POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 28(1): 43–51, Y. 2013

DEGRADATION OF THE RECREATIONAL FUNCTIONS OF URBAN LAKE: A PRELIMINARY EVALUATION OF WATER TURBIDITY AND LIGHT AVAILABILITY (STRZESZYŃSKIE LAKE, WESTERN POLAND)*

Tomasz Joniak, Natalia Jakubowska, Elżbieta Szeląg-Wasielewska

Department of Water Protection
Adam Mickiewicz University in Poznań

K e y w o r d s: urban lake, turbidity, water opalescence, water bloom, vertical availability of PAR.

A b s t r a c t

Turbidity, as an optical property describing water clarity, is a measure of the degree to which water loses its transparency due to the presence of suspended solids, including phytoplankton and dissolved substances. Lake Strzeszyńskie was regarded as the clearest lake in Poznań (western Poland) for many years. In July 2011 first time in the history of lake the watering place was closed due to picocyanobacteria bloom and high water turbidity. The subject of paper was the preliminary assessment of changes the vertical propagation and availability of PAR, turbidity and content of OAS in the lake before and at the time of phytoplankton bloom. To comparison were taken sample from a peak of summer season of 2009 and 2011, respectively. Large changes in depths of photic zone in both periods were stated as well as reducing of euphotic zone and increase the darker disphotic zone. Picocyanophyceae bloom and high light scattering caused by high content of OAS in surface layer resulted in visible effect of the water opalescence.

DEGRADACJA FUNKCJI REKREACYJNYCH MIEJSKIEGO JEZIORA: WSTĘPNA OCENA MĘTNOŚCI WODY I DOSTĘPNOŚCI ŚWIATŁA (JEZIORO STRZESZYŃSKIE, ZACHODNIA POLSKA)

Tomasz Joniak, Natalia Jakubowska, Elżbieta Szeląg-Wasielewska

Zakład Ochrony Wód
Uniwersytet im. A. Mickiewicza w Poznaniu

S ł o w a k l u c z o w e: jezioro miejskie, mętność, opalizacja, zakwit wody, dostępność promieniowania fotosyntetycznie aktywnego.

Tomasz Joniak, Adam Mickiewicz University, ul. Umultowska 89, 61-614 Poznań, Poland, phone: +48 (61) 829 57 80, e-mail: tjoniak@amu.edu.pl
Research work has been financed by Polish Ministry of Science and Higher Education as research projects N304 385538 and N305 100435.

Abstrakt

Mętność wody, jako cecha optyczna opisująca przejrzystość wody, jest miarą stopnia zanieczyszczenia wody przez zawiesiny (w tym fitoplankton) oraz substancje rozpuszczone. Jezioro Strzeszyńskie było przez wiele lat uważane za najczystsze w Poznaniu. Tymczasem nieoczekiwanie w lipcu 2011 r. pierwszy raz w historii wprowadzono zakaz kąpieli w tym jeziorze z powodu masowego zakwitu sinic pikoplanktonowych i wysokiej mętności wody. Przedmiotem badań była wstępna ocena zmian pionowego gradientu i dostępności promieniowania fotosyntetycznie aktywnego oraz mętności wody i koncentracji substancji optycznie aktywnych w okresie przed zakwitem i w jego trakcie. Zestawiono odpowiednio okres szczytu sezonu letniego roku 2009 i 2011. Stwierdzono duże różnice całkowitego zasięgu światła. W stosunku do roku 2009 w 2011 nastąpiła znacząca zmiana struktury strefy prześwietlonej z redukcją zasięgu strefy eufotycznej i wzrostem zasięgu strefy dysfotycznej. Masowy zakwit pikoplanktonowych sinic i silne rozpraszanie światła spowodowane nagromadzeniem substancji optycznie aktywnych w warstwie powierzchniowej wywołały efekt bardzo silnej opalizacji wody.

