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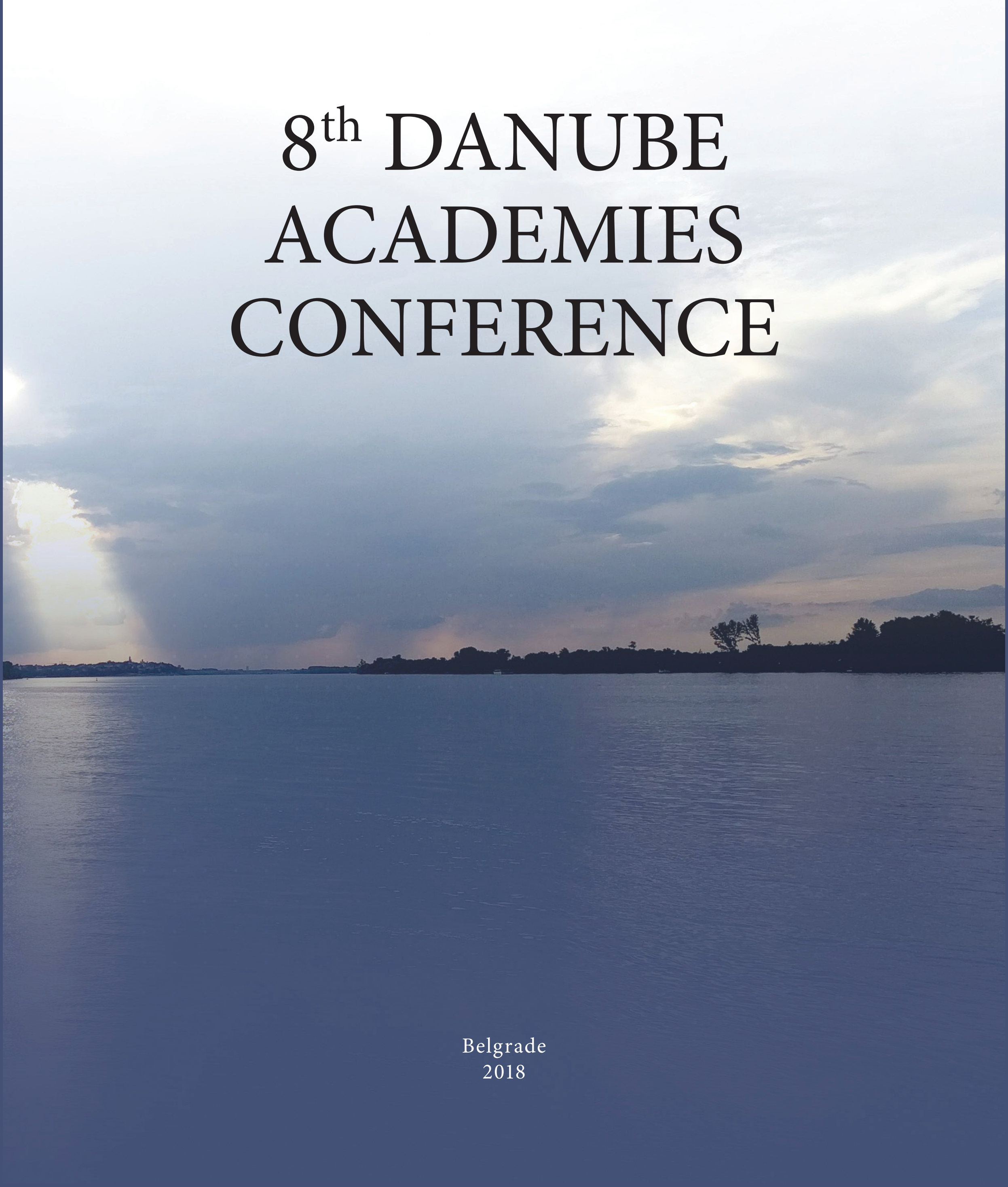
8th DANUBE ACADEMIES CONFERENCE



Belgrade
2018

8th DANUBE ACADEMIES CONFERENCE

8. КОНФЕРЕНЦИЈА АКАДЕМИЈА ПОДУНАВСКЕ РЕГИЈЕ

СРПСКА АКАДЕМИЈА НАУКА И УМЕТНОСТИ

ПРЕДСЕДНИШТВО

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БЕОГРАД 2018

SERBIAN ACADEMY OF SCIENCES AND ARTS

PRESIDENCY

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TOPIC 1:

Endangered Danube: What can we do?

LONG-TERM TROPHIC CHANGES IN BULGARIAN–ROMANIAN DANUBE RIVER SECTION AND IN ADJACENT WETLAND ON BULGARIAN TERRITORY DURING ITS RESTORATION

R. KALCHEV*, M. BESHKOVA*, V. EVTIMOVA*, R. FIKOVA*,
H. KALCHEVA*, V. TZAVKOVA*, V. VASSILEV*

Abstract. – Based mainly on literature data and results of the monitoring program of the Bulgarian Ministry of Environment and Water, the long-term changes of nutrients (nitrogen and phosphorus), suspended solids and chlorophyll-concentrations in the Bulgarian–Romanian section of the Lower Danube during the period 1950–2014 were studied. The addition of more recent data from years 2008–2014 revealed stable lowering with values of PO_4^{3-} concentrations close to those reported in the earliest 1962–1965 interval. The calculated load of dissolved inorganic nitrogen (DIN) showed a continuous but not significant decrease, while the PO_4-P load dropped at the end of the 1950–2014 period to the values of its beginning. These changes of nitrogen and phosphorus led to a substantial shift of the N P^{-1} ratio towards phosphorus limitation of phytoplankton growth in the 2008–2014 period.

The second part of the paper presented and analyzed the process of restoration of wetlands on the example of Srebarna Lake. The primary goal of this restoration was to sustain the valuable biodiversity supported by this lake, but as a wetland it should provide also most other services, one of which was nutrient removal. The monitoring of lake restoration started in 1990 and lasted with gaps until 2015. The main force driving the changes of other lake characteristics was the lake water level. Thus the lake water level correlated positively with water column transparency and negatively with

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chlorophyll-a, phytoplankton biovolume and the share of blue-greens from it. Since 1994 only one canal connected the lake with the Danube River, which seemed to be the reason for the limited success of the wetland restoration.

Keywords: Lower Danube, wetland restoration, nutrients, long-term changes, relationships

INTRODUCTION

The Danube River with 2826 km is the second longest river in Europe whose catchment collects water from 19 countries, which makes it the most international river of the world [24]. In line with the river's European dimension, its ecological status must be consistent with the norms and objectives of the EU Water Framework Directive (WFD) [3]. According to the EU WFD, the concentrations of main nutrients (nitrogen and phosphorus) were among the important characteristics defining the river's ecological status and therefore they have been an obligatory part of the joint Danube surveys and the regular monitoring program of the Trans-National Monitoring Network, results of which have been published by the International Commission for the Protection of the Danube River (ICPDR) in the TNMN yearbooks since 1996. The Danube basin analysis, prepared in line with the requirements of WFD Art. 5 in 2005 showed that 65% of the Danube River length was categorized at risk due to nutrient pollution [19].

In parallel with the regular river monitoring, the nutrients and other related characteristics of river environment have been investigated also in different small-scale studies of national and regional significance [1, 9, 13, 20, 30].

