Limnologica 41 (2011) 160–166

Limnologica

journal homepage: www.elsevier.de/limno

Variability of phytoplankton biomass in a lowland river: Response to climate conditions

Blanka Desortová[a,*], Pavel Punčochář[b]

[a] T.G. Masaryk Water Research Institute, Public Research Institution, Prague, Czech Republic
[b] Section of Water Management, Ministry of Agriculture, Prague, Czech Republic

ARTICLE INFO

Article history:
Received 9 April 2009
Received in revised form 8 July 2010
Accepted 27 August 2010

Keywords:
River
Phytoplankton
Chlorophyll-a
Flow rate
Seasonal dynamic
Year to year variation
Climate change

ABSTRACT

The results are presented of an intensive study of phytoplankton assemblage carried out in the Berounka River above its confluence with the Vltava River (Czech Republic) in the period 2002–2007. The annual and interannual changes of phytoplankton development (based on high frequency of sampling) and their relation to hydrological conditions and concentrations of main nutrients are analysed. A marked decline of nutrient concentrations was observed during the period 1996–2007. The annual mean values of total P decreased from 0.43 mg L^{-1} to 0.16 mg L^{-1}, those of N-NO_3 from 4.6 mg L^{-1} to 1.5 mg L^{-1} and N-NH_4 from 1.9 mg L^{-1} to 0.04 mg L^{-1}. Despite this, the phytoplankton biomass remained at a high level. The seasonal mean values of chlorophyll-a ranged from 51.0 μg L^{-1} to 116.8 μg L^{-1} in the same time period. An obviously stronger relationship was found of the phytoplankton biomass and pattern of its development to the variation of flow rates than to the existing level of nutrient concentrations. A significantly decreasing relationship ($R^2 = 0.384$, $P < 0.001$) of chlorophyll-a to flow rates and a significantly increasing relationship ($R^2 = 0.359$, $P < 0.001$) of chlorophyll-a to water temperatures were found, based on monthly mean values for the seasonal period 2002–2007. The results obtained indicate a remarkable increase of phytoplankton biomass and its prolongated occurrence in watercourses, which can be expected due to the consequences of the predicted climate change (i.e. higher occurrence of summer droughts and low precipitation amounts accompanied by a substantial drop of flow rates, increase of air and water temperatures), as described in the respective scenarios for the territory of the Czech Republic. Simulations by the regional climate models HIRHAM and RCAO and emission scenario SRES indicated the increase of air temperature by 2.5–5 °C, decrease of precipitation amount by 6–25% and decline of flows by 14–43% in the Berounka River for the scenario period 2071–2100.

Introduction

Phytoplankton represents one of the important elements for the assessment of the ecological status of surface water bodies according to the Water Framework Directive (WFD 2000/60/EC). It is the result of the high level of eutrophication in most of the European watercourses due to their loading of nutrients, namely various forms of phosphorus compounds (EEA 2003). The presence of high phytoplankton biomass in surface waters, including streams, is commonly related to an excess of nutrients. With regard to this fact, results of phytoplankton biomass monitoring are primarily used to estimate the level of trophy and development of eutrophication (e.g. Kelly and Whitton 1998; Dodds et al. 1998). However, the controlling role of discharge fluctuations and water temperature in the development of river phytoplankton is reported and nutrients are considered to be less important (e.g. Fruget et al. 2001). Based on the study of the Thames and the Humber Rivers (England), Hilton et al. (2006) and Neal et al. (2006) suggested that residence time and flow conditions determine the growth of algae in river systems.

A number of studies concerned with assessing climate changes impacts on the hydrological regime and quantity of surface waters (e.g. Ludwig et al. 2009). Less information is obtained on the effect of changing climatic conditions on water quality and especially on microscopic organisms in running waters.

Zwolsman and van Bokhoven (2007) summarised long term data on water quality in the River Rhine. They compared changes of water quality variables, including chlorophyll-a concentration, during the long periods of drought in 1976, 1991 and 2003. It was obvious that the chlorophyll-a concentration was much higher during the drought than under average flow conditions in the Rhine. A similar situation was observed when data on chlorophyll-a was analysed for the Meuse River in the drought periods of 1976 and 2003 (Vliet van and Zwolsman 2008). Based on water quality

* Corresponding author. Tel.: +420 220 197 411; fax: +420 233 333 804.
E-mail address: blanka_desortova@vuv.cz (B. Desortová).

0075-9511/$ – see front matter © 2010 Elsevier GmbH. All rights reserved.
doi:10.1016/j.limno.2010.08.002

modelling, Fischer et al. (2008) studied how changes of climatic conditions influence nutrient concentrations and phytoplankton growth in the Elbe River from the inflow of the Vltava River to Geesthacht (length of the river stretch = 700 km). They found that, at the present time, phytoplankton development is above all light-limited and depends on the water flow time.

The aim of this study was to detect phytoplankton biomass changes and possible factors which can influence the status of this natural biological component of the aquatic ecosystem in the lowland river Berounka. For this purpose an intensive monitoring of phytoplankton characteristics and several hydrochemical variables was carried out in the years 2002–2007. The hypotheses appointed to test were: (1) the temporal pattern of phytoplankton development is influenced by the meteorological and hydrological variables; (2) phytoplankton biomass is significantly related to flow rate; (3) clear dependency of phytoplankton biomass on nutrient concentrations is not obvious in the river Berounka.