Introduction

Lakes are very attractive components of urban landscape but in order to serve their function well they need to have good water quality. The anthropogenic transformation of the catchment area may accelerate the nutrient and organic substances enrichment of waters, particularly in strongly changed urban landscape (KUCZYŃSKA-KIPPEN and JONIAK 2010). During the last century a major problem of inland water bodies has been the increase of turbidity and other optical features of water (i.e. opalescence, green colour) as a result of increase water pollution. Water turbidity is caused by many types of dissolved and suspended substances such as silt, clay, tripton, organic and mineral compounds, plankton and other (DAVIES-COLLEY and SMITH 2001). Turbidity is highly variable in aquatic systems mainly due to differentiation of water body depth and surface (HOWICK and WILHM 1985). The major sources of inorganic turbidity are runoff, shoreline erosion, and resuspension of bottom sediments under influence of water movement across the surface of the sediments (BLOESCH 1995). The main source of organic turbidity is a seasonal change in algal development, and major phytoplankton blooms in few eutrophicated waterbodies (GALLEGOS and JORDAN 2002, YE and CAI 2012).

According to APHA (1998) turbidity is the “optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample” – in lake to the greater depth. Universally believed, that turbidity is a main cause of reduction the depth of light penetration (depth of photic zone). However, this theme it’s a great simplifying, because as turbidity is considered almost all what is suspended in water, and a lesser degree with dissolved substances. Meanwhile, as show the practice the increasing of water bodies eutrophication or humification causes increase the concentration of dissolved components for example algal-bacterial colloids and gels. In that situation we can observe water opalescence. This phenomenon (often neglected) causes a strong absorption of light. In view of the above, lower values of dissolved organic compounds increase the probability of deeper light transmission. In natural waters dissolved compounds and humic substances, as end product of decaying organic matter may impart also a brown or other colour to water (FORSBERG 1992, JONIAK 2007). There is evidence that human activity with different way leading to increased turbidity in aquatic systems. The aim of this study was preliminary evaluation of water turbidity, light conditions and content of optically active components in the lake before and at the time of phytoplankton bloom. Our main purpose was to draw attention to the problem of lake degradation and its implications for the recreational use.

Material and Methods

Strzeszyńskie Lake is of glacial origin located in the northwestern part of the Poznań. It is a dimictic lake with an area of 34.9 ha, maximum depth of 17.6 m and mean depth of 8.2 m. The direct catchment of lake is 133 ha of which approx. 61% comprises forests, 20% is arable land, and 16% is meadows (FISHER et al. 2012). The lake is fed by stream Rów Złotnicki (total length 3.5 km). The stream drains of agricultural area and partially area of the village Suchy Las. The lake is the source of the Bogdanka River.

For decades it has been one of Poznań's most popular recreational lakes used for bathing and swimming. A recreational resort is located at the lake, including a large guarded bathing area (grassy beach) and a hotel-restaurant complex with full water-sewage infrastructure. In summer the bathing site is visited by several thousand people per day. Research on the trophic state of lake using the phytoplankton community structure has been conducted from 1978 onward (SZELĄG-WASIELEWSKA 2006). Up to year 2011 the situation that bathing had to be prohibited due to the excessive algae bloom in the lake has never occurred. In July of this year the bathing area had to be closed because of the excessive cyanobacteria bloom and high turbidity was stated.

Sampling and field measurements in the lake were carried out in July 2009 and in July 2011. *In situ* on the station in the deepest place were measured temperature and oxygen content with the use of the multiparameter sonde (YSI 556 MPS) and water turbidity (nephelometrically, Eutech Instr. TN-100) in the whole water column, at 1 m intervals. Water samples for laboratory analysis were taken from subsurface layer (0.5 m) and from some depths in euphotic zone. In laboratory was measured total suspended solids TSS (after filtration through GF/F filter, gravimetrical method), inherent water colour (in water after filtration through GF/F filter, visual method after

HERMANOWICZ et al. 1999), amount of coloured dissolved organic matter (CDOM, characterized by beam attenuation coefficient of membrane 0.45 μm filtered water at 380 nm, measured by Cadas 200 UV-VIS spectrophotometer) (PAAVEL et al. 2008), and chlorophyll *a* (ISO 10260). Biological samples of autotrophic picoplankton (APP) were taken in both study periods from subsurface layer and preserved immediately in 50 ml or 100 ml sterile bottles with buffered formaldehyde. Samples were concentrated on polycarbonate black filters (0.2 μm pore size) at a low vacuum pressure. Microscopic analyses were conducted under an epifluorescence microscope. APP was classified as prokaryotic or eukaryotic on the basis of autofluorescence colour, shape and size of cells (MACISAAC and STOCKNER 1993).

