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THE ROLE OF WIND CONDITIONS IN THE HORIZONTAL DISTRIBUTION OF SUMMER PHYTOPLANKTON IN A SHALLOW LAKE – A PRELIMINARY STUDY

Wojciech Pęczuła, Wojciech Płaska, Jacek Rechulicz,
Monika Tarkowska-Kukuryk, Tomasz Mieczan

Department of Hydrobiology, University of Life Science in Lublin, Dobrzańskiego str. 37, 20-062 Lublin,
e-mail: wojciech.peczula@up.lublin.pl

Abstract. The paper aimed to get the analysis of spatial horizontal distribution of summer phytoplankton in a small and shallow lake (Głębokie, Western Polesie, CE Poland) in relation to wind conditions occurring during the research period. The study was conducted in 2011 from 5th of July to 5th of September with eight sampling dates between. Water was sampled in the littoral zone from the depth of 0.5 m in four sites situated in different and opposite to one another lake shores. We analyzed the phytoplankton abundance by the way of chlorophyll a determination as well as the community taxonomic structure. Our research revealed that: a) the direction of the wind, which occurred during sampling might have an important role in the horizontal distribution of planktonic algal biomass within the lake; b) the geomorphology of lake surroundings probably mitigated the influence of wind on phytoplankton distribution; c) even weak or mild wind may influence phytoplankton horizontal differentiation.

Key words: phytoplankton, horizontal distribution, wind conditions

INTRODUCTION

Numerous studies have documented the seasonal dynamics of phytoplankton communities in lakes of various trophic status and morphometrical features. Despite descriptive papers, most studies described phytoplankton dynamics in relation to water chemistry changes and zooplankton grazing pressure [Sommer *et al*. 1986]. However, phytoplankton communities, due to its short generation time are exposed also to disturbances determined by changes in meteorological conditions, which is especially true in shallow polymictic lakes [Padisak 1992]. For example such meteorological factors like wind and rapid storms have a strong influence on growth- and loss rates of phytoplankton populations [Padisak *et al*. 1988]. Cao *et al*. [2005] demonstrated that wind and waves directly influenced surface *Microcystis aeruginosa* blooms in great and deep Lake Taihu. Other studies in great reservoirs showed that the wind might play the important role in both vertical and horizontal distribution of cyanobacteria [George and Edwards 1976]. Recently, there has been renewed interest in meteorological factors influencing variability of planktonic communities, mainly in the aspect of global climate change. Climate seems to be a major factor responsible for changes of thermal properties and biological processes in freshwater ecosystems, in case when anthropogenic influences are absent [Carpenter *et al*. 1992]. Phytoplankton experience changes in climate through fluctuations in water level, ice-free period duration, stratification or nutrient inputs [Straile *et al.* 2003]. Knowledge about factors that influence long-term and short-term variability in plankton dynamics and the phenology of successional events is needed to predict how lake ecosystems will respond to current and future climate change [Garten and Adrian 2000].

Also spatial distribution of phytoplankton in lakes and reservoirs is one of the better studied problems in freshwater ecosystems research. However, much attention was focused on vertical phytoplankton distribution related to gradient of factors which occurs in deeper lakes such as temperature, light or nutrient concentration [Stewart and Wetzel 1986, Gervais 1991, Jones *et al*. 1996, Fott *et al*. 1999]. It was assumed previously that horizontal water mixing, induced by the wind, is responsible for some kind of horizontal homogeneity of phytoplankton communities [Harris 1980], nevertheless there is a growing body of literature that recognizes this problem recently. Phytoplankton horizontal distribution was well studied in large lakes [Jones *et al*. 1995, Bondarenko *et al*. 1996, Gervais *et al*. 1999, Tolonen *et al*. 2005, review in: Reynolds *et al*. 2000], however there is little detailed research concerning smaller water bodies [Wojciechowska and Solis 2001, Pełechaty and Owsianny 2003, Pęczuła 2013].