Materials and methods

Site description

The River Berounka (total length of the watercourse 139.1 km) is one of the main tributaries of the River Vltava, upstream of the capital city of the Czech Republic. The River Berounka drains an area of 8861.4 km^2 constituting about 31% of the whole Vltava catchment area. The sampling site was situated about 1.5 km above the confluence of the River Berounka with the River Vltava. As there are no important water reservoirs along the River Berounka and cross structures on the river comprise only several weirs, the manipulation with flow rate is not a significant factor and has no disturbance effect on phytoplankton development. The long-term average annual flow rate near the mouth is 36.0 $m^3\,s^{-1}$. The mean depth of the river at the sampling site is about 0.6 m and the river bed is about 55 m wide.

The River Berounka is an example of a eutrophic, phytoplankton-rich river where phytoplankton biomass reaches up to 280 $\mu g\,L^{-1}$ of chlorophyll-a in the middle and downstream stretches of the river during the seasonal period. According to the Behrendt and Opitz (2001) proposal of river classification, the River Berounka can be classified as a “phytoplankton dominated river”. Phytoplankton biomass transported from the River Berounka down the Vltava River markedly contributes to high chlorophyll-a concentrations in the River Elbe below the confluence with the Vltava (Desortová 2007).

Sampling

Water samples were collected at 2- to 3-day intervals during the growing season (March–October), and weekly out of this period. The number of samples taken varied between 63 and 172 per year for the period of 2002–2007.

Characteristics studied

The variables under study included the amount of phytoplankton (as chlorophyll-a concentration to express the total phytoplankton biomass) and species structure, nutrient concentrations (total P, N-NO_3, N-NO_2, N-NH_4), water temperature and flow rates (daily means), occurrence of precipitation and the sum of sunshine.

Chlorophyll-a concentration was estimated by the spectrophotometric method with acidification procedure (Lorenzen 1967). Phytoplankton taxonomic composition was examined by light microscopy.

Nitrogen compounds (N-NO_3, N-NO_2, N-NH_4) were determined by flow analysis (CFA-continual flow analysis) with the spectrometric detection. Total phosphorus was analysed by optical emission spectroscopy with inductively coupled plasma (ICP-OES method).

Water temperature was recorded at the time of sampling. Data on daily flow rates were obtained, as well as other meteorological characteristics (i.e. total sunshine and precipitation amount), from the web presentation of the Czech Hydrometeorological Institute (www.chmi.cz).

Meteorological and hydrological situation

Concerning the study period (2002–2007), the individual years were significantly different as regards climatic conditions and hydrological situation, as follows from the yearly assessment of the climatic situation for the Czech Republic (CHMI 2002–2007). Based on the average annual air temperatures, the whole monitoring period can be described as a period with above-average temperatures (www.chmi.cz). The years 2002, 2003 and 2007 were, in terms of temperature, significantly above-average (deviation from long-term normal 1961–1990 = 1.3 °C, 0.9 °C and 1.6 °C respectively), the years 2005 (deviation 0.3 °C) and 2006 (deviation 0.7 °C) slightly above-average. The only year with average (normal) temperatures was the year 2004. As regards precipitation amounts and discharge situations, the year 2002 was considerably above-average with consequent occurrence of extreme floods over the whole territory of Bohemia. Even the year 2006 was, in terms of precipitation amounts, above-average with flood episodes especially in the first six months of the year. These were caused by the high snow pack melting in the mountains and later (May) by the high rainfall amount. On the other hand, the year 2003 was extremely dry due to deficit precipitation amounts, in particular during the growing season. A similar situation occurred in the spring of 2007 following a mild winter with lack of snow and a deficit precipitation amount in March and especially in April. The differences between the individual years are illustrated in Table 1 showing for comparison the seasonal means of water and air temperature determined on the basis of measurements taken during sampling. This table is completed by seasonal means and minima of flow rates and seasonal sum of sunshine.

The results of regional studies (Kašpárek et al. 2006) were used to demonstrate possible impacts of global climate changes on climatic events and the water regime in the Czech Republic. The regional climate models HIRHAM and RCAO and the emission scenarios of greenhouse gasses concentrations SRES A2 (pesimistic) and B2 (optimistic) were applied to assess a climate development in the Czech Republic for the period 2071–2100. The reference period was 1961–1990. Outcomes from the model simulations indicate that the mean annual air temperature can increase in the range of 2.5–5 °C, the annual precipitation amount can decrease by 6–25% and minimum mean monthly flows can drop locally to 15% of their unaffected values.

Table 1
Seasonal (March–October) means of temperature, seasonal means and minima of flow rate at the Berounka sampling site and seasonal sunshine sum for the Bohemia territory.

Year	Temperature, °C		Flow rate ($m^3\,s^{-1}$)		Sunshine duration (hours)
	Water Mean	Air	Mean	Minimum	Total amount
2002	15.8	13.2	63.6	15.9	1498
2003	16.1	13.5	23.7	8.3	1865
2004	15.5	12.5	24.6	8.8	1575
2005	15.2	12.7	29.0	9.9	1657
2006	15.5	13.1	43.5	11.3	1638
2007	16.6	13.6	21.7	8.1	1610

Statistical analysis

Descriptive statistical analysis of the data was performed using the PAST software package (Hammer et al. 2001). To model dependence of monthly mean values of chlorophyll-a concentrations on water temperatures, flow rates (uni- and multivariately) and time, linear regression models with autocorrelated errors were estimated using the method of generalised least squares. For all models except the model evaluating the marginal dependence of chlorophyll-a concentration on flow rate, the chlorophyll-a concentration was logarithmically transformed to achieve linearity. Normality of errors was evaluated using the Shapiro and Wilk test (Shapiro and Wilk 1965). R software (R Development Core Team 2010) was used for practical computation.