True depth of illuminated zone (TDIZ, sum of euphotic and disphotic zone) was measured *in situ* using the spherical quantum sensor LI-193SA with LI-1400 Datalogger (LI-COR Corporation, Lincoln, Nebraska, USA). The spherical sensor expands the range of underwater study of light as it enables the measurement of total radiation from range 400–700 nm. The bottom border of the euphotic zone is the depth reached by 1.0% of light penetrating the water surface, and disphotic zone by 0.1%. Incident irradiance was measured in the air above surface of water, then in the subsurface layer and later in the water column at 0.5 m intervals. A vertical attenuation coefficient of PAR was calculated by regressing log-transformed light with depth (KIRK 1994) separately for sub-surface layer (K_{dSubs}) and euphotic zone (K_{dZeu}). Water transparency was measured using Secchi disk (white, diameter 30 cm). According to CARLSON (1977), "Secchi depth should only be used if there are no better methods available" for the assessment of the depth of water penetration by light. This suggests the possibility of using visible light quantum sensors. Trophic status was evaluated based on CARLSON (1977) classification. Statistic calculations were made with Statistica 8.0 software.

Results and Discussion

In July 2009 Strzeszyńskie Lake was mesotrophic (TSI_{Chl} = 49, TSI_{TP} = 41, TSI_{SD} = 44) whereas in 2011 eutrophic (54, 54, 53, respectively). In the first period the trophic state was mainly determined by chlorophyll, constituting the basis for the trophic classification. This variable is the most accurate in predicting algal biomass, and more reliable than phosphorus and Secchi depth (CARLSON 1977). In earlier research the fluctuations in trophic state was reported. Phytoplankton studies have shown that in first year of lake investigation (1978) among indicator taxa of algae over 64% were oligo- or mesotrophic, whereas in end of 90^{th} over 51% were eutrophic. On basis of the maximal summer phytoplankton biomass in the first period lake may be classified as mesotrophic and in the second as meso-eutrophic (SZELĄG--WASIELEWSKA 2006). Unfavourable, changes in July 2011 included not only an increase in the trophy, but also change in the relationships between TSI variables, suggesting stronger influence of algae on light attenuation.

Thermal conditions of water in both periods were similar – epilimnion ranged to 4 m (Figure 1). The content of dissolved oxygen in epilimnion and upper part of metalimnion was very high (>10 mg l^{-1} O_2), while below 9 m in 2009 and 7 m in 2011 the permanent oxygen deficit (anoxia) was registered (and strong smell of H_2S was sensed). The deterioration of oxygen conditions resulted in summer fish death. In 2009 the turbidity was low in whole water column but significantly higher in 2011. In the euphotic zone, a significant increase was observed at the boundary of epilimnion and metalimnion, whereas in the metalimnion the turbidity was low. The second increase of turbidity was recorded in the hypolimnion where H_2S occurred. Surplus of hydrogen sulphide gas in lake water can lead to strong water opalescence and high turbidity (SNOEYINK and JENKINS 1980). Between compared periods the statistical analysis revealed high and significant differentiation of turbidity (*t*-test, $t = -16.60$, $p < 0.000$, $n = 16$) and CDOM ($t = -12.57$, $p < 0.012$, $n = 16$). Relatively lower and weaker differences in case of water colour ($t = -2.32$, $p < 0.048$, $n = 16$), TSS ($t = -2.52$, $p < 0.045$, $n = 16$) and chlorophyll ($t = -2.53$, $p < 0.035$, $n = 16$) was stated.

