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RELATIONSHIPS BETWEEN TROPHIC STATE AND PHYSICOCHEMICAL VARIABLES OF SOME STANDING WATER BODIES ON THE TERRITORY OF EAST-AEGEAN RIVER BASIN DIRECTORATE, BULGARIA

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Abstract

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The objectives of the study were to describe the physicochemical variables and to assess the trophic state of the reservoirs Ovcharitsa, Byal Kladenets, Skalitsa, Zhrebchevo and the fishponds of Nikolaevo. Sampling was conducted at four occasions between April and August 2013. The concentrations of nutrients and the Carlson's trophic state indices were used to assess the trophic state of the water bodies. The trophic state spans over several trophic categories – from oligo-mesotrophic to hypertrophic, with majority of the water bodies being eutrophic. Very strong positive correlation was observed between the transparency and the chlorophyl trophic state indices. Weaker, but still strong correlation was observed between the transparency and the phosphorus trophic state indices. The relationships between the trophic state indices depended on the depth of the water body and the influence of the heated waters from the thermal power station "Maritsa Iztok-2". The trophic state of the water bodies depends not only on the amount of the available nutrients, but also on the circulation pattern and the length of the vegetation period. The thermal pollution from large steam electric power plants not only changes the environmental factors, but also the relationships between the physicochemical variables and the biological communities in the water bodies. Our results show the different response of the studied variables in thermally influenced water bodies, compared to different unaffected by heated waters systems.

Key words: Trophic state indices, phytoplankton, chlorophyll-a, reservoirs, thermal pollution

Introduction

The major part of the inland waters in Bulgaria are small and shallow artificial lakes (Michev and Stoyneva (eds.), 2007), however, the investigations of lentic water bodies is dominated by researches in the big, multipurpose reservoirs (Naidenow (1970); Saiz (1981; 1987); Naidenov (1984); Naidenov and Baev (1987); Beshkova (1996); Beshkova and Botev (1994); Kalchev (1994; 1999); Kalchev et al. (1996; 2003; 2004); Kalchev and Boumbarova (1996); Kozuharov (1994; 1996; 1999); Traykov (2005); Kozuharov et al. (2007; 2009). These studies revealed that different aspects such as geographical position and morphometry play an important role in determining the lake trophic state and corresponding biological communities. The relationship between the environmental variables and the trophic state of the water bodies is extensively studied and described in the big reservoirs, especially in the temperate regions where distinct seasonality is an annual occurrence (Reynolds, 1984; Elliott et al., 2002; Grover and Chrzanowski, 2006). On the other hand, anthropogenic environmental alterations, such as nutrient pollution, agricultural runoff, cage and open water fish farming, as well as changes in the thermal regimes of the water bodies induce modifications in the physical and chemical character-

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istics of the water, as well as in the biological communities (Yoshev, 1972; Zhivkov and Groupcheva, 1987; Hubenov, 2005; Cheshmedjiev et al., 2010; Stanachkova et al., 2010; Kalff, 2002; Pearl and Huisman, 2008; Elliott et al., 2006; Elliott and May, 2008; Elliott, 2012a и Elliott, 2012b; Stoychev and Danova, 2012).

In order to evaluate the influence of different environmental alterations on the relationship between the main physicochemical variables and the trophic state of the reservoirs, we selected water bodies with different management and exploitation regimes.

Our aims were to: (i) provide data and test the relationships between the selected physicochemical parameters in defined water bodies in the East Aegean Basin Bulgaria, and (ii) determine the influence of different management and exploitation regimes on the relationship between the physicochemical variables, the biological variables and the trophic state of the water bodies.

Materials and Methods

Four reservoirs on the territory of the East Aegean River Basin Directorate: Ovcharitsa (Ov), Byal Kladenets (BK), Skalitsa (SK) and Zhrebchevo (Zhr), as well as the fishpond complex of Nikolaevo (NF) were investigated in April, May, June and August 2013.

The reservoirs Ovcharitsa, Byal kladenets and Skalitsa are part of a complex used to supply and recirculate waters for additional water cooling for the steam electric power plant (SPP) Maritsa Iztok II. The water used as a coolant is withdrawn from the dam part of Ovcharitsa reservoir and consequently returned to the Byal Kladenets from where it flows back again into the middle sections of Ovcharitsa reservoir. The waters lost through evaporation are replenished by the transfer of river waters from Tundzha River by the open canal Hanovo – Skalitsa reservoir – Ovcharitsa reservoir. The fishpond complex of Nikolaevo is situated upstream of Zhrebchevo reservoir on Tundzha River. The morphometric characteristics of the water bodies are given in Table 1. During the sampling period the bottom sluices-gate of Skalitsa reservoir was under reconstruction, and the water level in the reservoir was kept low.

The sampling was done on one main site in the deepest part of the reservoirs and from the biggest water basin in the fishpond complex. Additional sampling sites were selected in the reservoirs as follows: two additional sampling sites in the middle and the upper part of Ovcharitsa reservoir; two additional sampling sites in the middle and the upper part of Zrebchevo reservoir and one additional sampling site in the upper part of Byal kladenets reservoir. The data from the main sites is used in the comparison between the reservoirs, while the data from the additional sampling sites is used together with the main stations data in the assessment of the relationships between the studied variables within the water bodies. At each sampling station, field measurements were made of physical variables including temperature, dissolved oxygen, pH, specific conductance and Secchi disk visibility. Integrated water samples were taken from the epilimnion, according to Wetzel and Likens (2000) for laboratory determination of chemical variables including total alkalinity (ISO 9963-1) and nutrients concentrations: total and phosphate phosphorus (EN ISO 6878); ammonium nitrogen (ISO 7150/1); nitrate and total nitrogen (MERCK – PMB method 14773). Biological variables included chlorophyll-*a* (ISO 10260) and phytoplankton abundance (Bürker hemocytometer chamber and a straight light microscope). Carlson's trophic state indices (TSI) were used to assess the trophic state of the water bodies (Carlson, 1977; Carlson and Simpson, 1996). TSI values between 40 and 50 are associated with mesotrophic conditions, between 50 and 70 with eutrophic conditions, while below 40 and above 70 – with oligotrophic and hypertrophic conditions, respectively.