The application of the MONERIS model [23] showed that 80% of calculated 684 kt nitrogen and 57% of 57 kt phosphorus emissions in the Danube River catchment for the 1998–2000 period came from diffuse sources. According to the WFD, the resulting loads of nutrients and other pollutants impairing the ecological status had to be reduced in order for the river to reach a "good ecological status/potential" in year 2015. Obviously, the achievement of this goal was postponed despite the increasing number of waste water treatment plants and other measures undertaken to reduce the anthropogenic impact coming from the catchment.

The restoration of adjacent wetlands was another approach, which, among other ecosystem services, was also able to retain nutrients. According to the Guidance Document 12 [6] for Implementation of the EU WFD, the complex and dynamic patterns of channels, oxbow lakes and temporary surface waters belong to riverine systems characterized by reference conditions of rivers estimated by hydro-morphological criteria of the WFD. Thus the wetlands are indivisible parts of river ecosystems with an important role in achieving and sustaining a good ecological status. Unfortunately, according to the World Wildlife Fund (WWF) report [5], the floodplain loss in the Danube catchment during the last two centuries was in excess of 80%, which made necessary a reversible process of their restoration, e.g. within the Green Corridor Initiative for the Lower Danube. The studies of natural and newly restored wetlands along the Danube River revealed the degree and frequency of connectivity to the river as the main driving force for their successful restoration and proper functioning [4, 7, 12, 14, 16, 17,].

Srebarna Lake as a Ramsar site and UNESCO biosphere reserve was a very important example for the restoration of Danubian wetlands on the Bulgarian territory. Its restoration process was a subject of an extensive monitoring program, results of which were already published in a monograph [26]. Despite the issuing of these comprehensive scientific work data on nutrients, algal biovolume, lake water level and water column turbidity could be analyzed in a new way, including the newly collected information since 2012.

Similarly, the new available information on nutrients in the Bulgarian–Romanian Danube River section during the 2008–2014 period will substantially contribute to supplementing the long-term changes already described by authors [13], especially regarding the phosphorus reduction and the shift in algal limitation conditions.

MATERIALS AND METHODS

The studied sites included the Bulgarian–Romanian stretch of the Danube River (river km 376–834; Fig. 1) and Srebarna Lake (river km 391–393; Fig. 2), which is the most famous and most profoundly studied Danubian wetland on the Bulgarian territory during its restoration. Most of the data about the Danube River originated from literature sources or the routine monitoring program of the Bulgarian Ministry of Environment and Water (BMEW).

They encompass the period between 1954 and 2005 and were already published to a great extent [10, 11, 21], but in the presented paper we supplemented them with data from 2008 until 2014. In order to make it easier for the reader, we would repeat here the primary data sources in brief. The earliest nutrient concentration data (NH_4^{1+}, NO_3^{1-} and PO_4^{3-}) in the proximity of Giurgiu–Rousse towns from the period between 1954 and 1985 were summarized by authors [21, 22].

Fig. 1. Map of the studied Bulgarian–Romanian Danube River stretch with locations of sampling sites close to Zimnicea–Svishtov, river km 554, Giurgiu–Rousse, river km 496 and Chiciu–Silistra, river km 376

Weber [29] published detailed monthly data on the same compounds, supplemented with $NO_2^{1-}$and total phosphorus for the period 1988–1990. The BMEW, like Weber [29], also delivered monthly measurements of the same nutrient concentrations since 1991 or 1995 and also monthly chlorophyll-a data for 2001–2005 and 2008–2014 periods. The data since 2001 originated from the sampling site close to Chiciu–Silistra. Even though the data of BMEW and Weber [29] also contained measurements of total nitrogen and phosphorus, they were not used in comparisons and calculations because they were completely absent in the earlier periods.

Petschinov [18] reported the first data about suspended solids (SS, annual averages) and river discharges (Q) for the period 1961–1985 for the sampling site Zimnicea–Svistov. Later, the BMEW delivered data after 1988 until 2005 and the most recent data of 2008–2014 about the SS from the Chiciu–Silistra site.

The monthly river discharges since 1991 until 1999 originated from an anonymous source, while after 2001 the annual values of the same site came from ICPDR TNMN yearbooks.

Most of the data for Srebarna Lake were published [2, 14, 27, 28]. In this paper the already published data were supplemented with those from years 2014 and 2015 and the composed data sets were statistically analyzed relating the lake water level to turbidity and phytoplankton biovolume and for the first time to nutrients. The lake water level was the basic hydrological characteristic measured continuously since 1990 until recent days in a weekly interval by means of the surveyor's rod according to the Baltic system i.e. in relation to

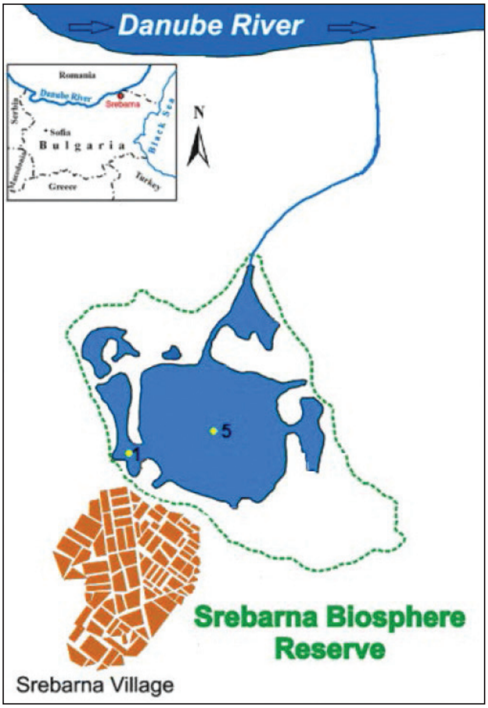

Fig. 2. Scheme of Srebarna Lake with location of the sampling sites

the sea level [12]. Further, we used the records of nutrient concentrations as nitrogen (NH_4^{1+}, NO_3^{1-}) and phosphorus (PO_4^{3-}) [8], available with gaps since 1998. The measurements of water column transparency using the Secchi disc started in the period before reconnection to the river (1989) and, after a big gap, continued after 1998 with variable frequency. The chlorophyll–a measurements carried out spectrophotometrically in 90% acetone [27] also started in 1990 and, after a big interruption, continued since 1998 until 2015, also with variable frequency.

Beshkova et al. [2] published and analyzed data about phytoplankton biovolume and the share of blue-green algae since 2002. Here we added unpublished phytoplankton data for the period 2014–2015. They were sampled also with variable frequency, usually monthly and predominantly during the vegetation season.

The updated data sets were statistically analyzed for significant differences between certain periods of pollution of the Danube River or wetland restoration (Mann and Whitney U–test) and for relationships between hydrology, nutrient and phytoplankton variables by means of correlation and regression analyses.