Results and discussion

The intensive study of the Berounka River phytoplankton connects to the previous long-term monitoring (3-weekly sampling interval) of several physico-chemical variables. These background data are briefly presented in Fig. 1A–D.

Fig. 1A–C demonstrates changes in annual mean values of ammonium and nitrate nitrogen and total phosphorus in the study site for the 1996–2007 period. From the pattern of individual curves it is apparent that a significant decrease has occurred in the level of nutrients during the last 12 years. The decline of N-NO_3, N-NH_4 and total P concentrations is expressed by a statistically significant linear regression ($P < 0.05$, resp. $P < 0.02$). The decrease in nutrient concentration, however, is not reflected by a decrease in phytoplankton biomass. This is documented in Fig. 1D where mean and maximum values of chlorophyll-a are presented for the growing season (March–October) from 1996 to 2007. A tendency to an increase in seasonal maxima of chlorophyll-a under the situation of nutrient concentrations decrease is demonstrated by a regression line (Fig. 1D). Analysing data for the 1996–2007 period no direct correlation was found between chlorophyll-a and nutrient concentrations. Thus the more detailed study was carried out to recognise the main driving factors of phytoplankton dynamic in the Berounka River.

Fig. 2 shows changes in phytoplankton biomass, expressed as monthly mean values of chlorophyll-a concentration and flow rates, during the 2002–2007 period. Phytoplankton biomass changes exhibit a typical annual periodicity, i.e. rapid increase of values and often biomass maximum in spring, high level of biomass in the summer followed by gradual decrease from the begining of autumn and a very low phytoplankton biomass in the winter. This pattern of seasonal phytoplankton development is generaly observed in European temperate rivers – e.g. in the middle stretch of the Elbe in Germany (Böhme and Guhr 2006) as well as in several rivers in England (Balbi 2000; Neal et al. 2006). Concerning phytoplankton species composition, a regular seasonal succession of algae groups was observed. The spring period represented by the occurrence of centric diatoms (i.e. namely *Stephanodiscus hantzschii*, *Cyclostephanos invisitatus*, *C. dubius*, *Cyclotella meneghiniana*, *Skeletonema potamos*) was replaced during summer by a large number of taxa from the group of coccal green algae. Species of the genus *Coelastrum*, *Crucigenia*, *Crucigeniella*, *Monoraphidium*, *Oocystis*, *Pediastrum*, *Scenedesmus* and *Tetrastrum* usually prevailed.

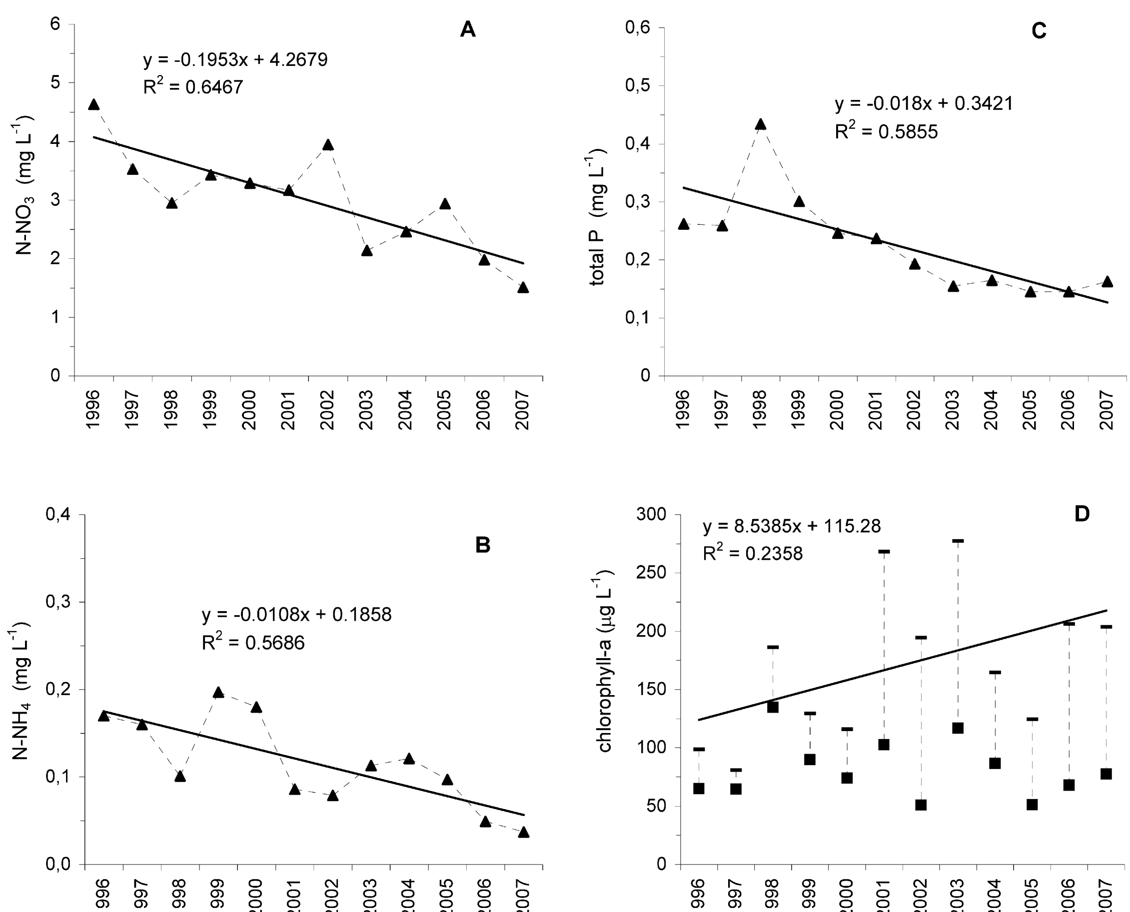

Fig. 1. (A–C) Annual mean values of ammonium and nitrate nitrogen and total phosphorus for the 1996–2007 period at the Berounka River sampling site. Linear regressions express decrease in concentrations of presented variables. (D) Seasonal means (black square) and maxima of chlorophyll-a. Linear regression expresses gradual increase in seasonal maxima of chlorophyll-a.

