake	Closed	Polymictic	7.9	11	1.2
Pereszpa (PER)	N 51°25'40.1" E 23°34'17.1"	Natural lake	Open	Dimictic	24.3	8	6.2
Brudzieniec (BRU)	N 51°24'38.4" E 23°36'45.0"	Natural lake	Closed	Polymictic	17.8	6	2.0
Płotycze (PLO)	N 51°23'34.9" E 23°37'03.8"	Natural lake	Closed	Dimictic	16.6	16	6.0

[1]– as per cent of area covered by rushes, approximate.

Table 2. Ranges of basic water quality parameters in studied water bodies (V – May, VI – June, VII – July, VIII – August, IX – September).

	Sampling period	Temperature (°C)	pH	EC (μS.cm^{-1})	TP (mg.L^{-1})	Water colour (mgPt.L^{-1})	Secchi depth (m)	Chl-*a* (μg.L^{-1})
Jelino (JEL)	2009 (VII)	24.6–25.0	4.8–4.9	20–25	–	165	0.5	20.5–44.7
Moszne (TMO)	2008 (VI)*	24.0	5.5	81	0.142	1500	0.2	237.0
Głęboki (GLE)	2008 (VI)*	18.9	6.8	168.0	0.23	143	0.7	84.0
Perkoz (PRK)	2010 (VI, VIII)	19.1–23.1	7.3–7.5	158–164	0.155–0.249	123–178	0.4–0.9	61.8–71.2
Święte (SWI)	2002 (V, VII, IX), 2003 (VII, IX)	6.4–27.0	5.9–7.0	132–135	0.028–0.193	28–70	1.1–1.6	12.5–37.4
Orchowe (ORC)	2008 (VI)*	20.3–21.3	8.3	62.0	0.05	171	0.9	92.0
Pereszpa (PER)	2002 (V, VII, IX), 2003 (VII, IX), 2008 (VI)*	9.1–25.7	6.7–8.3	109–135	0.036–0.129	86–236	0.7–1.4	19.8–149.9
Brudzieniec (BRU)	2002 (V), 2008 (VI)*	20.9–22.4	7.7–8.0	141–248	0.031–0.069	240–267	0.5–1.1	34.6–53.0
Płotycze (PLO)	2000 (VII, IX), 2002 (VII, IX), 2003 (VII), 2008 (VI)*	11.4–21.9	6.1–7.9	69–190	0.067–0.098	63–173	0.5–2.0	47.1–152.3

*Poniewozik *et al.* (2011).

Methods

Data on *Gonyostomum* were obtained from samples collected between 2002 and 2010; additionally, very few records come from Poniewozik *et al.* (2011). The samples were collected once a month between May and September. The lakes were sampled between 2002 and 2008 and the ponds and peat pits between 2008 and 2010. Details of the sampling are presented in Table 2. Water samples were taken from the central part of each water body with a Ruttner sampler (2 L capacity). In shallow freshwaters two samples (0.5 m beneath the surface and 0.5 m above the bottom) were poured together into one collective sample, whereas in stratified lakes, samples were collected separately from two vertical zones (one epilimnion and one hypolimnion samples). Sampling was carried out at the same time of the day (usually between 11 a.m. and 2 p.m.) to avoid sampling artefacts associated with dial vertical migrations of the species, which is emphasized by some authors (Salonen and Rosenberg, 2000). Additional qualitative samples for taxonomic analysis were taken with a planktonic net (mesh size 20 μm). They were examined under a microscope without preservation to properly determine *G. semen*. Samples for quantitative analysis were fixed in Lugol solution. *Gonyostomum* cells were counted with the help of an inverted microscope,