Descriptive statistics, Spearman rank correlation and regression analysis were performed using PAST software.

Results and Discussion

Physicochemical variables

We present data on selected physicochemical variables in the studied water bodies grouped in two complexes – Zhreb-

Table 1

Attributes of the water bodies, included in the study

Reservoir	Elevation, m a.s.l.	Surface aria, km^2	Max. depth, m^{-1}	Volume, m^3 × 10^6	Average depth, m^{-1}
Ovcharitsa	135	6.3	15	45	7.2
Byal kladenets	138	3.2	12	6.3	11.9
Skalitsa	143.5	u.n.	8.5 (≈ 1.5*)	11.1 (u.n.*)	≈ 0.7*
Zhrebchevo	260	25.8	41	400	15.5
Nikolaevo fishponds	265	2.84	4	u.n.	u.n.

* – approximate parameters at low water level; u.n. – unknown

Table 2

Physicochemical variables and biological attributes at main sampling station in the studied water bodies. AM – arithmetic mean; CV% – coefficient of variation

Water body / Variable	Zhrebchevo – (Zhr)		Nikolaevo fishponds – (NF)		Ovcharitsa – (Ov)		Skalitsa – (SK)		Byal kladenets – (BK)	
	AM	CV%	AM	CV%	AM	CV%	AM	CV%	AM	CV%
T°C	22.1	24.1	24.3	21.0	25.9	23.7	24.7	21.1	28.1	23.7
O_2%	115.3	9.8	135.5	19.1	124.3	37.1	161.8	43.7	100.1	19.0
O_2 mg/l	10.0	6.0	10.9	14.4	10.1	36.0	14.1	54.1	8.0	24.3
SD m	3.6	69.9	0.5	58.1	1.8	12.0	0.4	26.1	1.1	11.0
pH	8.60	4.0	8.69	3.8	8.58	1.6	8.94	2.4	8.54	1.2
EC µS/cm	304.5	10.4	371.75	9.2	824	1.9	691.5	28.9	835.75	2.3
PO_4-P mg/l	0.03	0.0	0.05	31.6	0.12	46.4	0.10	109.3	0.13	51.6
NH_4-N mg/l	0.07	23.6	0.22	106.9	0.07	42.1	0.12	77.0	0.06	59.2
NO_3-N mg/l	1.8	54.1	2.3	29.9	1.8	44.7	2.0	30.3	2.1	21.2
TP mg/l	0.06	21.9	0.37	72.4	0.23	43.9	0.44	32.7	0.25	33.5
TN mg/l	2.5	38.6	4.1	21.7	2.5	28.4	3.5	18.4	2.7	17.5
TA meq/l	2.35	17.5	2.81	10.9	4.01	5.4	3.90	18.4	4.05	4.3
N × 10^3 cells/ml	30.5	99.0	361.2	66.6	27.4	88.5	352.6	67.2	66.1	61.3
Chl-a µg/l	8.12	67.7	161.91	117.9	12.07	46.1	161.89	49.2	22.95	45.2
TSI(Chl)	48.4	19.7	75.3	15.3	54.3	8.3	79.5	6.4	60.7	6.5
TSI(Sd)	44.1	23.4	73.1	12.2	51.6	3.3	75.0	4.6	58.2	2.7
TSI(TP)	62.3	5.5	85.9	14.1	81.1	8.3	91.2	5.3	83.3	5.9
Avrg TSI	51.6	13.5	78.1	13.7	62.3	4.9	81.9	4.4	67.4	3.4

chevo complex (Zhr and NF) and Ovcharitsa complex (Ov, BK and SK) (Table 2), and the correlation matrix between the main variables (Table 3).

Comparison of water temperatures showed clear differentiation between the water bodies. The thermally influenced reservoirs (Ov and BK), have higher ranges of temperature fluctuations (14 and 14.9°C) as well as higher maximum temperatures. Minimum and maximum temperatures observed in this group were 17.2°C in April at Ov and 33.9°C in August at BK, respectively (Figure 1). The influence of the SPP on the thermal regime of the reservoirs in this complex is toward prolonging the growth season in contrast to the comparable reservoirs in the region. Average temperatures in 2013 were significantly lower (2.8°C and 4.3°C, respectively) at Ov and BK reservoir stations as compared to the observed in the beginning of the 1980's by Zhivkov and Groupcheva (1987).

Temperatures at SK station were typically 2 to 3°C lower than at Ov and BK reservoir stations, with a range of 12°C and a maximum of 29.3°C. The temperature regime at SK station is influenced mostly by the transfer of waters from Tundzha River, which brings in cooler river waters.

Table 3

Correlation matrix between physicochemical variables and biological attributes in the water body complexes – Ovcharitsa complex (grey shading) and Zhrebchevo complex (no shading). The significant correlations ($p < 0.05$) are in bold

	Chl-*a*, µg/l	SD, m	N, cells/ml	O_2, mg/l	T. °C	EC, µS/cm	pH
Chl-*a*, µg/l	1	–0.427	**0.951**	**0.651**	0.211	0.410	**0.534**
SD, m	**–0.604**	1	**–0.539**	–0.309	–0.450	–0.082	**–0.689**
N, cells/ml	**0.802**	**–0.569**	1	**0.560**	0.215	**0.511**	**0.524**
O_2, mg/l	**0.532**	–0.257	**0.609**	1	–0.276	0.282	0.266
T, °C	–0.200	0.044	–0.010	**–0.441**	1	–0.027	**0.634**
EC, µS/cm	**–0.594**	0.279	–0.367	–0.206	0.099	1	–0.267
pH	0.779	–0.493	0.704	**0.643**	–0.186	**–0.653**	1

Average growth season temperatures were significantly lower (3.8°C to 6.1°C) at NF and Zhr stations than at thermally influenced reservoir stations. Minimum and maximum temperatures observed in this group were 14.3°C and 27.4°C in Zhr and NF, respectively. Temperatures range is minimum at NF station (10.7°C), but comparable to the range at Zhr reservoir station (11.3°C). The temperature regime of this complex is unaffected by thermal pollution, with stronger influence of the river waters at NF station and slower increase of surface temperatures in the limnetic zone of Zhrebchevo reservoir.