Although above-mentioned aspects concerning phytoplankton are relatively well documented, there is lack of studies which undertake such research in small and shallow lake ecosystems. The paper aims to fulfill this gap and get the detailed analysis of spatial horizontal distribution of summer phytoplankton in small and shallow lake (Głębokie, Western Polesie, CE Poland) in relation to wind conditions which belongs to major meteorological factors influencing lake ecosystem.

MATERIAL AND METHODS

Lake Głębokie (51°17′20,7600″N; 23°05′42,0360″E) is a small (12 ha), shallow (max depth of 4 m) water body located in the eastern Poland (Cyców community) in the region of Western Polesie (the East European Plain). The lake is situated near the southern border of a flat area of the Łęczna–Włodawa Plain. However, near the southern and the southern-eastern lake’s shore, the lake neighbors on relatively high slopes (4–5 m high) with buildings of a village on the top (Fig. 1). Basic limnological parameters of the studied lake and meteorological conditions during the study are presented in Table 1. Macrophytes are well developed, although non diversed. Rushes are build with a broad belt of reed (*Phragmites australis* L.). Soft vegetation is represented by water lilies (*Nymphea alba* L.) and hornwort (*Ceratophyllum demersum* L.) which form dense beds covering almost all the lake bottom.

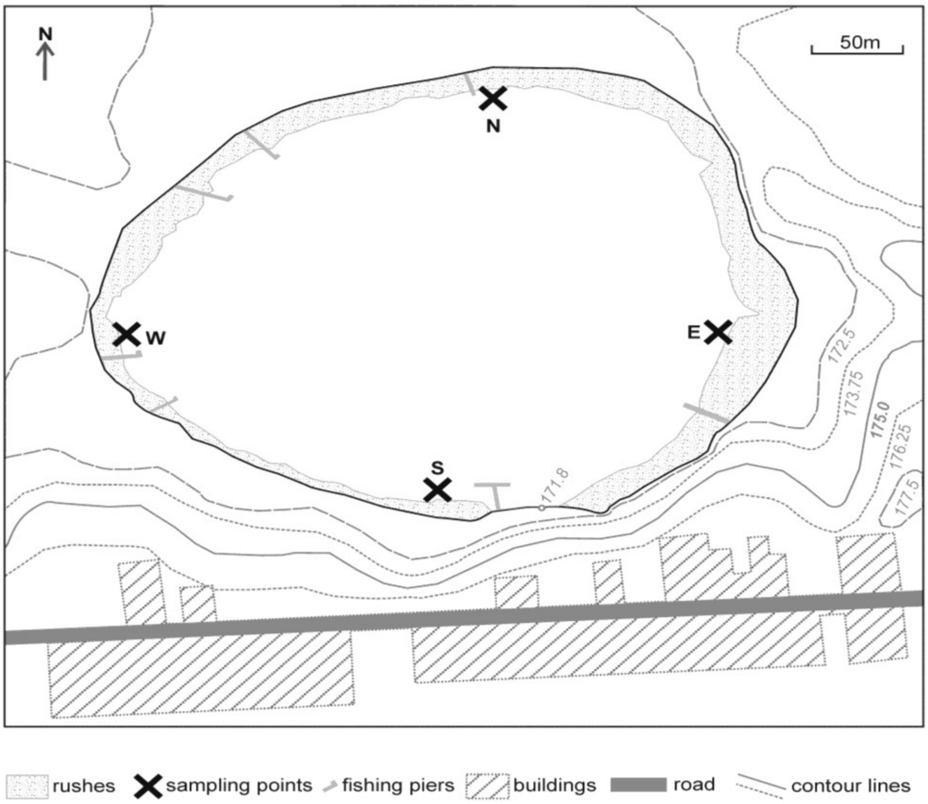

Fig. 1. Situation map of Lake Głębokie with sampling points marked

Water were sampled from the depth of 0.5 m eight times during summer of 2011: 5th, 10th, 17th and 25th of July (Jul); 2nd, 20th, 28th of August (Aug) and 5th of September (Sep) in four sites situated in different and opposite to one another lake shores (eastern, western, northern and southern; marked as E, W, N and S, respectively; Fig. 1). Samples were taken by the use of Ruttner sampler (2 dm^3 of