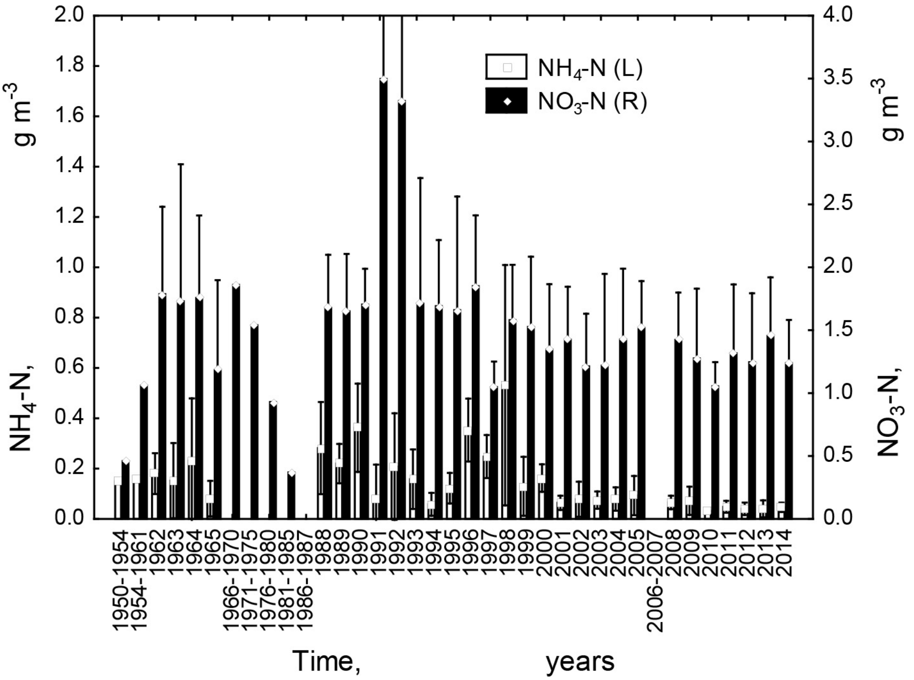

Fig. 3. Long-term trends of NH_4-N and NO_3-N presented by their arithmetic averages and standard deviations at Giurgiu–Rousse, river km 496 for 1959–1980 and Chiciu–Silistra, river km 376 for the 1988–2014 period. Supplemented and modified after Kalchev et al. [13]

RESULTS AND DISCUSSION

Trophic changes in Bulgarian–Romanian Danube River stretch

Considerable long-term trophic changes occurred in the Lower Danube River during the investigated period of about 60 years. The registered concentrations of NH_4-N remained relatively low throughout time, while NO_3-N changed more strongly (Fig. 3). Differently from the previous publication [13], the lowest concentrations of NH_4-N seemed to occur not in 1950–1960 but in the last 2008–2014 period, as a result of a slow decrease since the time of maximum pollution in the 1988–1998 period.

NO_3-N had lowest concentrations for the period 1950–1954, followed by a strong increase, reaching a maximum during 1991–1992. A slow and variable decrease similar to that observed for NH_4-N followed, which continued during the recent years.

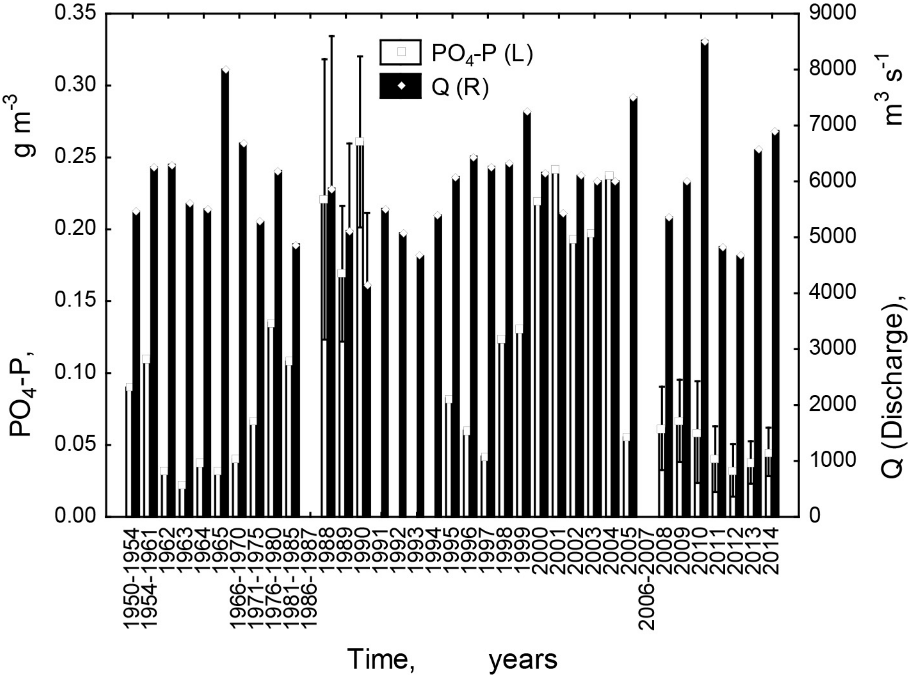

Fig. 4. Long-term trends of PO_4-P presented by their arithmetic averages and standard deviations at Giurgiu–Rousse, river km 496 for 1959–1980 and Chiciu–Silistra, river km 376 for 1988–2014 period; the river discharge for 1950–1961 from Giurgiu–Rousse, for 1962–1985 from Zimincea–Svishtov and 1988–2015 from Chiciu–Silistra, presented by annual values or annual averages, accompanied by standard deviations. Supplemented and modified after Kalchev et al. [13]

Differently from nitrogen compounds, the PO_4-P long-term changes were much stronger (Fig. 4).

The lowest concentrations in the past were in around 1962–1965; similar values were reached again about 45 years later. The visual comparison of PO_4-P changes with variations of discharge quantities showed that a part of these changes was due to varying discharge quintiles causing a concentration or dilution effect. Despite this, the maximum of PO_4-P occurred again around the 90s of the previous century. Similarly, high PO_4-P concentrations seemed to occur until 2004, after which a sharp drop was observed, sustained all the years afterwards.

The calculation of loads of nitrogen and phosphorus allowed to eliminate the concentration changes caused by varying river discharges as presented in Fig. 5. The dissolved inorganic nitrogen (DIN) was a sum of NH_4-N and NO_3-N, the last of which clearly dominated the obtained sum. As a result, the

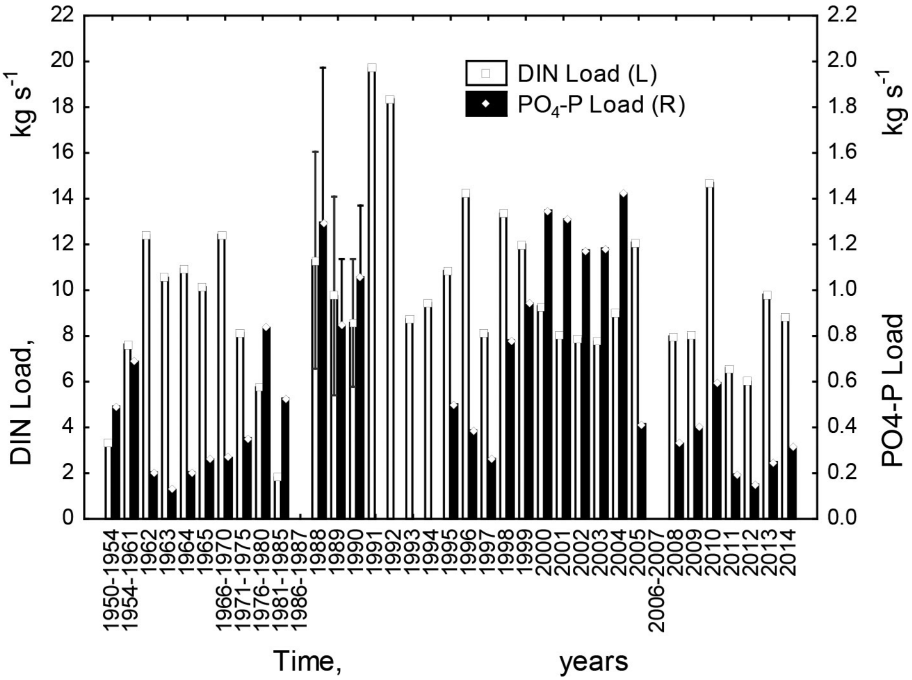

Fig. 5. Long-term variations of DIN and PO_4-P loads on an annual basis calculated by multiplying annual average concentrations with annual discharges presented in Fig. 3 and Fig. 4. Supplemented and modified after Kalchev et al. [13]