Dissolved oxygen levels varied from 5.7 $mg.l^{-1}$ at Ov station to 24.7 $mg.l^{-1}$ at SK station (Figure 1). The average oxygen levels at thermally influenced reservoir stations depended mostly on the water temperature (Table 3), with lowest average oxygen levels (8 mg/l) at BK station.

In the rest of the water bodies, the average oxygen levels depended on the phytoplankton development. The maximum oxygen levels at SK station were observed during the phytoplankton bloom in the reservoir. Differences with time were typically minimal at Zhr and NF stations, as evident by the low coefficient of variation, than at the thermally influenced stations. The average oxygen level at Ov station in 2013 was 0.4 mg/l lower than the observed in 1981 (Zhivkov and Groupcheva, 1987), while at Zhr station it was 2.0 mg/l higher, compared to the average from the corresponding periods from 2000 to 2012 (REI, 2013), and 1.5 mg/l higher than the observed by Kalchev et al. (2013) in the period 2009-2011. The latter authors also observed a tendency of increasing oxygen levels and relate it to the invasion of the *Dreissena polymorpha* mussels in the reservoir. Our results suggest that oxygen levels in the water bodies are controlled mainly by the amount of the phytoplankton. Near-surface oxygen values, at all sampling stations, almost always exceed saturation levels due to photosynthesis within the euphotic zone. In rare cases oxygen content dropped below saturation levels at Ov and BK reservoir stations due to rapid increase in temperatures, and correspondingly the respiration and decomposition of organic matter.

Water clarity, as indicated by Secchi disk visibility, generally decreased with the reduction of depth of the sampling station. Thus, mean visibility (Table 2) increases in the order SK, NF, BK, Ov and Zhr stations, though the lowest visibility (0.2 m) was observed in August at NF station, during a massive phytoplankton bloom (Figure 2). The highest visibility (7m) was observed at Zhr station in April. In the

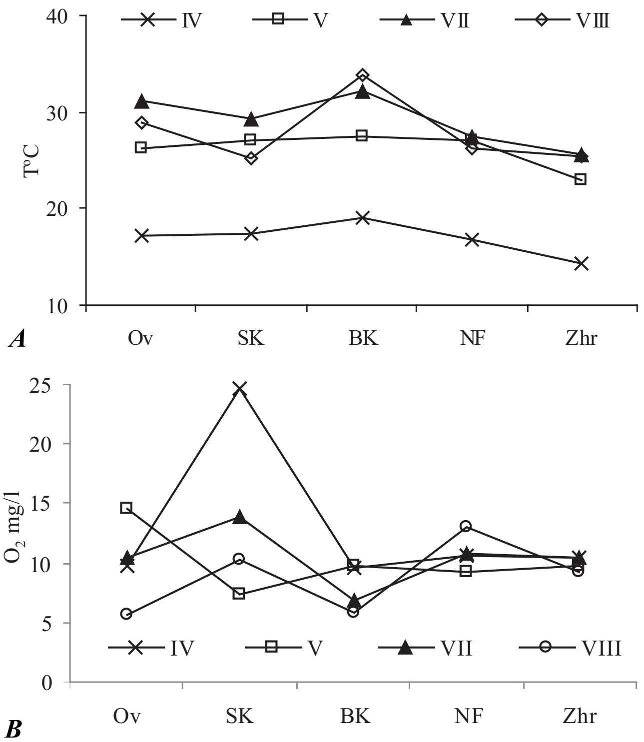

Fig. 1. Water temperature (T°C) and oxygen levels (O_2 mg/l) in the water bodies

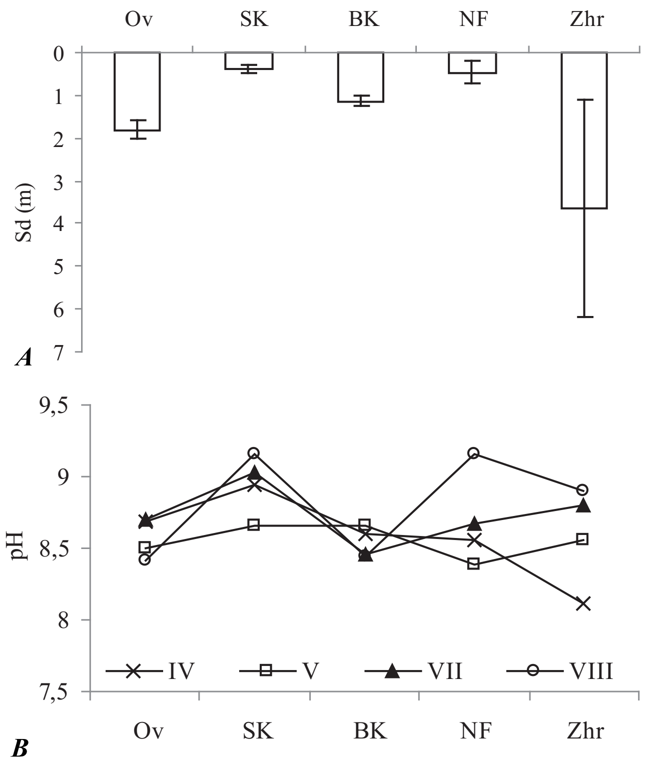

Fig. 2. Water transparency (Sd) and pH values (pH) in the water bodies

present study the mean transparency at Zhr station is 7% lower than the reported by Kalchev et al. (2013) and 3 times higher than the sited by Size fore the reservoir (Saiz, 1981). The slight difference between our results and the reported by Kalchev et al. (2013) is most probably due to the different periods of sampling. Nonetheless, our results confirm the observed by the author's significant increase in the water transparency after the invasion of *D. polymorpha*.