Table 1. Meteorological conditions during sampling and basic physicochemical parameters of the water in Lake Głębokie

Month	Day	Average air temperature °C	Sum of precipitation, mm	Average wind speed, km/h	Maximum wind speed km/h	Wind direction	Lake water temperature °C	Electrolityc conductivity µS cm^{-1}	pH
July	5	14.7	14.8	10.5	14.4	NE, NW	19.2	573	7.4
	10	21.2	0	9.4	16.2	N, NE	25.3	-	-
	17	20.7	0	11.0	18.0	E, SE	25.0	570	7.4
	25	18.8	16.6	9.1	14.3	E, SE	24.2	-	-
August	2	18.4	0.5	10.3	16.2	N, NW	23.0	564	7.7
	7	22.8	0	12.5	19.8	S	24.1	-	-
	20	16.9	3.5	21.8	30.5	W	24.8	558	7.9
	28	16.5	0	9.1	16.2	W	22.9	-	-
September	6	19.3	0	16.6	23.4	SE	21.8	552	7.9

the volume) in a submerged macrophytes zone. In samples from all terms the concentration of chlorophyll a was determined (the ethanol method, ISO 1992) as well as lake water temperature was measured. In five terms (5th, 25th Jul; 20th, 28th Aug; 5th Sep) phytoplankton taxonomical structure and biomass was calculated using an inverted microscope and the Utermöhl method [Vollenweider 1969] by comparing the algae cells to relevant geometric shapes [Hillebrand *et al*. 1999]. Fresh biomass of algae was then calculated per mg dm^{-3} assuming that the density of algae cells was 1 g cm^{-3}. Additionally we measured basic water parameters (pH, conductivity and oxygen concentration) by the use of YSI 556 Multi Probe on five days: 5th,17th Jul, 2nd, 20th Aug and 5th Sep. In all sampling dates basic meteorological data (mean diurnal air temperature, diurnal sum of preciptitation, mean diurnal wind speed and wind direction) observed in two weather stations (Włodawa: 42 km north-east from the lake and Lublin: 50 km west from the lake) were obtained from a free internet service [www.pogodynka.pl] belonging to the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) in Warsaw, Poland.

RESULTS

During the study, concentration of chlorophyll a in all four study points ranged from 2.9 to 14.8 µg dm^{-3}. On 5th Jul the concentration was as high as 10.4 ±3.6 µg dm^{-3} then decreased after five days down to 5.4 ±2.4 µg dm^{-3} (mean for the lake ±SD, Fig 2). From 10th Jul the values of this parameter generally had been increasing reaching the highest level on 28thAug (12.4 ±1.9 µg dm^{-3}). The differences in chlorophyll a concentration among sampling points were various and amounted between 1.1 µg dm^{-3} (SD = 0.46 µg dm^{-3}) on 7th Aug and 8.6 µg dm^{-3} (SD = 4.0 µg dm^{-3}) on 17th Jul.

We observed changes in phytoplankton taxonomic structure during the season and the general trend was the increase of cyanobacterial share in a total biomass of the community. On 5th of July, phytoplankton in most sampling points was yet dominated by dinoflagellates with *Peridinium bipes* Stein being the most numerous species (Fig. 3). The other groups were represented by cyanobacteria, chlorophytes and euglenophytes, having about 10–30% of the share in the total biomass. Only in sampling point „S", the taxonomical structure was more diverse with any group predominating. Starting from 25th Jul, cyanobacteria became more abundant contributing to 26–62% of the planktonic algae total biomass. On 20th Aug and 6th Sep blue-greens distinctly dominated the phytoplankton in all study points. The most numerous species within cyanobacterial community were: *Anabaena cylindrica* Lemmermann and *Lyngbya* sp. Some horizontal differentiation in the taxonomical structure among study points during the season was observed, but with no clear trends (Fig. 3).