DIN load showed bigger variations than NH_4-N and NO_3-N (Fig. 3). The main trends of increase from 1950 towards a maximum in around 1990 and a variable decrease afterwards were more clearly confirmed in Fig. 5.

The PO_4-P load was more variable than the DIN load and seemed to have two distinct maxima – the first one around 1990, coinciding with that of DIN and the second one in the 2000–2004 interval. After 2004, a strong and stable drop in PO_4-P load occurred, which was tested for significance (Fig. 6).

The DIN load showed a slow but continuous decrease from the earliest 1962–1965 period towards more recent years, but the differences between the four periods were not statistically significant (Fig. 6). On the contrary, as indicated in the text under Fig. 6, the PO_4-P loads of the earliest (1962–1965) and the latest (2008–2014) periods did not differ significantly, which means that, differently from [13], an effective reduction of phosphorus pollution occurred and the recently observed PO_4-P load was very close to the values measured in the 60s of the previous century. It seemed that the significantly higher loads of 1988–1990 and 2001–2005 periods already remained in the past.

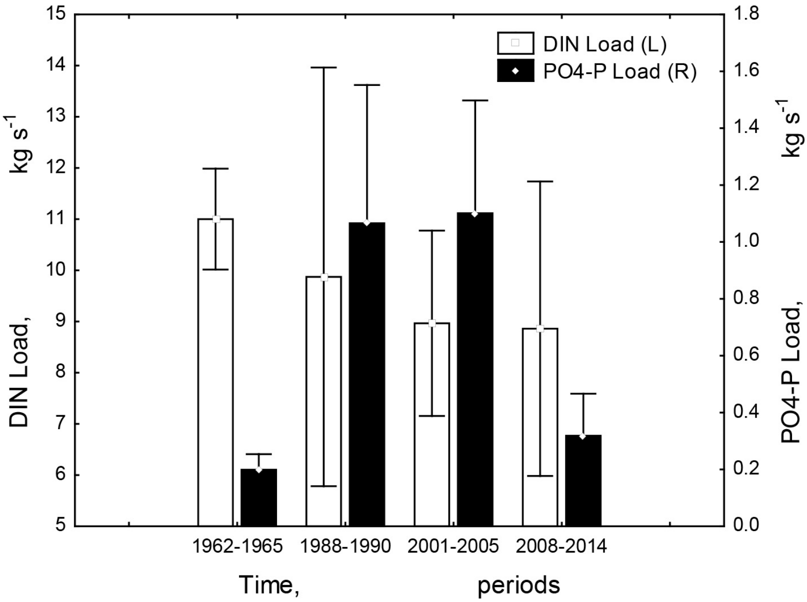

Fig. 6. Arithmetic means with standard deviations of DIN and PO_4-P loads. PO_4-P loads between 1962 and 1965 on one side and 1988–1990, 2001–2005 on the other differed for $P < 0.03$, 0.015 correspondingly, between 1988–1990, 2001–2005 on one side and 2008–2014 on the other for $P < 0.02$, 0.008, and no significant differences between 1962–1965 and 2008–2014 for $P < 0.20$. Supplemented and modified after Kalchev et al. [13]

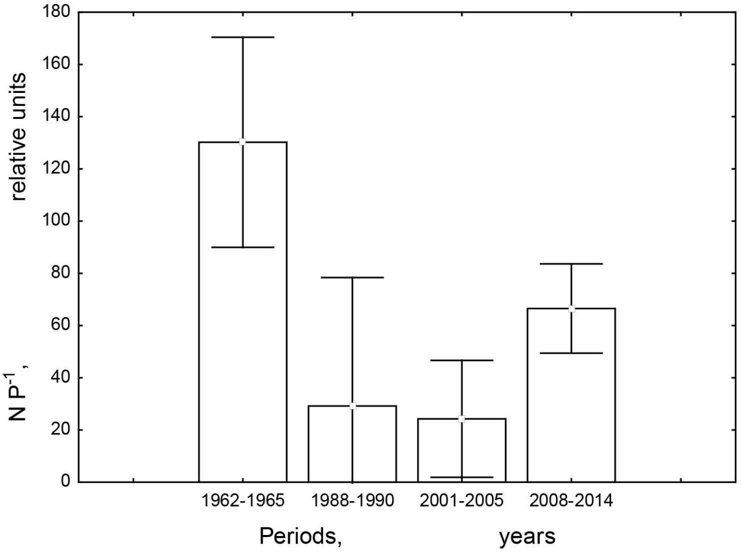

Fig. 7. Arithmetic averages with standard deviations of the N P^{-1} ratio with statistically significant differences between all compared periods, without 1988–1990 and 2001–2005, for the level of significance P ranging between 0.01 and 0.03

The addition of the last period (2008–2014) also introduced changes in the N P^{-1} ratio, as shown in Fig. 7. Now we observed a clearer tendency towards the restoration of phosphorus limitation of phytoplankton growth from the past. Although the N P^{-1} ratio of 2008–2014 was still statistically lower than that observed in the 1962–1965 period, there was a clear increase after the long periods of 1988–1990 and 2001–2005, with a low N P^{-1} ratio indicating nutrient conditions close to the optimal supply of algae with nitrogen and phosphorus, or nitrogen limitation.

Differently from long-term changes of nutrient distinguished by low values in the 50–60s, followed by peaks, and again by more or less pronounced lowering, the concentration of suspended solids (SS) showed a very steep decrease during a very long period (1960–1990), followed by a less pronounced decrease afterwards (Fig. 8). As already stated by authors [13, 18, 24] and others, this is a result of the numerous reservoirs and weirs built on the Danube River and its tributaries in the near past. One of the stepwise decreases shown in Fig. 8 seemed to coincide well with the start of operation of the Iron Gate I Reservoir in 1971, which is in line with [25], while the commissioning of Iron Gate II in 1983 did not have a pronounced effect on the amount of SS in our graph.