Overall mean pH values for the sampling period varied from 8.1 to 9.1 pH units at Zhr and, both, SK and BK reservoir stations, respectively (Figure 2). The lowest variability was observed at the reservoir stations in the Ovchritsa complex, where average coefficient of variation was less than 2%, while in Zhrebchevo complex it was approximately 4%. In our study the pH values are by 0.5 units higher than the observed by Kalchev et al. (2013).

Overall mean specific conductance (*EC µS/cm*) shows clear differentiation between the two complexes. In the Ovcharitsa complex the mean specific conductance ranges from 691 to 835 µS/cm during the sampling period (Figure 3). The highest variability was observed at SK reservoir station due to the input of river waters through the supply canal.

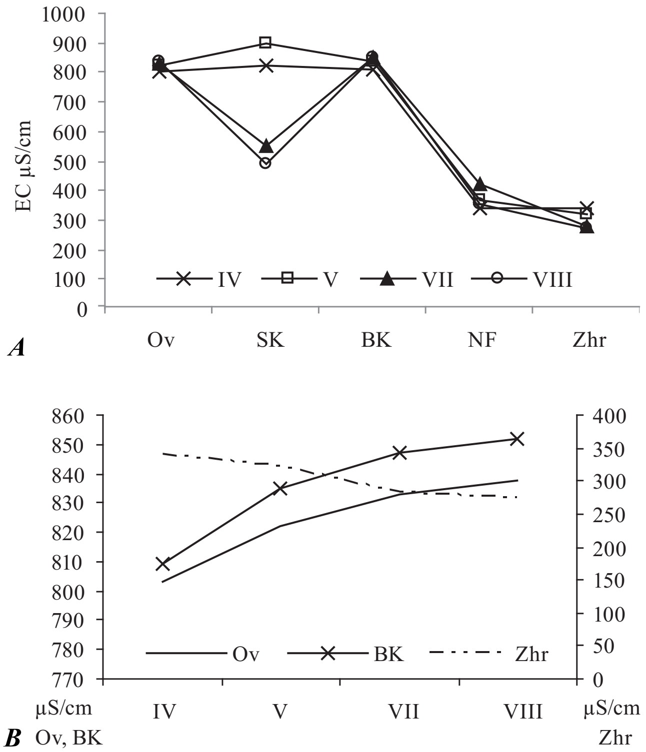

Fig. 3. Specific conductance (EC) in the water bodies and changes of EC at the thermally influenced stations and Zhr station

Specific conductance values differed between Ov and BK stations sampled during the same day, with higher values observed at BK. Throughout the sampling season the specific conductance increased at the thermally influenced stations and decreased at Zhr reservoir station. The opposite trends are due to increase in the concentration of the total dissolved solids through evaporation at thermally influenced Ov and BK stations, and due to biological decalcification throughout the active growth season at Zhr station.

Total alkalinity varied within the range of 1.9 to 4.6 meq/l. Mean total alkalinity values were similar at thermally influenced reservoir stations – 3.9, 4.01 and 4.05 meq/l at SK, Ov and BK, respectively (Figure 4). The mean TA values in Zhrebchevo complex were 2.35 and 2.81 meq/l at Zhr and NF stations. Total alkalinity values varied little at Ov and BK stations and their variation increased at NF and Zhr stations. Similar to the specific conductance, the variation of the TA values was maximal at SK station due to the influence of the river water input. The observed differences of alkalinity with time at some stations were a result of biological decalcification throughout the active growth season or, as defined by Wetzel (1983), due to photosynthetic utilization of CO_2 in the trophogenic zone.

Concentrations of ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and total nitrogen varied within the following ranges: NH_4-N, 0.03 to 0.52 mg/L; NO_3-N, 0.8 to 3.2 mg/L; and total nitrogen, 1.6 to 4.9 mg/L (Figure 4). Consistent differences associated with reservoir complexes and water body uses were apparent. The highest values (Table 2) of the mean concentrations of ammonium, nitrate and total nitrogen were at the intensive aquaculture sites – NF station, followed by the SK station. The lowest mean values were measured, usually, at the deepest stations Zhr and Ov. Only the lowest mean value of the ammonium nitrogen was measured at the thermally influenced BK station.

Orthophosphate phosphorus and total phosphorus concentrations during the sampling period ranged from less than 0.03 to 0.27 mg.l^{-1} and from 0.04 to 0.67 mg.l^{-1}, respectively. Orthophosphate phosphorus and total phosphorus content of samples collected from the thermally influenced stations shows consistent increasing trends with time. Total phosphorus concentrations showed higher values at the SK and NF stations due to the constant fertilization and input of fish food in the fish basins.