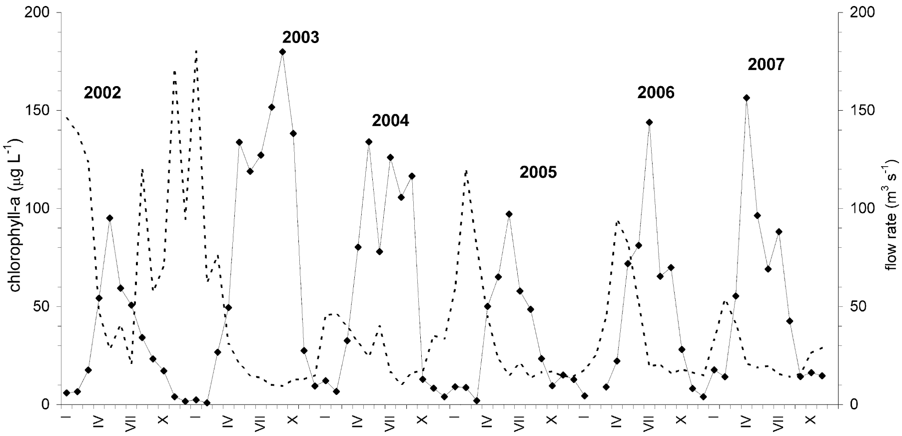

Fig. 2. Monthly means of chlorophyll-a concentration (full line) and flow rate (dashed line) at the Berounka River sampling site in the years 2002–2007.

The mixed assemblage of diatoms and chlorococcal algae characterised phytoplankton of the late summer and autumn. Blue-green algae occurred sporadically and never prevailed in the phytoplankton samples during the years under study. All of the other groups of algae were present in a low number of taxa. Prevalency of diatoms and coccal green algae in phytoplankton composition is common for the large temperate rivers in Europe (e.g. Garnier et al. 1995; Reynolds and Descy 1996). The phytoplankton biomass regularly formed 1 or 2 sharp peaks during the year at the River Berounka study site as shown in Fig. 2, where monthly means of chlorophyll-a concentration are presented. However, when the whole data set is used, the higher fluctuations of phytoplankton biomass are more obvious. A detailed presentation of the data was restricted to the three consecutive years 2003–2005 as they represent different combinations of weather and flow conditions. Fig. 3 demonstrates the changes of chlorophyll-a concentrations and flow rates recorded on sampling days during the years 2003–2005. The spring onset of phytoplankton biomass is obvious after the decrease of high winter flows in all those three years. In 2003 the extremely dry and hot weather during summer caused a relatively long period of high water temperatures and very low flow rates, which resulted in the fast growth of phytoplankton and the prolongation of its high biomass occurrence. The chlorophyll-a concentrations above 150 $\mu g\,L^{-1}$ were present from May to October and the seasonal chlorophyll-a maximum (277.3 $\mu g\,L^{-1}$) was recorded as late as at the begining of October. The unusually dry weather and the absence of precipitation over the Bohemian territory led to low flow rates and to a substantial increase of retention time of water in the watercourse. Changes in retention time along the Berounka River during the summer 2003 were derived from measurements of transport time by a colour tracer. The Berounka River Board Authority provided these measurements in upstream stretches of the river during 1971–1974 (unpublished data). The estimated retention time increased from about 7–8 days up to 17–20 days, due to a steady decrease of flow rate from 31 $m^3\,s^{-1}$ to 9.5 $m^3\,s^{-1}$ during April–September 2003 respectively. These values represent 58–49% of long-term (1951–1980) mean monthly flows. The period of stable low flow rates as well as high water temperatures (reaching up to 27 °C) during summer 2003 led to the development of an excessive phytoplankton biomass in the River Berounka. A similar situation was observed during the extremely dry growing season in 2003, for example, in the middle Elbe (Germany) where the concentration of chlorophyll-a reached about 150 $\mu g\,L^{-1}$, data by Baborowski et al. (2004) gained from weekly monitoring. When analysing the years 1976, 1991 and 2003, evaluation of the data for the River Rhine at Lobith (the Netherlands) also showed much higher chlorophyll-a concentrations during the summer drought period (Zwolsman and van Bokhoven, 2007).

In 2004, meteorological and hydrological conditions were close to the long-term averages with the exception of the relatively low level of sunshine (see Table 1). During the period July–September of that year chlorophyll-a values fluctuated independently of flow rate changes (see Fig. 3). In 2004, the seasonal maxima of chlorophyll-a reached 164.6 $\mu g\,L^{-1}$ and the seasonal mean value 86.5 $\mu g\,L^{-1}$.

In the year 2005, the lowest level of chlorophyll-a concentration was detected (seasonal mean value of chlorophyll-a was only 51.2 $\mu g\,L^{-1}$ and maxima 124.3 $\mu g\,L^{-1}$) and the annual development of phytoplankton biomass was substantially influenced by flow rate fluctuations in the River Berounka (Fig. 3).