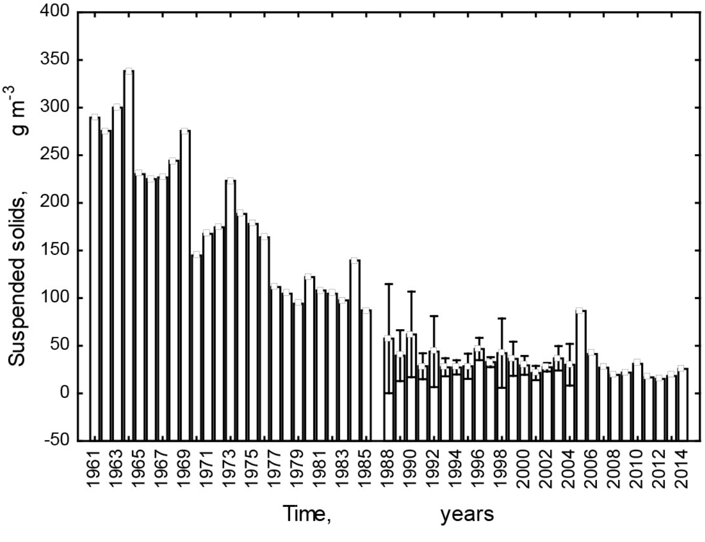

Fig. 8. Long-term trends in concentration of suspended solids (SS) at Zimnicea–Svishtov, river km 554, 1961–1985 and at Chiceu–Silistra, river km 376, 1988–2014. Supplemented and modified after Kalchev et al. [13]

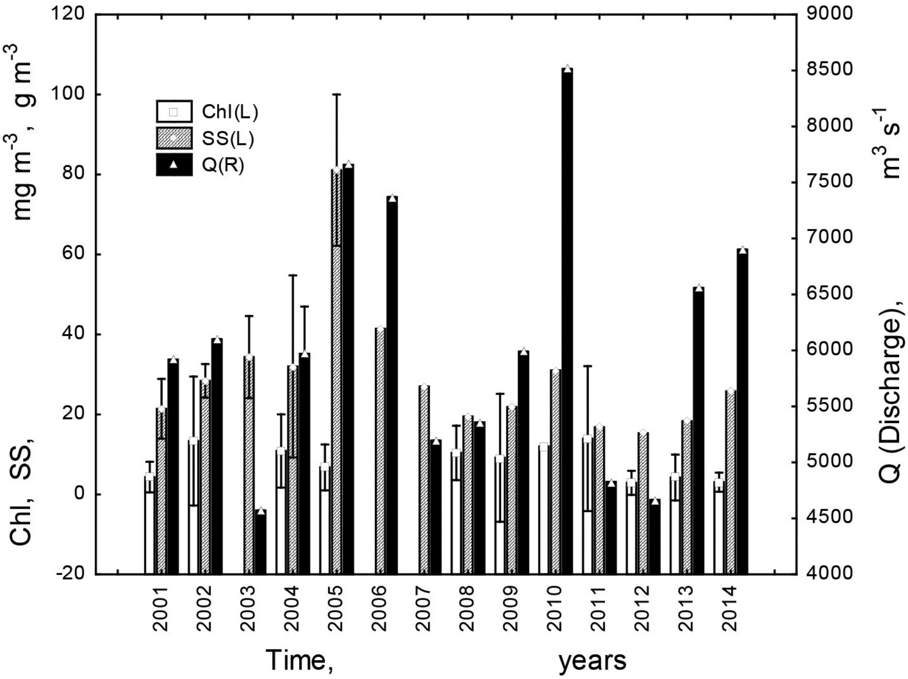

Fig. 9. Annual arithmetic averages with standard deviations and annual values of chlorophyll-a (Chl), suspended solids (SS) and discharge (Q) at the sampling site Chiceu–Silistra, river km 376

Thus the SS concentrations of the last five–six years (2008–2014) were about ten times lower than those of the 1960s, which implied a very strong increase in water column transparency. As generally known, transparency is closely related to SS and thus led to considerable improvement of underwater light conditions favoring phytoplankton development. It seemed that the effect of lowering nutrient concentration on phytoplankton development could be compensated by considerable improvement of underwater light conditions. This made impossible the restoration of the past situation characterized by high turbidity and low nutrient concentrations causing low phytoplankton development. Indeed, regarding the variations of Chl-concentrations, there was no substantial reduction after 2008 (Fig. 9) due to a considerable drop in PO_4-P concentration (see Fig. 4). If we use Chl as a measure of the trophic status, there were no indications for improvement towards a lower trophy level after year 2004 (Fig. 9).

Differently from the past, recently we might expect an increased share of phytoplankton algae in SS concentration, i.e. Chl might be correlated positively and significantly with SS. The annual averages and annual values of Chl, SS and Q presented in Fig. 9 offered the possibility to test how far the hydrology factor (Q) and Chl contribute to the variations of SS under the recent conditions. We found no significant correlation between Chl and SS, but a statistically significant $R=0.56$, $P<0.04$ between $\lg_{10}Q$ and $\lg_{10}SS$, which implied that the river discharge might still be the factor determining the SS concentration under the recent conditions at an annual scale. However, our empirical observations reminded that if we move to a monthly or more detailed time scale at low river water levels, we would encounter strong temporary phytoplankton development during which the algae might compose a substantial share of SS in the Lower Danube River.

Trophic changes in Srebarna Lake during its restoration

Like many other Danube wetlands on the Bulgarian territory, Srebarna Lake was isolated from the river by a dam in the past, in around 1950 and then reconnected again in 1994. The difference was that before 1950 the lake was naturally connected by one inlet and one outlet canal, while after 1994 the connection was restored by only one canal (Fig. 2). The staff operated the canal gates and usually opened them at high levels, and closed when the river level began to fall. We analyzed changes of several important variables characterizing the trophic status before and after the restoration of connection between Srebarna Lake and the Danube River. The comprehensive more or less regular monitoring program had the task to record the success of the restoration process since 1994, which continued with some gaps during the next 20–25 years. Fig. 10 showed the course of long-term changes of the lake water level (WL), water column transparency (SD) and chlorophyll-a concentration (Chl). WL was used as a measure of the effect of hydrological connectivity and SD and Chl as indicators of trophic status variations. Unfortunately, during the time before the reconnection of the lake to the river in 1994 we had records of SD and Chl available, but no data about WL fluctuations for 1990. However, without incurring a considerable risk of error, we could assume a lake WL in 1990 similar to those registered in the next four years before restoration of connection to the river and the first considerable WL rise occurring in 1995. Since 1998, both SD and Chl followed closely the variations of lake WL and even Fig. 10 showed indications of the degree of efficiency of restoration measures carried out. During years of extremely low lake WL such as 1998, 2002–2003 and 2007, SD and Chl reached values very similar to those recorded during the year 1990 before the reconnection. This was the first indication of the instable character of improvement of the lake ecological status after the reconnection.