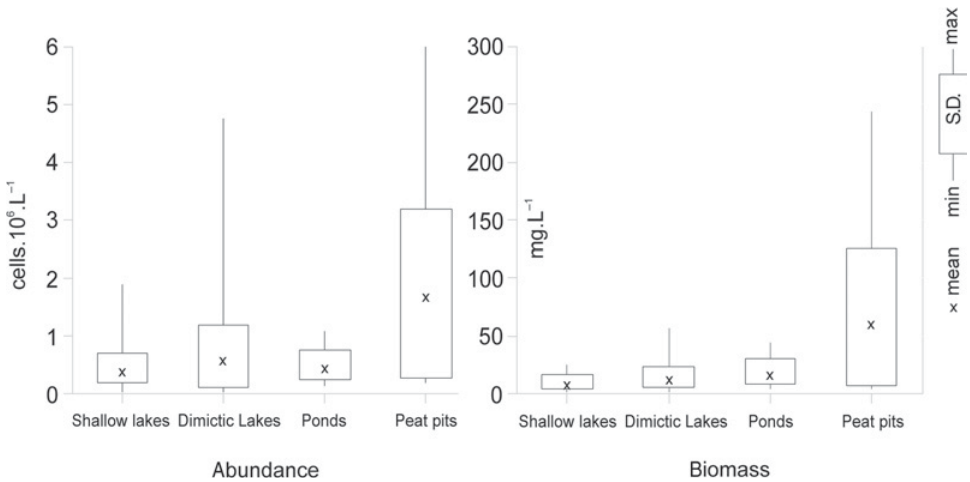

Fig. 2. Abundance and biomass of Gonysotomum semen in studied groups of water bodies.

according to Utermöhl's method (1958). As there is no generally accepted formula for *Gonyostomum* biovolume calculation available in the published data, we used a prolate spheroid as a geometric model for biovolume calculation of the species. It is a commonly applied formula for the estimation of the biovolume in some similarly shaped flagellates (Hillebrand *et al.*, 1999). We then recalculated the biovolume to fresh biomass, with an assumption that the density of algal cells equals 1 g.cm^{-3}.

Samples for the analysis of water chemistry were taken simultaneously with phytoplankton samples, with the use of the Ruttner sampler. Water transparency (with a standard Secchi disc), temperature, pH and specific conductance (with YSI 556 Multi Probe, MPS) were measured in the field. The concentration of total phosphorus (ammonium molybdate method, Hermanowicz *et al.*, 1999), as well as chlorophyll-*a* (ethanol method, ISO, 1992) and water colour (spectrophotometrically) were determined in the laboratory on the day of sampling. Water colour was calculated according to Lean (1998), using the formula: water colour [mgPt.L^{-1}] = 18.216 × (A_{440} × l × 2.303)–0.209; where: A_{440} = absorbency at 440 nm and l = optical length of a cuvette.

In order to determine the significance of differences among *Gonyostomum* biomass in various groups of water bodies (natural lakes, fish ponds and peat pits), one-way ANOVA analysis was performed. We also correlated the species biomass with environmental factors (pH, colour, specific conductance and total phosphorus concentration) by calculating Pearson correlation coefficient. The analyses were performed using Gnumeric v. 1.10.16 software.

Results

Freshwaters with high biomass of *G. semen* (≥ 1.4 mg.L^{-1}) were characterized by both acidic and slightly alkaline conditions, as well as a broad range of mineral content (Table 2). Water colour in lakes was in most cases higher than 100 mg Pt.L^{-1}. Owing to this colouring, water transparency was low, from 0.2 to 2.0 m. Chlorophyll-*a* concentrations were high, up to 237 µg.L^{-1}. The temperature of water in shallow water bodies and in epilimnion of dimictic lakes oscillated between 18.9 and 27.0 °C. Water temperature ranged between 6.4 and 11.4 °C in the hypolimnion.

The density of *Gonyostomum* in the analysed samples varied between 0.031 × 10^6 and 6.106 × 10^6 cells.L^{-1}, whereas the biomass ranged between 1.4 and 243.6 mg.L^{-1} (Fig. 2). In fish ponds and peat pits, *Gonyostomum* densities ranged between 0.140 × 10^6 and 6.107 × 10^6 cells.L^{-1} while in natural lakes between 0.0308 × 10^6 and 4.760 × 10^6 cells.L^{-1}. In lakes the species abundance did not always correspond to biomass values. Sometimes large numbers of *G. semen* were accompanied with lower biomass, but in some cases the situation was reverse. In natural lakes, the biomass ranged from 1.4 to 56.3 mg.L^{-1}, in the other water bodies, it was 4.2–43.9 mg.L^{-1}. In all types of water bodies, extremely high abundance was observed in some sampling instances, with over million cells per litre (Lake Pereszpa – 1.280 × 10^6 cells.L^{-1} in June 2008; Lake Orchowe – 4.760 × 10^6 cells.L^{-1}in June 2008 and pond Perkoz – 1.093 × 10^6 cells.L^{-1} in June 2010). The highest density expressed both by the number and biomass was observed in Moszne peat pit (6.107 × 10^6 and 243.6 mg.L^{-1}, respectively). Despite the fact that *Gonyostomum* biomass varied among the studied water bodies, the ANOVA results showed no statistical significant differences in biomass among lake groups (F = 1.44, P = 0.25, ANOVA). We also tested the correlation between the species' biomass and morphological and chemical habitat variables. Water colour was highly correlated with the species' biomass (r = 0.98, P < 0.05), while the lake surface area and depth showed weak and negative correlations (r = −0.34 and r = −0.32, respectively, P < 0.05). The differences regarding the total phosphorus concentration, specific conductance and pH correlation were statistically insignificant.