Considerable differences of chlorophyll-a concentrations become evident when comparing the data for individual years of the investigated period (2002–2007) in spite of the similar level of main nutrients. Seasonal mean values of chlorophyll-a in the range of 51.0–116.8 $\mu g\,L^{-1}$ do not correspond with the concentrations of main nutrients. In contrast, a significantly increasing relationship ($P < 0.001$) of chlorophyll-a concentrations to water temperatures and a significantly decreasing relationship ($P < 0.001$) of chlorophyll-a concentrations to flow rates were detected using the regression models with autocorrelated errors based on monthly mean values for the seasonal period of 2002–2007 (see Fig. 4A and B). Moreover, also in a multivariate regression model, both the water temperature and the flow rate significantly influences the chlorophyll-a concentration ($P < 0.001$, 0.027, respectively) leading to the prediction expression

$$\text{chlorophyll-a} = 17.889\,e^{0.082\,\text{temperature} - 0.0055\,\text{flow rate}}$$

Neither in the univariate regression models ($P = 0.88$, 0.58, respectively), nor in the multivariate regression model ($P = 0.55$) has non-normality of errors been detected.

This suggests that climatic and hydrological conditions are stronger factors influencing seasonal pattern and phytoplankton biomass values rather than the level of main nutrients in the River Berounka.

A rapid increase of phytoplankton amount following the decrease of winter flow as well as the influence of flow instability on chlorophyll-a fluctuation confirm the obvious dependency of phytoplankton biomass on flow pattern and magnitude. Similarly, high flow rates also have an important impact on phytoplankton biomass and can cause a shift in the seasonal pattern of its development. Data obtained for 2006 and 2007 (Fig. 5A and B) can be used as an example. Atypical development of the climatic situation in the winter and in the spring of the year 2007, i.e. above-average

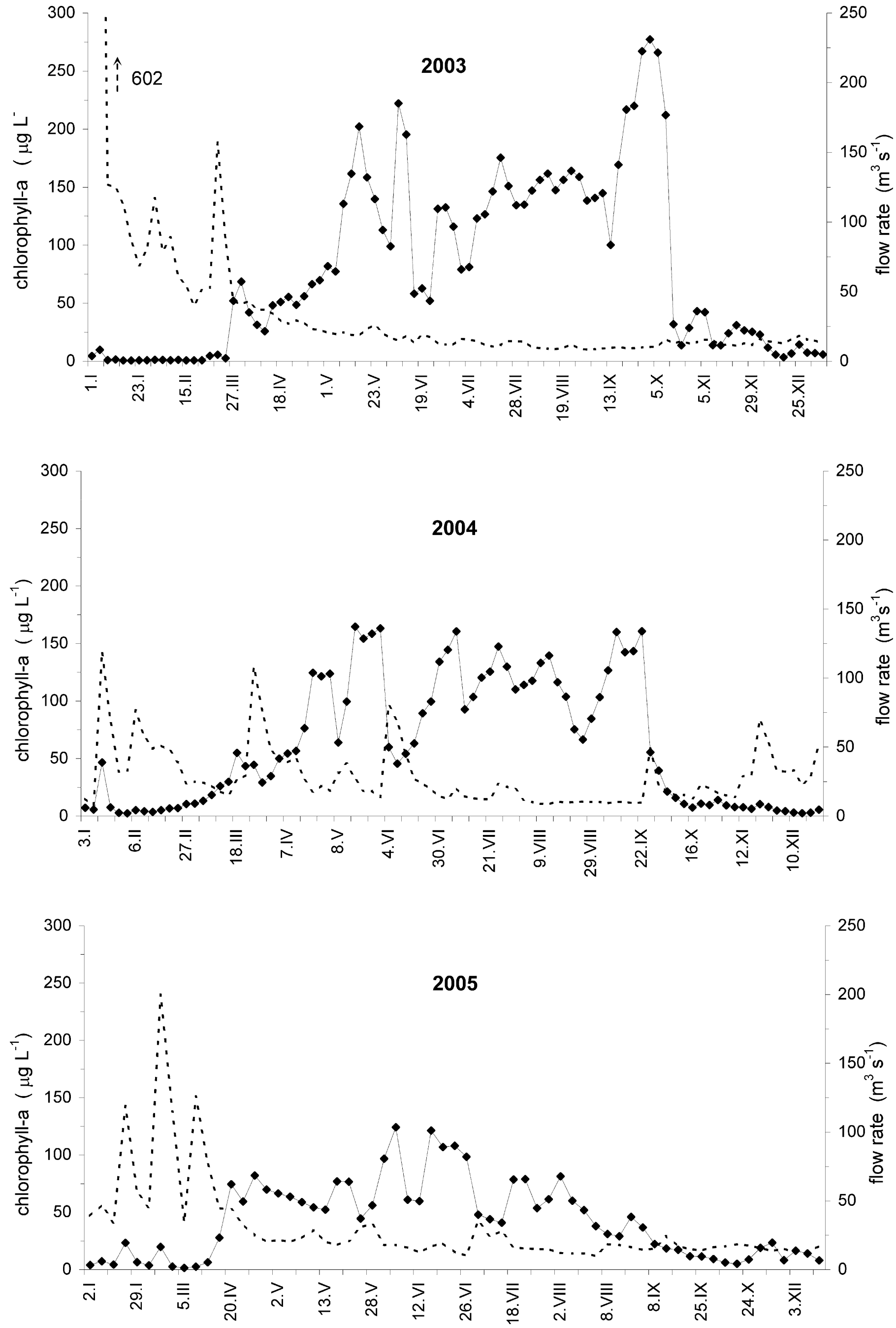

Fig. 3. Annual pattern of chlorophyll-a concentration (full line) and flow rate (dashed line) at the Berounka River sampling site in the years 2003–2005.