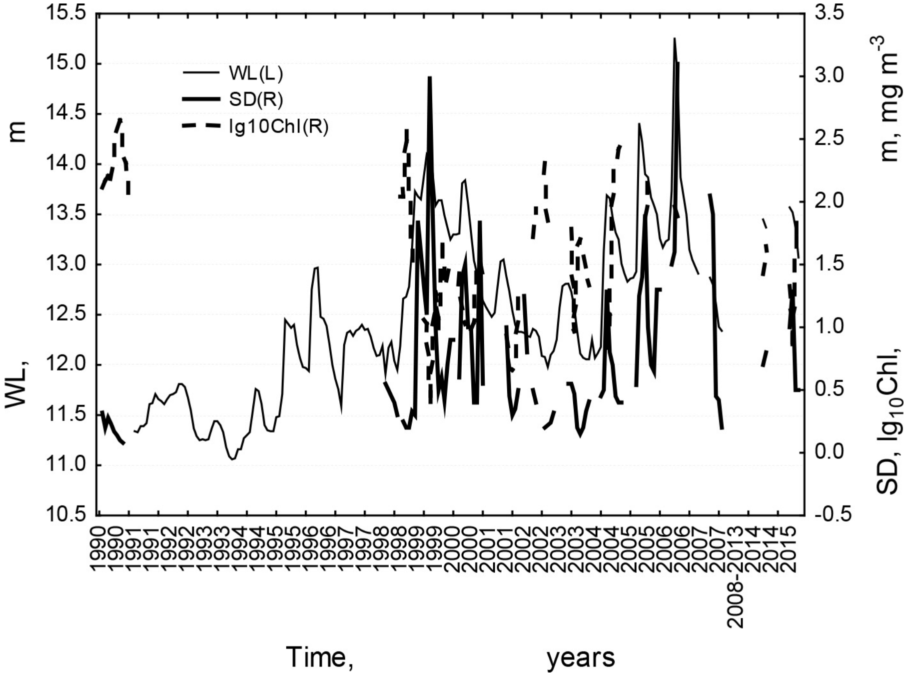

Fig. 10. Monthly values of Srebarna Lake water level (WL), Secchi disk transparency (SD) and chlorophyll-a (Chl)

The variations of concentrations of the two main nutrients were also closely connected to variations of lake WL (Fig. 11). There were some occasional peaks of NH_4-N during low WL years such as 1998, 2000, 2003, with a tendency of lower values toward 2007, which indicated improvement of the lake ecological status. This was confirmed by the negligible values of NO_2-N throughout the studied period. The NO_3-N concentrations had the biggest amplitude of variations, which were also connected to the lake WL variations. There were pronounced peaks of NO_3-N concentrations coinciding with low values of lake WL. These peaks might originate only from the sewage waters entering the lake from the nearby village. It seemed that these nitrate peaks were also accompanied with small rises of PO_4-P concentration, but without doubt the main pollutant was of nitrate nature. Obviously river waters entering the lake and increasing the lake WL caused a dilution effect and masked the pollution coming from the village. Mihaljević et al. [17] reported similar high total nitrogen and total phosphorus concentrations during high water levels although the investigated Lake Sakadaš was much better connected to the Danube than Srebarna Lake. However, the comparison did not seem correct because the in-

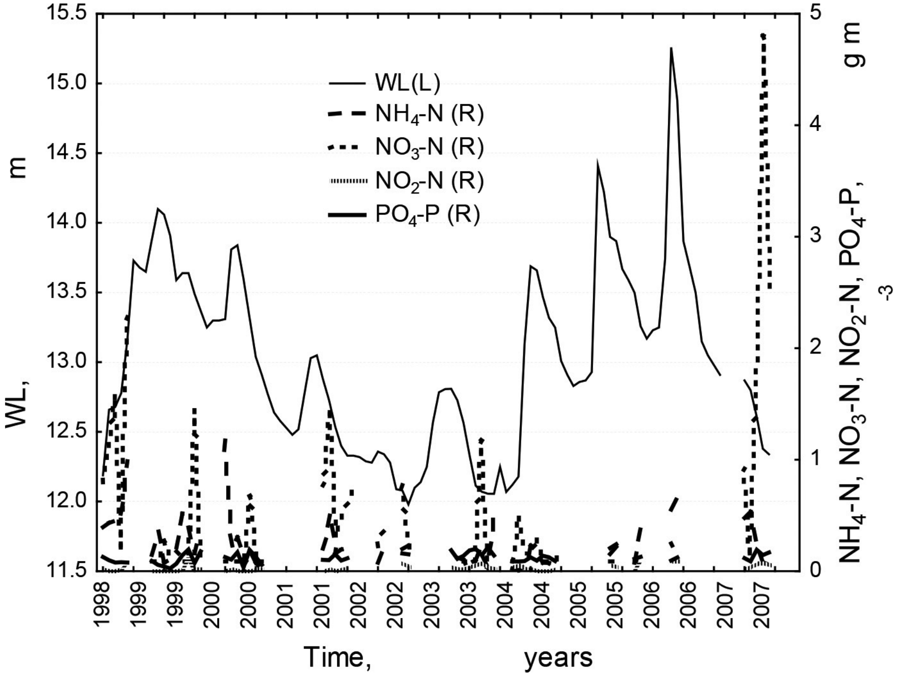

Fig. 11. Monthly values of Srebarna Lake water level (WL) and measurements of NH_4-N NO_3-N, NO_2-N and PO_4-P

organic soluble forms of nutrients are not fully comparable with their total concentrations. Hein et al. [7] reported increased nutrient concentrations at greater hydrological connectivity, which again was not comparable with the case of Srebarna Lake, because the connectivity of the Regelsbrunn side arm was measured in duration of surface connection to the river, not in water level variations in or outside the river.

The high values of NO_3-N and their big amplitude of variations during low WL in Srebarna Lake determined the high amount of the N P^{-1} ratio, which indicated phosphorus limitation conditions of phytoplankton growth. As Fig. 12 shows, the high NO_3-N concentrations were leading to high values of N P^{-1} only for a short time, while in the rest we might assume low values indicating either an optimal nutrient ratio or nitrogen limitation of phytoplankton growth. The latter seemed to be characteristic also for other Danubian wetlands in Bulgaria [15].

The phytoplankton development measured quantitatively as biovolume also followed closely the variations of lake WL (Fig. 13). The high BV concentrations coincided with low values of lake WL and vice versa, which was once more confirmed by the statistically significant correlation not only between