Seasonal pattern in the species' quantity (including abundance and biomass) could be observed. The highest values were recorded in the samples from June (mean: 1.863×10^6 cells.L^{-1}; range: $0.295–6.106 \times 10^6$ cells.L^{-1} and mean: 53.0 mg.L^{-1}; range: 5.5–243.6 mg.L^{-1}, respectively), followed by lower values in July, August and September (0.049×10^6 cells.L^{-1} ; 1.881×10^6 cells.L^{-1}; 1.4–56.3 mg.L^{-1}). In the samples from May, the abundance and the biomass were the lowest for the whole study period (mean: 0.043×10^6 cells.L^{-1}; range: $0.031–0.059 \times 10^6$ cells.L^{-1} and mean: 2.0 mg.L^{-1}; range: 1.4–3.2 mg.L^{-1}, respectively). The high biomass of the alga in Lake Płotycze (2.4–56.3 mg.L^{-1}) was usually found only in deeper hypolimnetic layers, especially in the samples from July. In Lake Święte, however, the distribution was different: higher biomass usually occurred in the surface layers. In the third lake, *Gonyostomum* had a diverse distribution, with higher abundance both in epilimnetic and hypolimnetic depths.

Discussion

A review of the literature concerning phytoplankton in the freshwaters of Central–Eastern Poland from 1980s to 1990s revealed that *G. semen* was not reported on that area (Wojciechowska and Krupa, 1992; Wojciechowska *et al.*, 1996, 2002; Radwan *et al.*, 1997). Thus, on the basis of our research we can claim that the studied region is a new area of the species' spreading. On that area, high biomasses (> 5 mg.L^{-1}) of *Gonyostomum* were observed for the first time in 1997 (Pęczuła, 2007). Wojciechowska and Solis (2009) found *Gonysotomum* to be dominant in four lakes of Polesie in 2006 and 2007.

G. semen was first reported from a stratified, coloured and nutrient rich small lake with circumneutral pH in 1997 (Pęczuła, 2007). These conditions are similar to habitats, in which the species was more often observed in other European countries (Rosén, 1981; Lepistö *et al.*, 1994). Our recent research shows that the species can form dense populations in other types of habitats with different chemical and physical conditions: from very small peat pits with acidic water and low mineral contents, through larger ponds with neutral pH and intermediate conductivity, rich in total phosphorus, to small, dimictic lakes. Nevertheless, a common characteristic for these habitats is the colour of their waters, always higher than 30 mg Pt.L^{-1}. This confirms that dissolved organic carbon is the main factor which enhances *G. semen* development (Eloranta and Järvinen, 1991; Findlay *et al.*, 2005). The species is mixotrophic, which enables an assimilation of additional source of carbon (apart from inorganic carbon) in such waters, as it was proved by Rengefors *et al.* (2008).

As *G. semen* can migrate in the vertical water column and stay at different depths during the 24-h period (Cowles and Brambel, 1936; Cronberg *et al.*, 1988; Pithart *et al.*, 1997; Salonen and Rosenberg, 2000), the vertical distribution in any lake depends on the time of sampling. Nevertheless, a mixed pattern of the species' vertical distribution occurs in the stratified water bodies of Polesie. In less coloured Lake Płotycze (water colour: 63–173 mg Pt.L^{-1}, Secchi depth $\leq$ 2.0 m), *Gonyostomum* preferred deeper layers, but in more "humic" Lake Pereszpa (water colour: 83–236 mg Pt.L^{-1}, Secchi depth $\leq$ 1.4 m) it formed high biomass also in the surface water, thus the light penetration through the water column could play a certain role in the species' distribution in the analysed lakes. However, the species occurred with high biomass also in polymictic shallow habitats, where the environment is more or less homogenous. Thus, the depth and light penetration of the water body are not the only factors affecting the spread of *Gonyostomum* in the studied area.