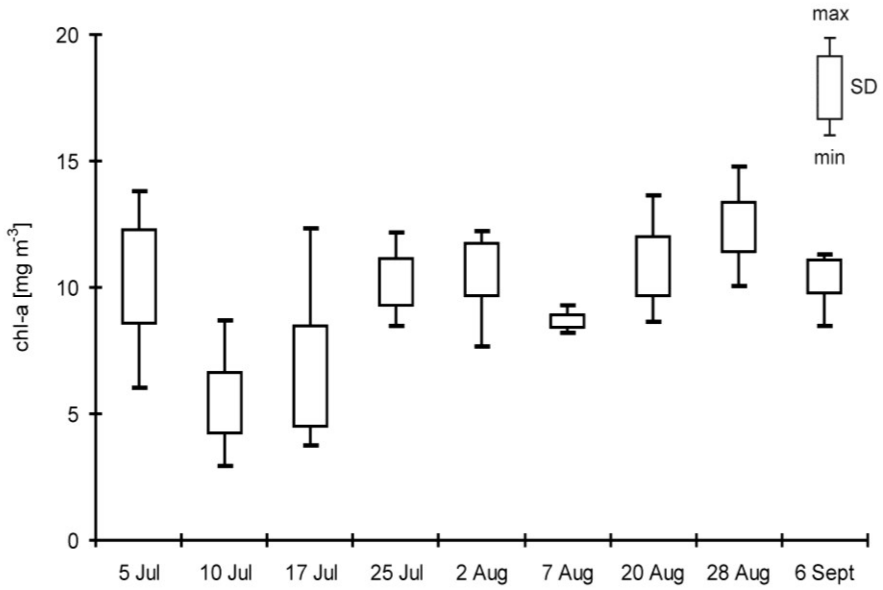

Fig. 2. Concentration of chlorophyll a in summer of 2011

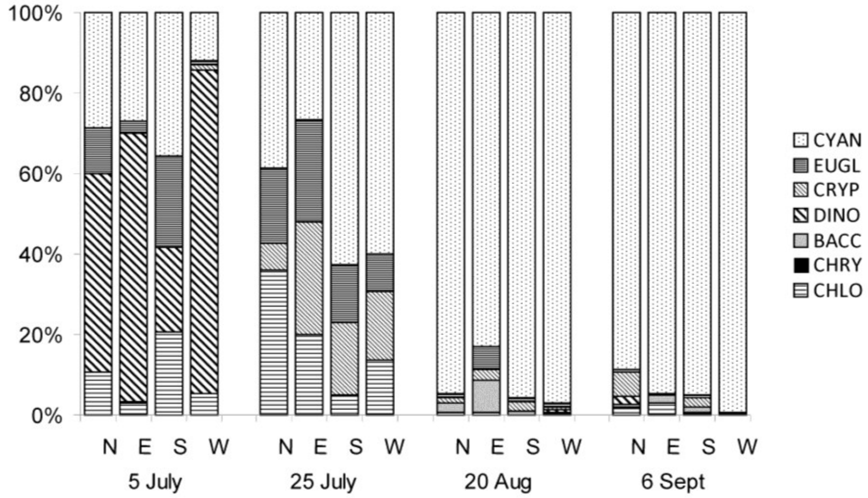

Fig. 3. The pertencage share of taxonomical groups in the total phytoplankton biomass in Lake Głębokie in summer 2011 (CYAN = cyanobacteria, EUGL = euglenophytes, CRYP = cryptophytes, DINO = dinoflagellates, BACC = diatoms, CHRY= chrysophytes, CHLO = chlorophytes)

The wind speed during the study dates varied between 9.1 km/h to 21.8 km/h (average diurnal speed, mean for two weather stations: Lublin and Włodawa). Categorizing these values to the Beaufort scale, we observed a moderate wind (4°B) only on one sampling date (20th Aug), mild wind (3°B) on two days (7th Aug, 6th Sep) and weak wind (2°B) on all other sampling occasions (Fig. 4). The wind direction varied among sampling days: north directed (N, NW or NE) winds prevailed on three occasions, on four other dates wind from southern or eastern direction occurred (S, SE, E) and during two days in August there was a direct wind from the west (W).