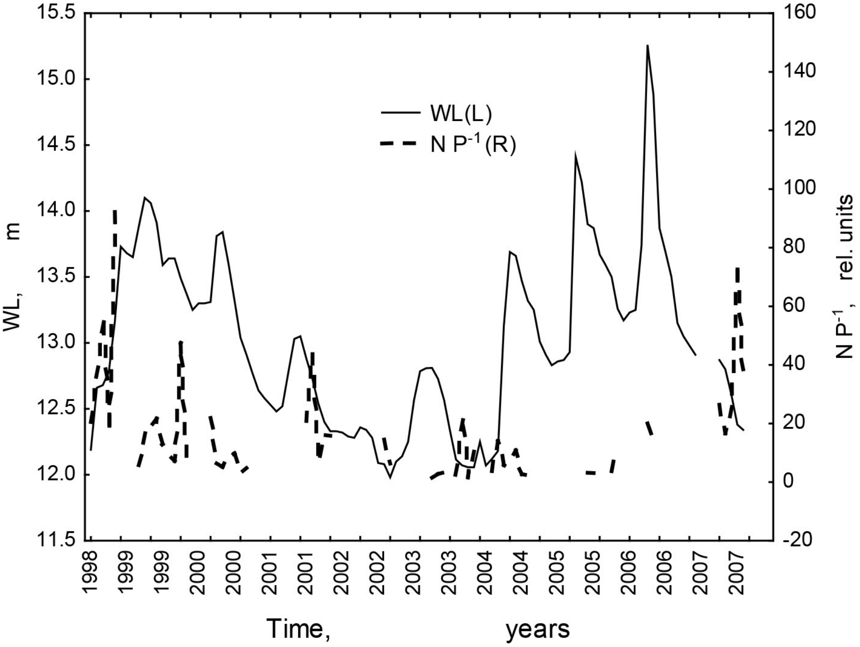

Fig. 12. Monthly values of Srebarna Lake water level (WL) and N P^{-1} ratio

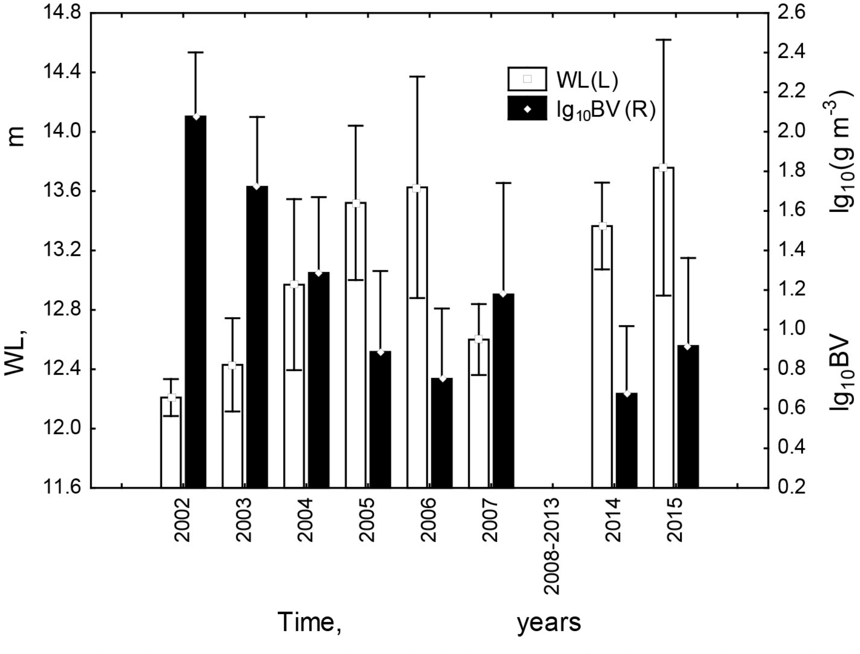

Fig. 13. Annual arithmetic averages and standard deviations of Srebarna Lake water level (WL) and phytoplankton biovolume (BV)

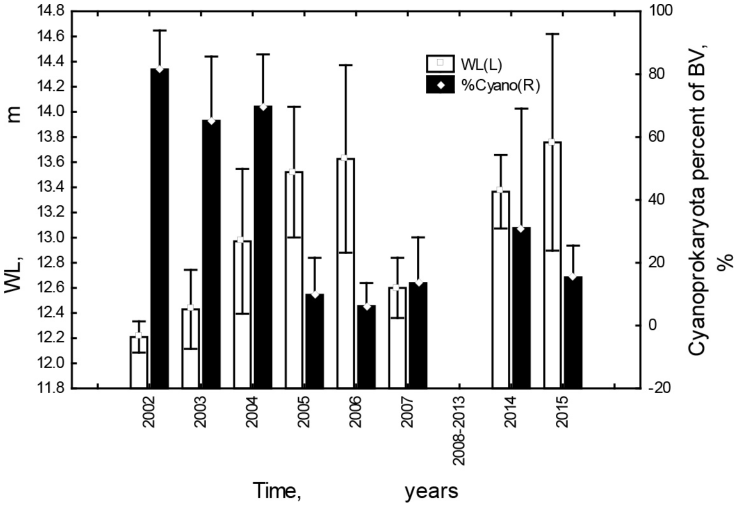

Fig. 14. Annual arithmetic averages and standard deviations of Srebarna Lake water level (WL) and percentage of blue green algae from phytoplankton biovolume

the average values in Fig. 13 but also between single values of BV and lake WL (R=-0.72, P< 0.0000001). Mihaljević et al. [17] registered similar reverse changes of low Chl and BV at high water levels in Lake Sakadaš, which were less pronounced at extremely high river levels.

Another characteristic of phytoplankton serving as an indicator of ecological status of standing waters is the percentage of blue green algae from total phytoplankton biovolume. Fig. 14 shows a similar negative relationship between the percentage of blue green algae from BV and the variations of lake WL. Thus, one could conclude that low lake WL led to a large share of blue green algae, which meant the worsening of the lake ecological status, while high lake WL led to its improvement. This seemed to be in contradiction with the obtained high values for the N P^{-1} ratio (Fig. 12) and the generally known rule that the development of blue green algae is favored by low values of the N P^{-1} ratio. In our case, the big share of blue greens coincided with the high N P^{-1} ratio, most probably because, first, the nitrogen limitation occurred accidentally only for a short time, and second, the hydrological factor might be of greater significance for phytoplankton development than the nutrient ratio. Usually the increase in lake WL was accompanied by higher turbulence and weak stratification caused by river waters entering the lake than the periods of low lake WL, usually characterized by calm, permanently thermally stratified water column, which favored the development of blue green algae.

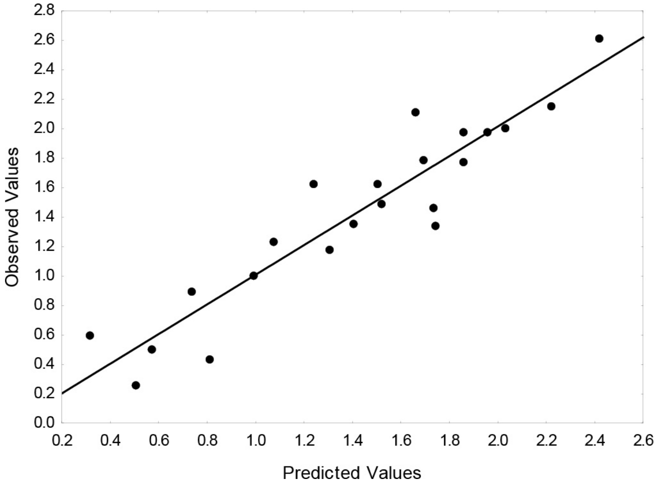

Fig. 15. Multiple linear regression equation for Srebarna Lake: $lg_{10}BV = 8.208 - 0.596WL - 0.465lg_{10}Chl + 0.317DIN$ presented by predicted and observed values with level of significance of regression coefficients for WL – P=0.0000001, Chl – P=0.003, DIN – P=0.02 and $R_{(multiple)}=0.93$

This assumption seemed to be supported by the results of multiple linear regression calculation, which presented a very strong relationship between total algal BV as dependent and WL, Chl and DIN (dissolved inorganic nitrogen) as independent variables (Fig. 15). The regression coefficient of WL had the strongest contribution for explaining the variations of phytoplankton BV (P=0.0000001), followed by Chl concentration and finally the DIN with the smallest level of significance (P=0.02). This is a clear indication of the decisive role of the hydrological factor for favoring the phytoplankton development in Srebarna Lake. The appearance of DIN as the third significant variable in the multiple regression equation let us suppose that nitrogen is more probable than phosphorus as a nutrient limitation factor of phytoplankton growth. The derived very strong multiple linear regression equation relating closely phytoplankton BV to variables that were more easily to measure such as WL, Chl and DIN offered a good possibility for precisely predicting the algal development in Srebarna Lake.