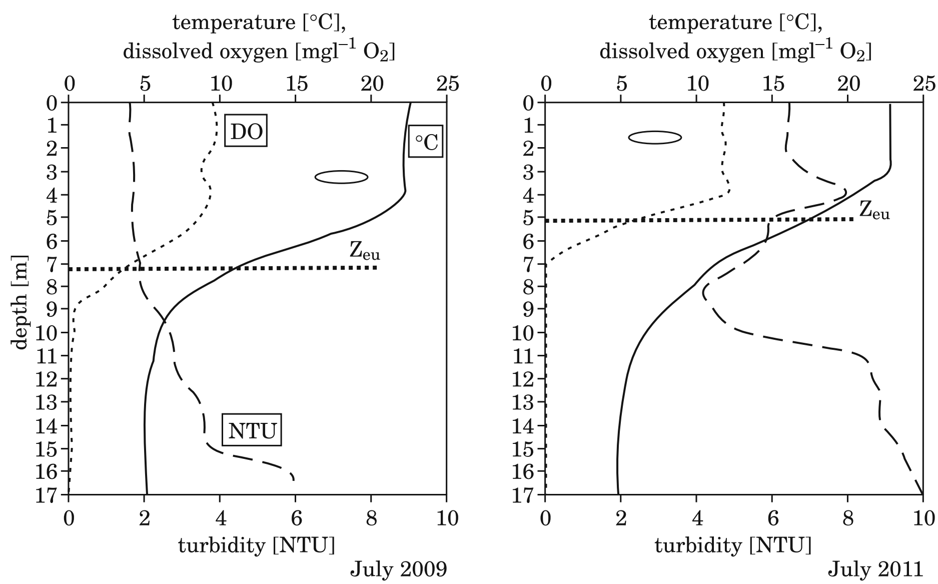

Fig. 1. Vertical profile of temperature (°C), dissolved oxygen (DO) and turbidity of water (NTU) in relation to depth of euphotic zone (Zeu) and Secchi depth in study period (white ellipse = Secchi depth)

Weather conditions were stable during both times of study with 20% of cloudiness and light wind causing only a ripple on the water. During measurement in July of 2009 cloudiness was caused by *Cirrus* and in 2011 by *Cumulus* clouds. PAR irradiance in air above surface of lake (PAR_{Air}) and in the subsurface layer (PAR_{SubI}) was higher in 2011, but depth of photic zone was smaller (Table 1). According to MATUSZKO (2009) at sun height >50° neither of the types of cloudiness cause significant changes in insolation. The study revealed that as result of covering the sun with translucent Cirrus clouds, minimum PAR dispersion occurs which increases the albedo. Other situation is in the case, when the sun is covered by vertical clouds which enable unrestricted radiation penetration only when the sun is not covered.

Table 1

Comparison of the PAR irradiance in air (PAR_{Air}), and at subsurface layer (PAR_{SubI}) in relation to solar elevation, albedo, true depth of illuminated zone (TDIZ) and diffuse attenuation coefficients of subsurface layer ($K_{d\ Subs}$) and euphotic zone ($K_{d\ Zeu}$). In down part of Table average values of OAS in subsurface and euphotic zone in both study periods

Parameter	Time	2009	2011
PAR_{Air} [μmol s^{-1} m^{-2}]	–	2300	2680
PAR_{SubI} [μmol s^{-1} m^{-2}]	–	2060	2500
Solar elevation [°]	–	57.5	54.9
Albedo [%]	–	10.4	6.7
TDIZ [m]	–	8.9	8.0
K_{dSubs} [m^{-1}]	–	0.18	0.37
K_{dZeu} [m]	–	0.59	0.78
TSS [mg l^{-1}]	Subs	4.25	7.1
	Zeu	5.30	8.9
Turbidity [NTU]	Subs	1.64	6.40
	Zeu	1.73	7.12
Chlorophyll [μg l^{-1}]	Subs	3.2	7.2
	Zeu	5.7	12.2
Water colour [mg Pt l^{-1}]	Subs	3.0	4.0
	Zeu	3.4	4.0
a_f (380) [m^{-1}]	Subs	0.4	0.8
	Zeu	0.4	0.9

The increase of water trophy and concentration of OAS during *Cyanophyceae* bloom caused a significant change in vertical gradient of PAR and availability of light in water column. The ranges of zones with various light intensity (euphotic and disphotic zone) developed differently than in July 2009. The analysis of vertical variability of the diffuse attenuation coefficient for downwelling irradiance (K_d) in the first period showed low values in subsurface layer and in deep waters (Table 1). Statistical analysis revealed a significant differentiation of K_d values in vertical profile of lake between both periods (t = –2.85, p < 0.011, n = 18). In July 2009 PAR was transmitted deeper, and penetrated the lake's waters almost up to 9 m. During algal bloom the K_d in the subsurface layer doubled. In result, the euphotic zone was shallower and the disphotic zone was deeper (Figure 2). Therefore, substantial changes in the features of the light climate caused a decrease in TDIZ thickness by less than 1 m. However, the comparison of Secchi depth showed an almost twice larger difference (Figure 1).