The mean concentration of orthophosphate phosphorus at OV station was comparable to the reported values in 1981 by Zhivkov and Groupcheva (1987) and higher than the reported concentrations for the period 1968-1970 (Yoshev, 1972). The amount of ammonium nitrogen doubled and that of nitrate nitrogen tripled since 1981 at Ov station. This is

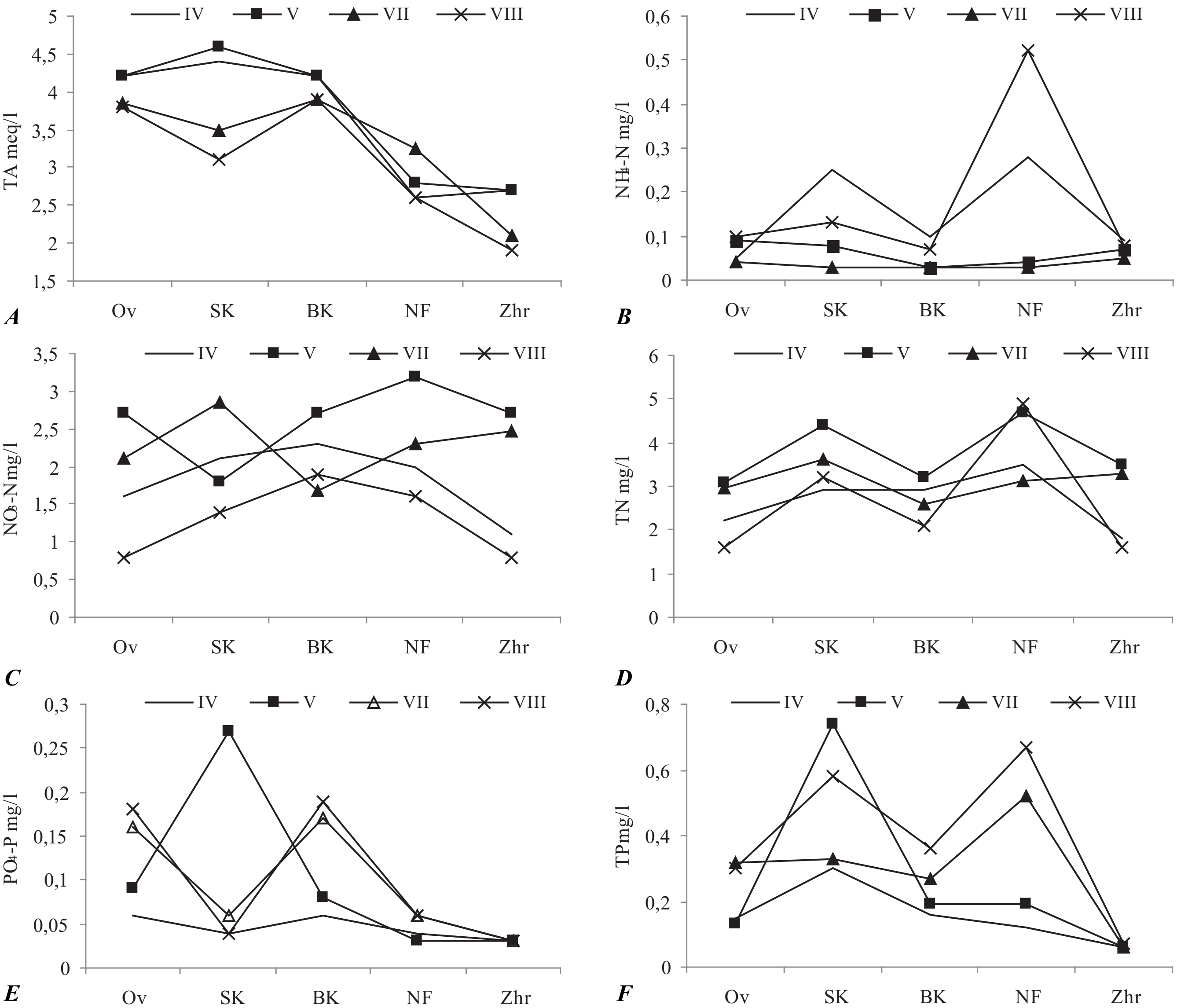

Fig. 4. Changes in the total alkalinity (TA), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total nitrogen TN), phosphate phosphorus (PO_4-P) and total phosphorus (TP) in the water bodies

mostly due to the concentration of the dissolved solids by evaporation with time. Zhivkov and Groupcheva (1987) have noted significant increase of the major ions, including the nutrients, as well as of the organic content of the waters in Ovcharitsa reservoir since the works of Yoshev (1972). Obviously, the main effect of sustained higher temperatures, due to thermal pollution, on the chemical variables is the increase of the dissolved solids with time.

The comparison of the mean values of the chemical variables in Zhrebchevo reservoir with the mean values for the water body, available from the national monitoring program for the period between 2000 and 2012 (REI, 2013), showed no differences, except for the amount of nitrate and total nitrogen, which are significantly higher at the present study. The mean values of the variables are, generally, comparable also to the reported by Kalchev et al. (2013) and confirm the observed by the author's tendencies, in the values of the chemical variables, due to the invasion of *D. polymorpha* in the reservoir.

Biological variables

Chlorophyll-*a* (Chl-*a*) content of samples during the sampling period ranged from 1.6 to 440 µg.l^{-1} at Zhr and NF stations, respectively. Mean Chl-*a* values were equal at both fish farms stations, 161.9 µg.l^{-1} at SK and 162 µg.l^{-1} at NF. The lowest mean value was observed at Zhr reservoir station – 8.1 µg.l^{-1}, while the thermally influenced stations had mean values of 22.9 µg.l^{-1} and 12 µg.l^{-1} at BK and Ov, respectively (Table 2). Chl-*a* levels at Ov and SK stations peaked in April and August, with a decline in between. A single peak was observed at BK station in May during a reduced production of electricity due to maintenance works at the SPP (Figure 5). Chl-*a* content at NF was highly variable and gradually increased throughout the sampling period. The peak of Chl-*a* content at Zhr station was in June.

The mean Chl-*a* content at the stations with minimum variance, Zhr and Ov, were similar to the mean values reported by the REI for the period 2008/2012 – 7.4 µg.l^{-1} and 11 µg.l^{-1}, for Zhr and Ov stations, respectively (REI, 2013).