A similar strong multiple linear regression was used as an approximate expression of the share of different components contributing to the turbidity of water column in Srebarna Lake (Fig. 16). The regression coefficient of lake WL had the highest significance and the strongest contribution for explaining the variations in water column turbidity (presented at the reciprocal value of SD). Besides the share of turbidity due to living particles, e.g. phytoplankton algae, a considerable part of turbidity was caused by detritus particles and

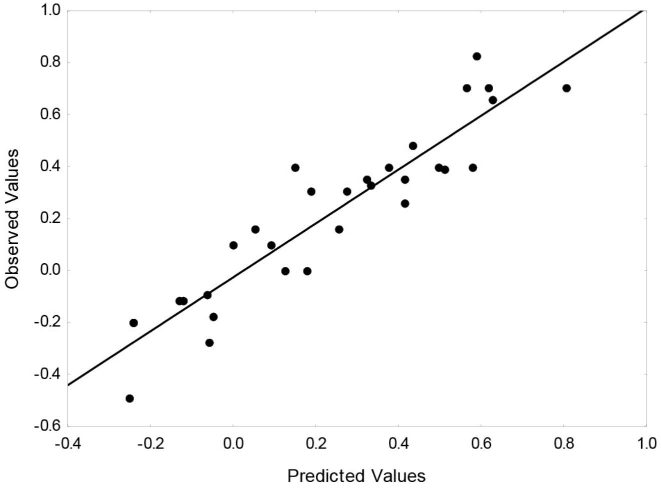

Fig. 16. Multiple linear regression equation for Srebarna Lake: $lg_{10}(1/SD) = 2.221 + 0.202lg_{10}BV - 0.187WL + 0.136lg_{10}Chl$ presented by predicted and observed values with a level of significance of regression coefficients for BV – P=0.013, WL – P=0.0005, Chl – P=0.05 and $R_{(multiple)}=0.93$

soluble colored substances, whose availability in the water column is governed by waters entering from the Danube River and by the wind. This was the so-called non-algal turbidity, whose absolute values remained unchanged before and after the restoration and its share amounted up to 60% of total turbidity according to Kalchev et al. [14]. These high amounts of non-algal turbidity are caused by the availability of the thick layer of sapropel substances on the lake bottom. These substances could be easily re-suspended in the water column but could not be washed out the lake because the restored connectivity by only one channel allowed either weak or no flushing effect throughout the lake during high water levels of the Danube River.

SUMMARY

The presented paper consists of two parts. The first one deals with long-term changes of NH_4^{1+}, NO_3^{1-} , PO_4^{3-}, suspended solids and chlorophyll-a concentrations, accompanied also by data for surface river discharges in the Bulgarian–Romanian section of the Lower Danube. Most of the data encompassing the period between 1950 and 2014 originated from literature sources, but also from the routine monitoring program of the Bulgarian Ministry of Environment and Water and from ICPDR TNMN yearbooks. The data from the last 2008–2014

period updated substantially the data set already published by Kalchev et al. [13] and allowed to draw new important conclusions. Thus the PO_4^{3-} concentration and the PO_4-P load showed a substantial and stable drop after year 2008, whose values were very similar to those from the earliest 1962–1965 period. Further, the relatively modest decrease in the dissolved inorganic nitrogen load and the low PO_4-P values in years 2008–2014 lead to a high N P^{-1} ratio, which despite being statistically lower than in the 1962–1965 period presented substantial return towards the phosphorus limitation of phytoplankton in the past. However, despite the strong and stable PO_4^{3-} decrease, the chlorophyll-a concentration did not drop after 2008, most probably due to considerable improvement of underwater light conditions caused by about a ten times decrease of concentration of suspended solids since 1950, which lasted also after 2008.

The second part of the paper treats the restoration of the Danubian wetland of Srebarna Lake. The monitoring of restoration progress started in 1990, a few years before the reconnection of the lake to the river in 1994, and continued with variable sampling frequency until 2015. The last two years of 2014 and 2015 supplemented the data set, applied in the previous publications analyzing the restoration development. From the variety of variables included in monitoring of lake restoration we selected the lake water level, water column transparency, NH_4^{1+}, NO_2^{1-}, NO_3^{1-}, PO_4^{3-}, and chlorophyll-a concentrations, phytoplankton biovolume and the percentage of blue-green algae of it. The lake water level as an indicator of the hydrological connectivity between the lake and the river was strongly and significantly correlated with most of the above listed variables. For the first time the nutrient concentrations were related to the lake water level, indicating that the strong rises of NO_3^{1-} concentration during low water levels were most probably coming from sewage waters of the nearby village. The lake water level correlated negatively with chlorophyll-a and positively with water column transparency. At low water levels both variables showed values close to those before restoration, which meant occasional worsening of the lake ecological status most probably caused by the limited connectivity operated by only one canal opened by the staff at high levels and closed when the river level began to fall. The phytoplankton biovolume and the share of blue-green algae were also significantly negatively correlated with the water level confirming the worsening of the ecological status at low water levels. However, for first time we managed to derive a very strong multiple regression equation between phytoplankton biovolume as dependent and lake water level, chlorophyll-a and dissolved inorganic nitrogen as independent variables (R=0.93), allowing to predict phytoplankton biovolume by more easily measurable variables with good accuracy.

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ДУГОТРАЈНЕ ПРОМЕНЕ ТРОФИЈЕ У БУГАРСКО-РУМУНСКОМ ДЕЛУ ДУНАВА И ОКОЛНИХ МОЧВАРА НА ТЕРИТОРИЈИ БУГАРСКЕ ТОКОМ ЊЕНЕ РЕСТАУРАЦИЈЕ

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Резиме

На основу, пре свега, података из литературе и резултата програма праћења Министарства за животну средину и воде Бугарске, проучене су дугорочне промене нутријената (азота и фосфора), суспендованих чврстих честица и концентрација хлорофила у бугарско-румунском делу доњег тока Дунава током периода 1950–2014. године. Анализом и скоријих података за године 2008–2014, регистровано је стабилно снижавање са вредностима концентрација PO_4^{3-} близу онима које су забележене у најранијем интервалу – у годинама 1962–1965. Израчунато оптерећење раствореног неорганског азота (*DIN*) показало је стално, али не значајно смањење, док је оптерећење PO_4-P пало крајем периода 1950–2014. на вредности са почетка. Те промене азота и фосфора довеле су до значајне промене показатеља $N\ P^{-1}$ ка фосфорном ограничењу раста фитопланктона у периоду 2008–2014. године.

У другом делу рада представљен је и анализиран процес санације мочварних подручја на примеру језера Сребарна. Главни циљ санације јесте одржавање вредног биодиверзитета који подржава то језеро; међутим, као мочварно подручје, оно треба да пружи и већину других услуга, које укључују, између осталог, уклањање нутријената. Праћење санације језера почело је 1990. и с прекидима трајало до 2015. године. Главни покретач промена других карактеристика језера био је ниво воде у језеру. Постојала је позитивна корелација између нивоа воде у језеру и прозирности воденог стуба и негативна корелација са хлорофилом а, биозапремином фитопланктона и уделом њихових плавозелених облика. Од 1994. године, само један канал повезује језеро са Дунавом, што вероватно представља разлог ограниченог успеха санације мочварног подручја.

Кључне речи: доњи ток Дунава, санација мочварног подручја, нутријенти, дугорочне промене, односи