air temperatures, precipitation deficit and consequent drought as well as a decline of flow rates in February–March caused favourable conditions for phytoplankton development in the river. This situation resulted in the occurrence of chlorophyll-a values exceeding the level of 200 μg L^{-1} as early as at the beginning of April (Fig. 5B). Consequently, the shift in the species succession of phytoplankton assemblage was observed too, i.e. the unusual early onset of coccal green algae in May, after the spring peak of phytoplankton biomass with the prevalency of centric diatoms dropped. Unlike the situation in 2007, high snow pack and large precitipation quantity in 2006 resulted in the spring flood episodes with the highest flow rate values in the River Berounka recorded in April and May. A different pattern of flow rates in 2006 and 2007 is obvious from Fig. 5C where the monthly mean values are presented. Due to the hydrological situation in the spring of 2006 the annual maximum of chlorophyll-a concentrations shifted into the summer period (July/August) (Fig. 5A). Fig. 6 shows phytoplankton biomass development during January–May/June of the years 2006 and 2007. Ten days' mean values of chlorophyll-a are presented for the comparison of both these years. Exponential curves express a significantly different development (P = 0.011) of chlorophyll-a concentrations during the period of January–May/June under the distinct climatic and hydrological conditions described above. Based on this comparison, the influence of flow rate changes on phytoplankton biomass development in the Berounka River is evident.

The obtained results can be used to consider the impacts of the possible climate development as regards the presence of phytoplankton in watercourses. The prediction of the climate change impact is very relevant with regard to the anticipated adverse effects on water resources, water quality (Kundzewicz et al. 2007)

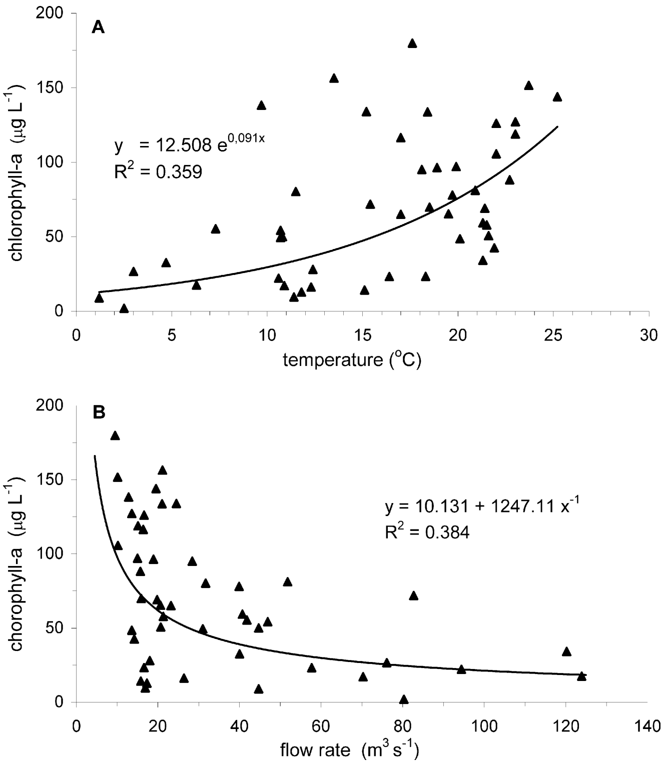

Fig. 4. Relation of chlorophyll-a concentrations to water temperatures (A) and relation of chlorophyll-a concentrations to flow rates (B) based on monthly mean values for the growing season (March–October) of 2002–2007.

as well as on the status of biological components of aquatic ecosystems (e.g. Wade 2006; Fruget et al. 2001).

Scenarios of climate change and of its impact on the hydrological regime in the Czech Republic identically assess an increase of the mean annual air temperature by 2.5–5 °C and a change in the annual development of precipitation (Kašpárek et al. 2006). The annual precipitation amount will drop approximately to the level of 75–94% and its time distribution followed by more frequent occurrence of extremes will significantly change. The dry period in summer months will be longer which will result in significantly lower flow rates in watercourses. The study with a regional focus on water resources in the Vltava River basin implies (Novický et al. 2008) that in the lower course of the River Berounka the annual mean flow rate may be expected to drop by 14–43%. The flow rate drop in summer months would be especially critical because the annual discharge minima are observed in the lower stretch of the River Berounka primarily in August and September.

Based on the results presented, it may be expected that with the assessed development of climate change the climatic and hydrological situation will lead to an earlier phytoplankton development in the spring period and consequently to high phytoplankton biomasses during the whole seasonal period which will extend well into the autumn period. A prefiguration of this situation may be seen in the state during the year 2003 (Fig. 3) which may be considered to be typical for the period when the average scenario of the climate development for the Czech Republic becomes a reality, i.e. in the time horizon of 50–70 years.