Phytoplankton abundance during the sampling period ranged from 1.1 × 10^3 to 708 × 10^3 cells.ml^{-1}at Zhr and NF stations, respectively (Table 2, Figure 6). The abundance at Ov reservoir station changed between 9.7 × 10^3 and 63 × 10^3 cells.ml^{-1}, respectively in May and July. At BK station the minimum abundance values of 19.4 × 10^3 cells.ml^{-1} were observed in April, followed by a 5.5 fold increase to a maximum value of 117.8 × 10^3 cells.ml^{-1}in May.

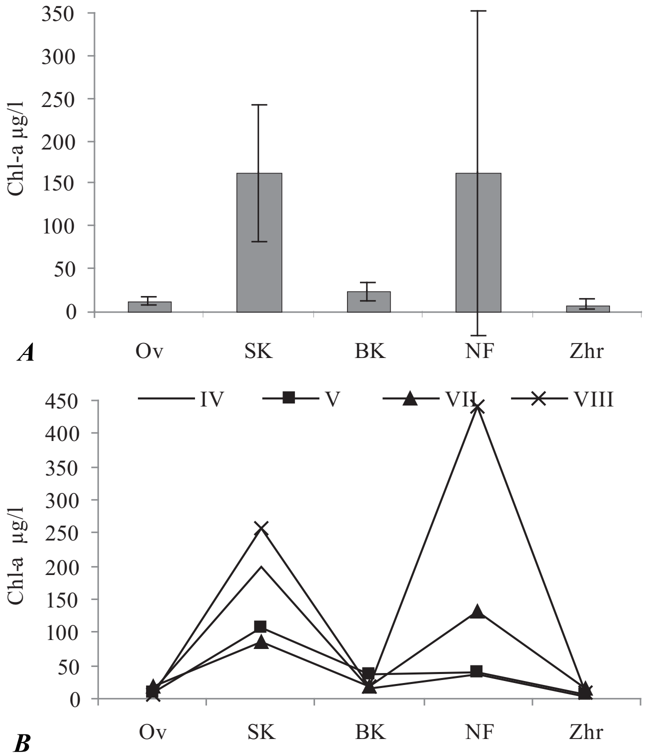

Fig. 5. Mean values of chlorophyll-a content and changes of Chl-*a* with time in the water bodies. Vertical bars denote ± one standard deviation

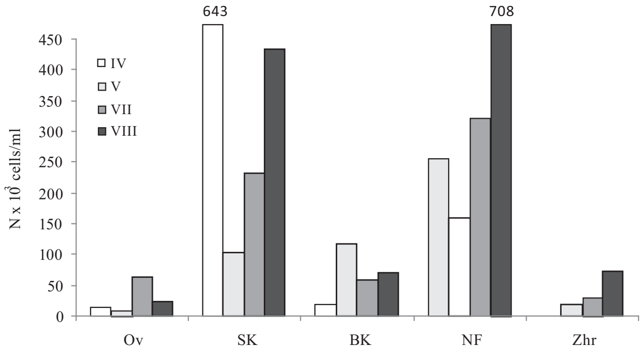

Fig. 6. Changes of the phytoplankton abundance in the water bodies

Phytoplankton abundance at SK station is characterized by strong bimodal distribution throughout the growth season. The maximum abundance of 643 × 10^3 cells.ml^{-1} developed in April during a phytoplankton bloom. In May the abundance crashed to its minimum value of 102.5 × 10^3 cells.ml^{-1}, followed by a secondary peak of 434 × 10^3 cells.ml^{-1} in August. The abundance of the phytoplankton is also bimodal at NF station with a smaller peak in the spring 255 × 10^3 cells.ml^{-1}, minimum in May (160.4 × 10^3 cells.ml^{-1}) and a maximum of 708 × 10^3 cells.ml^{-1} in August.

The minimum in the phytoplankton abundance at Zhr reservoir station was observed in April, followed by a gradual increase to a value of 72 × 10^3 cells.ml^{-1} in August. The seasonal dynamics in the phytoplankton abundance at Zhr station corresponds well to the previously described seasonal patterns in Zhrebchevo reservoir (Saiz, 1981). According to Saiz the gradual increase in the phytoplankton abundance close to the dam is due to a combined influence of the exploitation regime and wind induced currents. Beshkova et al. (2014) have shown that the invasion of *D. polymorpha* in the reservoir results in increased abundance and decreased biomass of the phytoplankton. This, according to the authors, is due to an adaptation of the phytoplankton to the increased filtration rates by the *D. polymorpha,* i.e. replacement of the *k*-strategists with *r*-strategists.

The Chlorophyll-a content of the samples reflects the amount of the phytoplankton. The relationship between the two variables was very strong (Figure 7) for the log transformed data. The strength of the relationship varied in the different water body complexes. It was strongest in the data