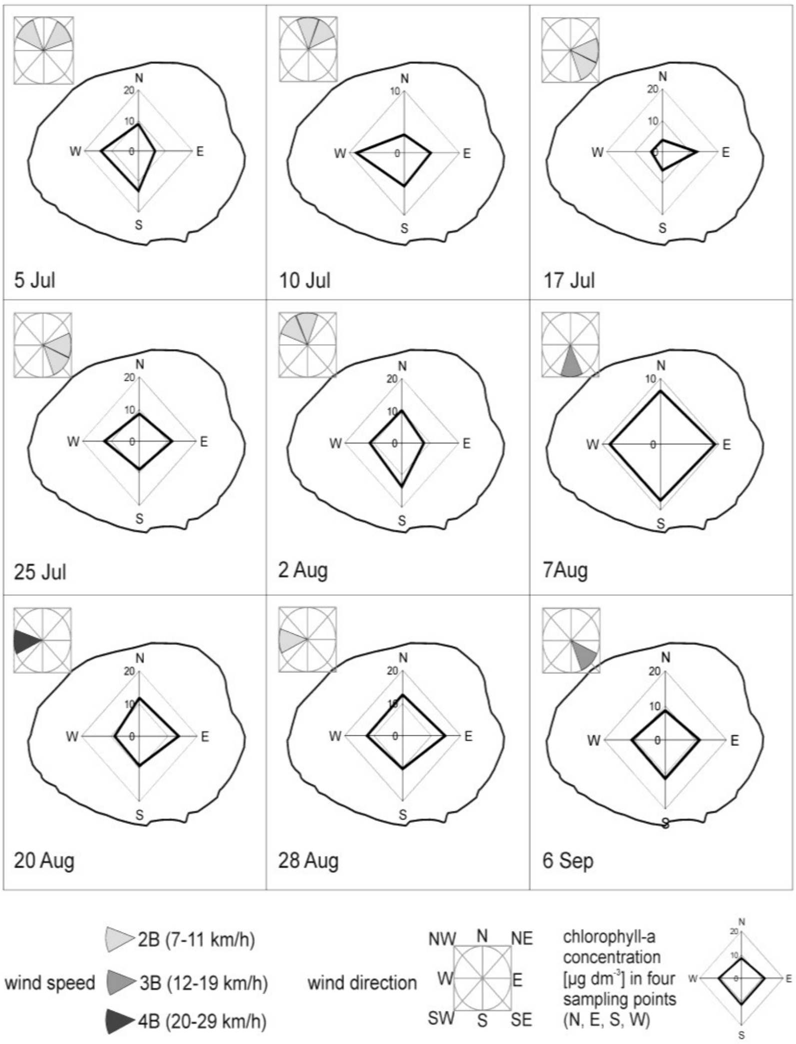

Fig. 4. Concentration of chlorophyll a in four study points against wind direction and speed in Lake Głębokie in summer 2011

While analyzing the variation of chlorophyll a concentration among sampling sites and the direction of prevailing wind in the relevant day one can see some relationship (Fig. 4). During days with north or west winds (N, NW, NE, W), the chlorophyll a concentration in the opposite (to the wind direction) sampling sites was usually higher in comparison to the others. As the most clear example may serve 20th Aug, when moderate (4°B) west wind blew and the concentrations of chlorophyll a in "E" site was almost twice lower as in „W" site (8.6 µg dm^{-3} and 13.7 µg dm^{-3}, respectively) but the similar pattern can be seen also in days when weak (2°B) wind occurred (Fig. 4). Interestingly, this relationship was not observed in dates with south or east winds (S, SE, E). For example, on 7th Aug, when mild (3°B) wind blew from the south, the concentration of chlorophyll a in all sampling sites was very similar and ranged from 8.2 µg dm^{-3} to 9.3 µg dm^{-3}; SD = 1.1 µg dm^{-3} (Fig. 2, Fig. 4).

DISCUSSION

The present study was designed to get the analysis of spatial horizontal distribution of summer phytoplankton in small and shallow lake (Głębokie, Western Polesie, CE Poland) in relation to wind conditions which belongs to major meteorological factors influencing lake ecosystem. Our results have shown that during two months of the study the phytoplankton fluctuated both in space and in time as well as that wind conditions might play an important role in horizontal distribution of algal planktonic communities.