High phytoplankton biomass causes a high autochtonous load of organic substances on aquatic ecosystems accompanied by a number of associated adverse consequences (changes of oxygen regime, pH etc.). Apparently, it is not possible to expect such a decisive reduction of available phosphorus concentration to the level which would be limiting for the growth of algae. An increased level of phytoplankton biomass compared to the current situation thus

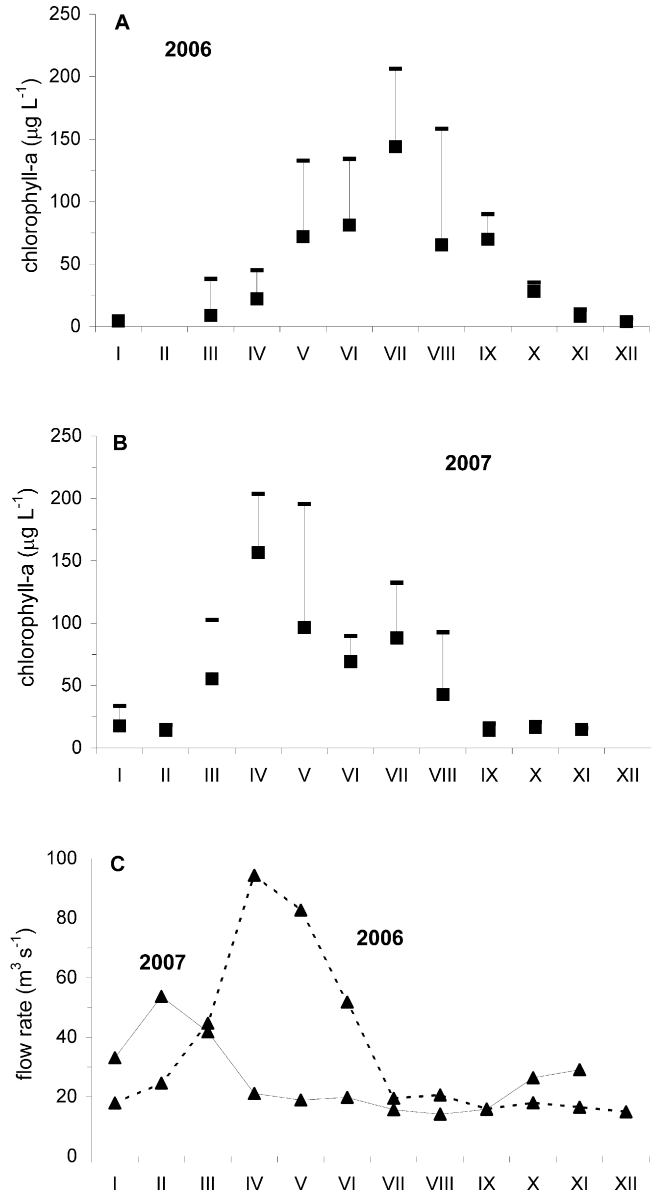

Fig. 5. Monthly means and maxima of chlorophyll-a concentration (A, B) and flow rate (C) at the Berounka River sampling site in the years 2006 and 2007 [A: Interrupted curve in February 2006 = period without sampling due to deep ice cover].

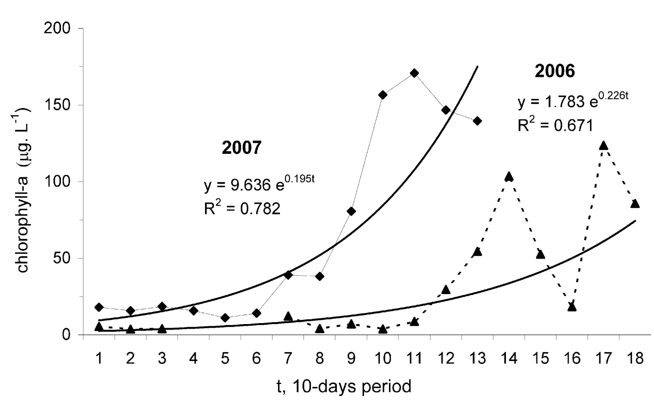

Fig. 6. Changes of chlorophyll-a concentration (10-days' mean values are pictured) during January–May/June period of the years 2006 and 2007. Exponential curves illustrate a different pattern of chlorophyll-a increase due to distinct hydrological conditions described in text.

will be one of the potential adverse impacts of climate change on the ecosystem of running waters.

Conclusions

Results of the six-year (2002–2007) intensive study of phytoplankton changes in the lower stretch of the River Berounka can be summarised as follows:

Seasonal changes of phytoplankton development exhibited a regular pattern, i.e. rapid spring onset after drop down of high winter flow rates, high biomass in the summer and low level of biomass in the winter period (Fig. 2). Phytoplankton taxonomic composition was characterised by a regular occurrence of centric diatoms in spring followed by chlorococcal green algae in the summer and by mixed assemblage of both of algae groups in autumn.

Year to year variations of phytoplankton biomass values were evident, as a consequence of different hydrological conditions in the individual years. This means that the annual pattern and the flow rates magnitude and water temperature strongly influenced the development of phytoplankton biomass and more than the current level of main nutrients in the years under study. Comparable nutrient concentrations resulted in a wide range of phytoplankton biomass values in the study site.

The pattern of phytoplankton biomass development during the dry year 2003 and the dry spring period of 2007 (Figs. 2 and 5B respectively) can be a reflection of the possible impact of the expected climate change on the ecosystem of running waters. This impact would include an earlier phytoplankton onset in the spring, high biomass levels during the whole season and a prolongation of the growth period until late autumn.

A sensitivity of phytoplankton biomass development to the variability of flow rates is evident from the study performed on the Berounka River. In reflection of this, flow conditions have to be included in a phytoplankton based classsification system for the assessment of the ecological status of rivers according to the Water Framework Directive.