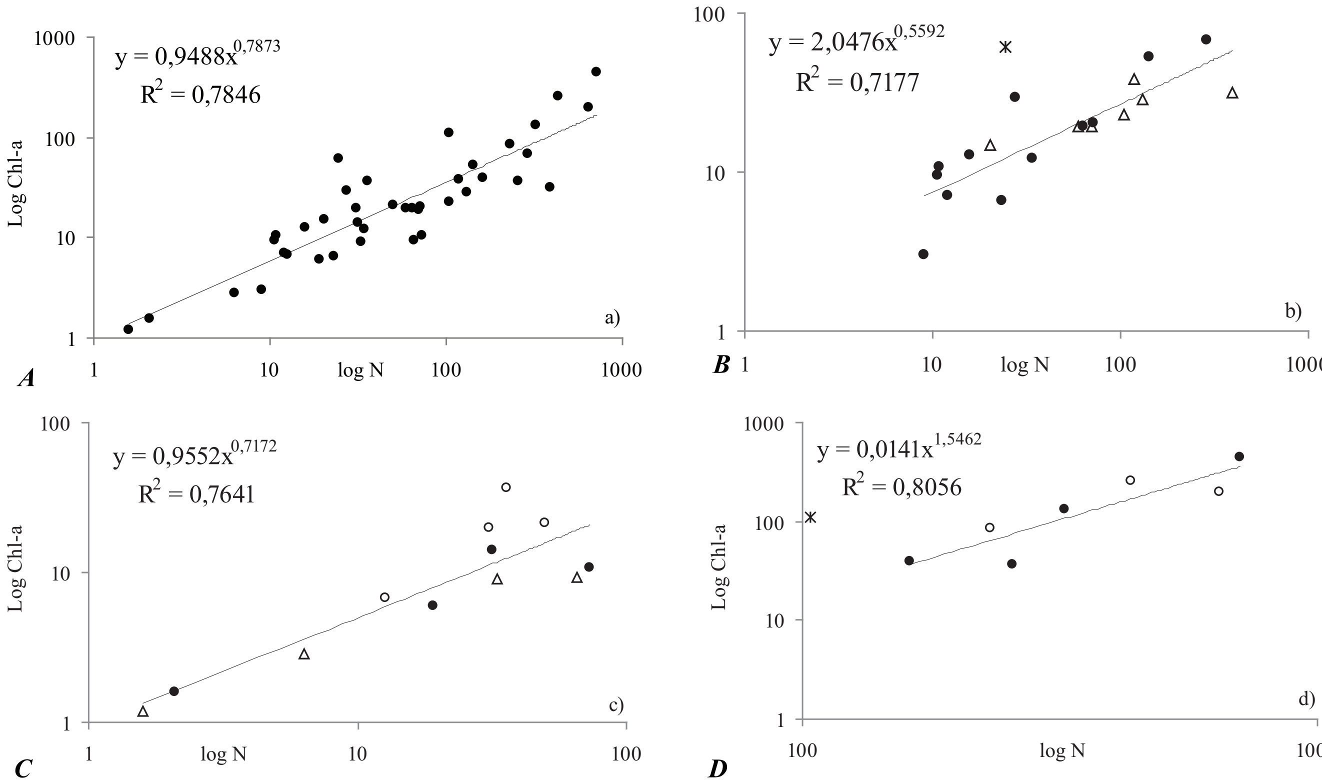

Fig. 7. Relationships between log transformed amounts of phytoplankton and log transformed chlorophyll-a content of the samples (N-Chl-a): a) – whole data set; b) – thermally influenced Ov (marked with ●) and BK (marked with Δ) stations; c) – Zhrebchevo reservoir: ○ – upper; Δ - middle and ● – lower stations; and d) – fish farm NF (marked with ●) and SK (marked with ○) stations. Omitted values are marked with (ж)

set of the intensive fish farm stations – NF and SK (Figure 7d), slightly lower in Zhrebchevo reservoir (Figure 7c), and weaker, but still significant, in the thermally influenced reservoir stations (Figure 7b). We have excluded single points out of the data sets from both, fish farm stations and thermally impacted stations. The omitted data represented the development of bigger plankton species in lower abundance, but with high Chl-a content. Our data suggests that despite the apparent differences between the water bodies the relationship between phytoplankton abundance and its chlorophyll-a content is constant and varies little with regard to exploitation regime and anthropogenic influence. Normally, the relationship is strongest in the fish ponds, where factors, such as fertilization and food chain interactions increase the relationship. In Zhrebchevo reservoir, the relationship is influenced by different factors along the water body. Thus, turbidity, induced by the main river inflow, alters the Chl-a content of the phytoplankton in the upper reservoir section, while the influence of nutrient limitation and zooplankton grazing increases toward the dam.

Trophic state

Carlson trophic state index (TSI) is a commonly applied method to determine the trophic state of the water bodies.

According to the TSI values the trophic state increases slightly between the lower and upper stations in Ovcharitsa reservoir, but remains within the eutrophic boundaries (Table 4, Figure 8). The trophic state at SK and NF stations is stable and corresponds to hypertrophic conditions. The TSI values at Byal kladenets reservoir also increase toward the upper reservoir sections, reflecting a change from eutrophic to hypertrophic conditions. The upper reservoir station in Zhrebchevo reservoir is eutrophic and gradual decrease to mesotrophic conditions is observed toward the limnetic zone.

Beshkova et al. (2014) also report for a discrepancy in the trophic state assessment of Zhrebchevo reservoir. The authors classified the reservoir as eutrophic to hypertrophic according to the phosphorus content in the waters, and as oligo-mesotrophic, according to the biomass of the phytoplankton.

Table 4.

Mean values of individual trophic state indices at sampling sites in 2013. Avrg represents average of the individual TSI values at each station.

	Ov-lower	Ov-middle	Ov-upper	SK	BK-lower	BK-upper	NF	Zhr-upper	Zhr-middle	Zhr-lower
TSI_{CHL}	54.3	56.8	59.5	79.5	60.7	65.1	75.3	59.0	44.4	48.4
TSI_{SD}	51.6	58.3	60.2	75.0	58.2	65.2	73.1	53.5	41.9	44.1
TSI_{TP}	81.1	83.9	86.0	91.2	83.3	84.6	85.9	67.4	63.1	62.3
Avrg	62.3	66.4	68.6	81.9	67.4	71.6	78.1	60.0	49.8	51.6