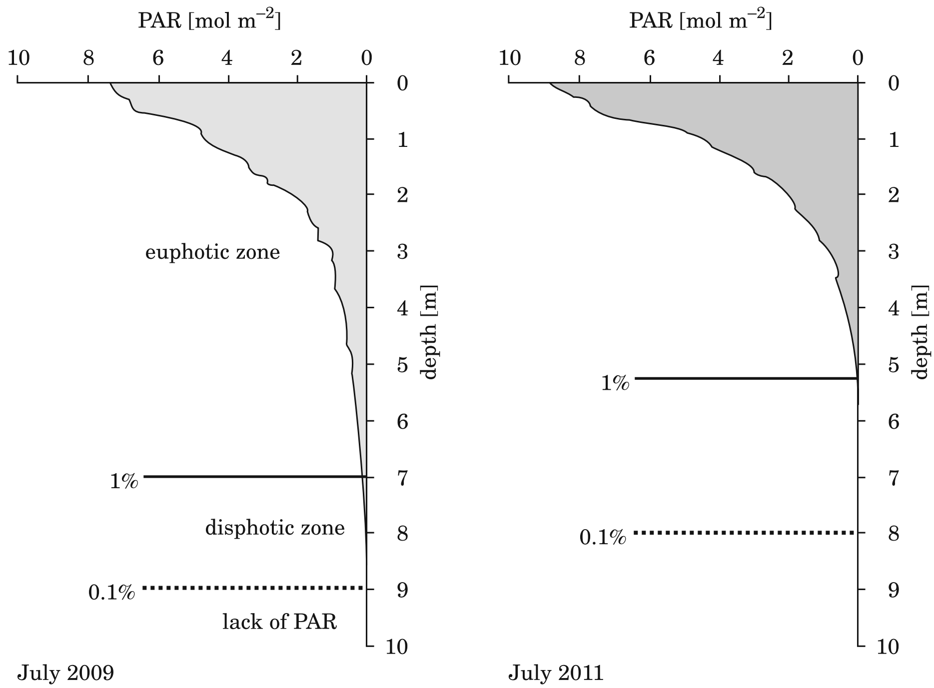

Fig. 2. Vertical distribution of PAR in lake during study periods (solid line – border of euphotic zone, dashed line – border of disphotic zone)

In July 2011 the abundance of algae in the surface layer was so high that it had a form of water bloom. Because it was the bloom of cyanobacteria the bathing site was closed, and bathing in the lake was forbidden. We are not aware of any records of algal blooms in lake before 2011. The bloom was constituted by picocyanobacteria (P-cy) from genera *Aphanocapsa* and *Aphanothece*. In 2009, their density in the surface layer reached 420 thous. cells ml^{-1}, and in 2011 it was higher by more than 200 thous. cells ml^{-1}. Earlier studies revealed that the smallest size fraction of organisms, i.e. autotrophic picoplankton (APP) (< 2 μm) is the main component of the lake phytoplankton

(SZELĄG-WASIELEWSKA 2006). Throughout the vegetation season in APP picocyanobacteria dominate over eukaryotic picoplankton, in particular in terms of biomass (SZELĄG-WASIELEWSKA 2004). High P-cy frequency in the surface layer is related to light intensity as well as light spectrum, considered a major axis of niche differentiation in P-cy communities (STOMP et al. 2004). The consequence of high cell concentration was strong scattering of sunlight and water opalescence (result of excretion of organic substances) which caused high light utilization and low water transparency. Similar states, but with clearly higher reduction of photic zone were noted in lakes of higher trophy, where the strong light scattering and absorption in shallow subsurface layer (a type of microstratification) was related to a strong bloom of larger species of blue-green algae (SOBCZYŃSKI et al. 2012). The value of the turbidity reading is influenced by both APP, belonging to phytoplankton with size >0.1 μm, and dissolved organic and mineral substances (size <0.45 μm) (BILOTTA and BRAZIER 2008).

To sum up it should be said that the water turbidity caused by strong bloom of picocyanobacteria in the examined lake had a very bad effect on its recreational function. Probably the main component of turbidity and barrier limiting the light transmission into the water were bacterial colloid suspensions or gels released in abundance by plankton, frequently forming layers of varied thickness. The excess of organic compounds results in the opalescence of surface water similar to that observed in the deoxygenated near-bottom waters rich in H_2S.

Translated by MAŁGORZATA KORNIJÓW

Accepted for print 21.11.2012

References

APHA 1998. *Standard methods for the examination of water and wastewater*. 20th ed. Am. Public Health Assoc., Washington.