Lake acidification was also believed to be the factor responsible for *Gonyostomum* mass occurrence in Scandinavian lakes (Cronberg *et al.*, 1988). It was even claimed that the species preferred low values of pH: between 4.9 and 6.2 (Willén *et al.*, 1990; Korneva, 1996; Hörnström, 2002). Further research revealed that the species developed also in a broader range of pH – from 4.0 to even almost 8.0 (Kato, 1991 after Korneva, 2000; Laugaste and Nõges, 2005). High biomass of the species found in the habitats under study (pH from 4.8 to even 8.3) and a lack of correlation with pH confirm species' high tolerance to this factor.

Our water bodies with high biomass of *G. semen* are also characterized by low or medium mineral content (specific conductance: 20–168 μS.cm^{-1}), which means that they are rather poor in calcium and hydrocarbonates (predominating ions in natural surface waters, Golterman, 1975). This is consistent with the opinion expressed by other authors claiming that high calcium content does not favour the species' spreading (Le Cohu *et al.*, 1989) and that *G. semen* occurs in lakes usually having a low calcium content (Reynolds *et al.*, 2002). This "calcium-avoidance" seems to result from the fact, that humic lakes (in which the species is usually observed) have low calcium content due to the complexation of the element with humic compounds (Jones, 1998).

Lakes with high biomass of *Gonyostomum* were rich in phosphorus, despite their low or medium conductivity. High phosphorus content is very often associated with the species' occurrence (Rosen, 1981; Cronberg *et al.*, 1988; Rengefors *et al.*, 2012). Findlay *et al.* (2005) experimentally proved that phosphorus addition stimulates *Gonyostomum* recruitment from sediments what can explain its domination in nutrient-rich lakes.

Based on the recent research, Rengefors *et al.* (2012) stated that *G. semen* expansion in Sweden is driven by higher temperatures observed in the lakes in the last 30 years. The high biomass of the species in Polesie lakes was recorded within a broad range of temperatures, from 6.4 to 11.4 °C in hypolimnetic waters of stratified lakes to 24–25 °C in shallow peat pits. There are no observations, however, on changes in the temperature of surface water in this region in the last decades, so we cannot exclude or include this factor as favouring the species in our freshwaters.

Our results suggest that *G. semen* can form high biomass in a broad spectrum of habitats (including morphometric features and chemical parameters of a water body, such as pH and conductivity). Like other authors (Eloranta and Järvinen, 1991; Findlay *et al.*, 2005), we support the hypothesis claiming that the mass occurrence of *Gonyostomum* in a new area is a result of multiple factors, including unknown biological changes in the ecosystem. High values of water colour, as well as high phosphorus concentration could be necessary but insufficient requirements for the development of *Gonyostomum* bloom. We have also observed a seasonal pattern of *G. semen* distribution in studied lakes. The biomass of the species was rather low in May and reached its highest value in the samples taken in June. In other European freshwaters, the species' density peaks occur from late July to even late September (Eloranta and Jarvinen, 1991; Pithart *et al.*, 1997; Willén, 2003; Peltomaa and Ojala, 2010). This may suggest the key role of temperature as it was suggested by Rengefors *et al.* (2012), yet it may also point to factors connected with the development of seasonal zooplankton. The role of zooplankton in *G. semen* control is still far from clear understanding. There was a supposition that due to its large size and presence of trichocysts the alga is inedible (Havens, 1989; Lebret *et al.* 2012) but some researchers suggested that large zooplankton species may have a negative effect on alga abundance (Cronberg *et al.*, 1988; Findlay *et al.*, 2005). Two experimental studies (Lebret *et al.*, 2012; Johansson *et al.*, 2013) proved that some large species (like *Daphnia magna* and *Eudiaptomus gracilis*) could feed on the alga. Together with the fact that *G. semen* cyst recruitment is inhibited by the presence of Cladocera (Hansson, 2000) it is possible that the structure of zooplankton in lakes plays a role in the alga bloom forming. As we do not have enough data on the zooplankton structure and seasonal dynamics in the studied lakes, further research on the subject is required.

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