Acknowledgements

The study was supported by the research project MZP 0002071101 of the Ministry of Environment, Czech Republic. We are grateful to Assistant Professor A. Komárek (Faculty of Mathematics and Physics, Charles University in Prague) for statistical advice and computation by R software. We also thank two anonymous reviewers for their comments on an earlier version of the manuscript.

References

Baborowski, M., Guhr, H., Bittner, O., von Tümpling Jr., W., Friese, K., 2004. The influence of extreme low water flow on the water quality of the Elbe River at Magdeburg monitoring station. In: Geller, W., et al. (Eds.), Proceedings of the 11th Magdeburg Seminar on Waters in Central and Eastern Europe: Assessment, Protection, Management. UFZ, Leipzig-Halle, pp. 23–24.

Balbi, D.M., 2000. Suspended chlorophyll in the River Nene, a small nutrient-rich river in Eastern England: long-term and spatial trends. Sci. Total Environ. 251/252, 401–421.

Behrendt, H., Opitz, D., 2001. Preliminary approaches for the classification of rivers according to the indicator phytoplankton. Monitoring and assessment of ecological quality of aquatic environments. Thema Nord 563, 32–36.

Böhme, M., Guhr, H., 2006. Phytoplanktondynamik. In: Pusch, M., Fisher, H. (Eds.), Stoffdynamik und Habitatstruktur in der Elbe. Weiβensee Verlag, Berlin, Ökologie, pp. 33–55.

CHMI, 2002–2007. Hydrological Yearbook of the Czech Republic for the Years 2002–2007. Czech Hydrometeorological Institute, Prague.

Desortová, B., 2007. Phytoplankton distributions along the River Vltava (the Czech Republic): a case of watercourse with cascade of dam reservoirs. In: Naselli-Flores, L. (Ed.), Abstr. 5th Symp. Europ. Freshw. Sci., SEFS 5. University of Palermo, Palermo, Italy, p. 192.

Dodds, W.K., Jones, J.R., Welch, E.B., 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen and phosphorus. Water Res. 32 (5), 1455–1462.

EEA (Europ. Envir. Agency), 2003. Europe's Environment: The Third Assessment. Environmental Assessment Report, vol. 10, Luxembourg.

Fischer, H., Kirchesch, V., Quiel, K., Schöl, A., 2008. Simulating the effects of global change on the water quality of the Elbe River. In: Magdeburger Gewässerschutzseminar, Oktober 7–10, 2008, IKSE, Magdeburg, pp. 84–86.

Fruget, J.-F., Centofanti, M., Dessaix, J., Olivier, J.-M., Druart, J.-C., Martinez, P.-J., 2001. Temporal and spatial dynamics in large rivers: example of a long-term monitoring of the middle Rhône River. Ann. Limnol. 37 (3), 237–251.

Garnier, J., Billen, G., Coste, M., 1995. Seasonal succession of diatoms and Chlorophyceae in the drainage network of the Seine River: observations and modeling. Limnol. Oceanogr. 40 (4), 750–765.

Hammer, R., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistical software package for education and data analysis. Paleontol. electron. 4 (1), 9 pp.

Hilton, J., O'Hare, M., Bowes, M.J., Jones, J.I., 2006. How green is my river? A new paradigm of eutrophication in rivers. Sci. Total Environ. 365, 66–83.

Kašpárek, L., Novický, O., Peláková, M., 2006. Climate change and water regime in the Czech Republic. In: T.G.M. WRI Collection of Papers 1. T.G. Masaryk Water Research Institute, Prague, 79 pp.

Kelly, M.G., Whitton, B.A., 1998. Biological monitoring of eutrophication in rivers. Hydrobiologia 384, 55–67.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Şen, Z., Shiklomanov, I.A., 2007. Freshwater resources and their management. In: Parry, M.L., Canzani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, pp. 173–210.

Lorenzen, C.J., 1967. Determination of chlorophyll and phaeopigments; spectrophotometric equations. Limnol. Oceanogr. 12 (2), 343–346.

Ludwig, F., Kabat, P., van Schaik, H., van der Valk, M., 2009. Climate Change Adaptation in the Water Sector. London, Sterling.

Neal, C., Hilton, J., Wade, A.J., Neal, M., Wickham, H., 2006. Chlorophyll-a in the rivers of Eastern England. Sci. Total Environ. 365, 84–104.

Novický, O., Vyskoč, P., Vizina, A., Kašpárek, L., Picek, J., 2008. Klimatická změna a vodní zdroje v povodí Vltavy (Climate Change and Water Resources in the Vltava River Catchment). T.G. Masaryk Water Research Institute, Prague, 29 pp.

R Development Core Team, 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org.

Reynolds, C.S., Descy, J.-P., 1996. The production, biomass and structure of phytoplankton in large rivers. Arch. Hydrobiol., Suppl. 113, Large Rivers 10, 161–187.

Shapiro, S.S., Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). Biometrika 52, 591–611.

Vliet van, M.T.H., Zwolsman, J.J.G., 2008. Impact of summer droughts on the water quality of the Meuse River. J. Hydrol. 353, 1–17.

Wade, A.J., 2006. Monitoring and modelling the impacts of global change on European freshwater ecosystems. Sci. Total Environ. 365, 3–14.

Water Framework Directive 2000 (WFD), 2000/60/EC. OJ 2000, L 327, 1–72.

Zwolsman, J.J.G., van Bokhoven, A.J., 2007. Impact of summer drought on water quality of the Rhine River – a preview of climate change? Water Sci. Technol. 56, 45–55.