BILOTTA G.S., BRAZIER R.E. 2008. *Understanding the influence of suspended solids on water quality and aquatic biota*. Wat. Res., 42: 2849–2861.

BLOESCH J. 1995. *Mechanisms, measurements and importance of sediment resuspension in lakes*. Mar. Freshwat. Res., 46: 295–304.

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

DAVIES-COLLEY R.J., SMITH D.G. 2001. *Turbidity, suspended sediment, and water clarity: A Review*. J. Amer. Wat. Res. Assoc., 37: 1085–1101.

FORSBERG C. 1992. *Will an increased greenhouse impact in Fennoscandia give rise to more humic and coloured lakes?* Hydrobiologia, 229: 51–58.

GALLEGOS C.L., JORDAN T.E. 2002. *Impact of the spring 2000 phytoplankton bloom in Chesapeake Bay on optical properties and light penetration in the Rhode River, Maryland*. Estuaries, 25(4a): 508–518.

HERMANOWICZ W., DOJLIDO J., DOŻAŃSKA W., KOZIOROWSKI B., ZERBE J. 1999. *Physical-chemical analyses of water and wa*stewater. Wyd. Arkady, Warszawa.

HOWICK G.L., WILHM J. 1985. *Turbidity in Lake Carl Blackwell: Effects of water depth and wind*. Proceed. Oklahoma Acad. Sci., 65: 51–57.
JONIAK T. 2007. *The seasonal variability of dominants in phytoplankton of humic forest lakes*. Oceanol. Hydrobiol. Stud., 36(2): 49–59.
KIRK J.T.O. 1994. *Estimation of the absorption and the scattering coefficients of natural waters by use of underwater irradiance measurements*. Appl. Optic., 33: 3276–3278.
KUCZYŃSKA-KIPPEN N., JONIAK T. 2010. *Chlorophyll a and physical-chemical features of small water bodies as indicators of land use in the Wielkopolska region (Western Poland)*. Limnetica, 29: 163–169.
MACISAAC E.A., STOCKNER J.G. 1993. *Enumeration of phototrophic picoplankton by autofluorescence microscopy*. [In:] Eds. P.F. Kemp, B.F. Sherr, E.B. Sherr, J.J. Cole, *The handbook of methods in aquatic microbial ecology*. CRC Press, Boca Raton, 187–197.
MATUSZKO D. 2009. *Wpływ zachmurzenia na usłonecznienie i całkowite promieniowanie słoneczne na przykładzie krakowskiej serii pomiarów*. Wyd. UJ, Kraków.
PAAVEL B., ARST H., REINART A. 2008. *Variability of bio-optical parameters in two North-European large lakes*. Hydrobiologia, 599: 201–211.
SNOEYINK V.L., JENKINS D. 1980. *Water chemistry*. John Wiley & Sons. New York.
SOBCZYŃSKI T., JONIAK T., PRONIN E. 2012. *Assessment of the multi-directional experiment of restoration of Lake Góreckie (western Poland) with particular focus to oxygen and light conditions: first results*. Pol. J. Environ. Stud., 21(4): 1025–1031.
STOMP M., HUISMAN J., DE JONGH F. 2004. *Adaptive divergence in pigment composition promotes phytoplankton biodiversity*. Nature, 432: 104–107.
SZELĄG-WASIELEWSKA E. 1995. *The phytoplankton and the abiotic elements in the pelagial of the Strzeszyńskie Lake*. [In:] *Surface waters of Poznań. Water problems of urban areas*. Eds. A. Kaniecki, J. Rotnicka, Sorus, Poznań, 361–373.
SZELĄG-WASIELEWSKA E. 2004. *Dynamics of autotrophic picoplankton communities in the epilimnion of a eutrophic lake (Strzeszyńskie Lake, Poland)*. Ann. Limnol. Internat. J. Limnol., 40: 113–120.
SZELĄG-WASIELEWSKA E. 2006. *Trophic status of lake water evaluated using phytoplankton community structure – change after two decades*. Pol. J. Environ. Stud., 15(1): 139–144.
YE L., CAI Q. 2012. *Spring phytoplankton blooms in Xiangxi Bay of Three-Gorges Reservoir: spatiotemporal dynamics across sharp nutrient gradients*. J. Freshwater Ecol., 26(1): 11–18.