One of the major findings of our study was that the direction of wind, which occurred during sampling might have a potential role in the distribution of planktonic algal biomass within the small and shallow lake. Earlier studies revealed that wind speed correlated with the vertical distribution of algae in shallow lakes [Carrick *et al*. 1993] or deep reservoirs [Serra *et al*. 2007]. Also horizontal patchiness of phytoplankton as an effect of wind activity was an object of some studies, mainly in large lakes and reservoirs [George and Edwards 1976, George and Heaney 1978]. Our results are in the agreement in most of previous findings, confirming the important role of meteorological factors in shaping of planktonic biocoenoses.

We also supposed that the geomorphology of lake surroundings may mitigate the influence of wind on horizontal phytoplankton distribution. In our study we found that in days with wind from south or east – the direction in which the lake is neighbored on a relatively high slope with buildings on its top, the influence on phytoplankton horizontal distribution was probably weak, resulting in more homogenous community within the lake ecosystem. It is in coincidence with earlier reports made by Podsetchine and Schernewski [1999] which revealed that the surrounding topography decreased the influence of wind on lake ecosystem, especially on plankton community distribution. Although they made a research in a large and deep lake, they hypothesized, that the part of the water surface under the shelter is larger in small lakes, thus such kind of mitigation is stronger in those type of lakes.

Our study showed that even weak or mild wind (2°B – 3°B; 7–19 km/h, respectively) may influence phytoplankton distribution. It is in agreement that the wind can influence the phytoplankton in water surface layers even when its speed is lower than 4 km/h [Webster and Hutchinson 1994]. It is also previously assumed that cyanobacteria is a phytoplankton group which is most susceptible to wind movements due to its buoyancy [Webster 1990, Cao *et al*. 2005]. In our study cyanobacteria was the dominant group in the majority of sampling days, thus probably making the wind-induced differences more visible.

Our results provided some new knowledge to the role of meteorological factors in shaping the horizontal distribution of phytoplankton in small and shallow lakes. However, with a small sample size and lack of statistically verified results, caution must be applied, as the findings might not be applicable to the other lake ecosystems. Thus, presented study should be treated as the preliminary one, and further research should be undertaken to investigate the role of meteorological conditions in a spatial and temporal changes in phytoplankton communities in small and shallow lake ecosystems.

CONCLUSIONS

1. The direction of the wind, which occurred during sampling might have an important role in the horizontal distribution of planktonic algal biomass within the small and shallow Lake Głębokie.
2. The geomorphology of lake surroundings probably mitigated the influence of wind on the phytoplankton distribution.
3. Even weak or mild wind may influence phytoplankton horizontal differentiation.

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ROLA WARUNKÓW WIATROWYCH W ZRÓŻNICOWANIU PRZESTRZENNYM LETNIEGO FITOPLANKTONU W PŁYTKIM JEZIORZE – WSTĘPNE BADANIA

Streszczenie. Celem badań była analiza przestrzennego horyzontalnego zróżnicowania letniego fitoplanktonu w małym i płytkim jeziorze (J. Głębokie, Polesie Zachodnie, środkowo-wschodnia Polska) na tle warunków wiatrowych występujących w okresie badań. Próby wody pobierano w roku 2011 pomiędzy 5 lipca a 5 września w ośmiu terminach w litoralu z głębokości 0,5 m w czterech punktach usytuowanych po przeciwnych stronach brzegów jeziora. Analizowano obfitość fitoplanktonu (koncentracja chlorofilu a) oraz strukturę taksonomiczną zbiorowiska. Badania wykazały, że: a) kierunek wiatru mógł mieć duże znaczenie w poziomym rozmieszczeniu fitoplanktonu; b) geomorfologia otoczenia jeziora prawdopodobnie osłabiała wpływ wiatru na przestrzenne zróżnicowanie fitoplanktonu; c) nawet słaby lub łagodny wiatr może mieć wpływ na poziome rozmieszczenie tego zbiorowiska.

Słowa kluczowe: fitoplankton, poziome zróżnicowanie przestrzenne, warunki wiatrowe