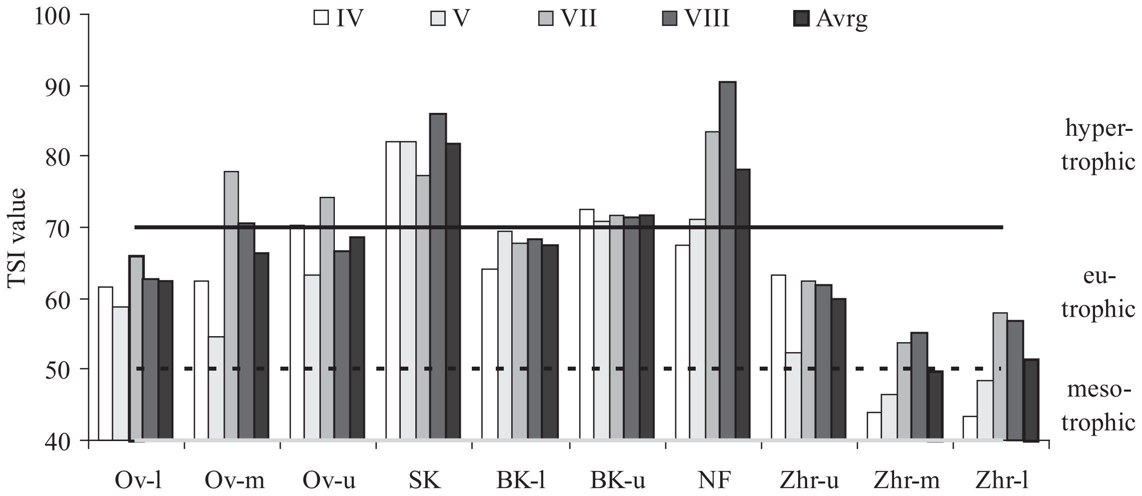

Fig. 8. Changes of the mean values of the Trophic State Indices individual sampling dates and sites. Avgr – overall seasonal mean at each station. Horizontal lines denote trophic state boundary values

The observed higher values of the index, based on the total phosphorus content (TSI_{TP}), reflect the potential trophic state, i.e. the maximum achievable trophic state if all of the phosphorus is transformed into phytoplankton biomass. As this is unlikely to happen in the real world, due to limitation by other nutrients and food chain interactions, the TSI_{TP} values always tend to predict higher trophic state than the Secchi depth (TSI_{SD}) and Chlorophyll-a (TSI_{CHL}) based indices. Beshkova et al. (2014) pointed out that the observed discrepancies in Zhrebchevo reservoir are partly due to the invasion and mass development of *D. polymorpha* in the reservoir and partly to nitrogen limitation.

Our results also indicate nitrogen limitation, especially in the upper reservoir station and at all Zhr stations, in August. As such discrepancies were observed in the reservoir prior to the invasion of the zebra mussels (Saiz, 1981), as well as in other non infested reservoirs in Bulgaria (Tosheva and Traykov, 2012; Traykov et al., 2010; Savchovska et al., 2013; Mihailova et al., 2013) we think that the role of *D. polymorpha* in this case is exaggerated.

The individual TSI values change differently at a given station, depending on the local conditions such as depth, and the amounts of total suspended solids, dissolved organic substances and seston concentration. The values of such variables are more stable in the shallower upper reservoir stations; this is reflected by the small variation of the TSI there.

The above mentioned additional factors influence the relationship between the trophic state indices. The Spearman correlation coefficient is highest when relating TSI_{CHL} to TSI_{SD} ($r = 0.946$, $n = 40$, $p < 0.01$), followed by the relation of TSI_{SD} to TSI_{TP} ($r = 0.786$, $n = 40$, $p < 0.01$). The correlation between the TSI_{TP} to TSI_{CHL} is weakest, but still significant ($r = 0.701$, $n = 40$, $p < 0.01$).

Conclusions

The simultaneous increase of temperature and nutrient concentration has strong effect on the abundance and chlorophyll-a content of the phytoplankton. The increase of the temperature has lower effect than the increase in nutrient concentration. This is due to the fact, that phytoplankton development is directly related to nutrients concentration in the water, while the increased temperatures influence nutrients dynamics and transformation, i.e. increasing denitrification and shifting the system toward nitrogen limitation later in the summer. It was evident that the main effect of long-term thermal pollution on the physicochemical variables of the water bodies is the increase of the dissolved solids with time. Our data suggests that despite the apparent differences between the water bodies the relationship between phytoplankton abundance and its chlorophyll-a content is constant and varies little with regard to exploitation regime and anthropogenic influence. The relationship is strongest in shallow, fertilized water bodies, while in the big reservoirs the relationship is influenced by different factors along the water body. Turbidity alters the Chl-a content of the phytoplankton in the upper reservoir sections, while nutrient limitation and zooplankton grazing increases toward the dam. These relationships determine the observed changes in the trophic state along the water bodies.

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References

Beshkova, M., 1996. Horizontal distribution of the phytoplankton and characteristics of the Struma River – Pchelina Reservoir ecotone. *Khidrobiologiya*, **40:** 43–54 (Bg).

Beshkova, M. and I. Botev, 1994. Seasonal and annual changes in phytoplankton composition in Pchelina reservoir. *Khidrobiologiya*, **39:** 17–32 (Bg).

Beshkova, M., R. Kalchev and H. Kalcheva, 2014. Phytoplankton in the Zhrebchevo Reservoir (Central Bulgaria) before and after invasion of Dreissena polymorpha (Mollusca: Bivalvia). *Acta zool. bulg.,* **66** (3): 399–409.

Carlson, R., 1977. A trophic status index for lakes. *Limnol. Oceanogr.* **22:** 361–369.

Carlson, R. and J. Simpson, 1996. A biomass based trophic state index. In: A coordinator's guide to volunteer lake monitoring methods. *North American Lake Management Society,* 96 pp.

Cheshmedjiev, S., D. Belkinova, R. Mladenov, I. Dimitrova-Dyulgerova, and G. Gecheva, 2010. Phytoplankton based assessment of the ecological status and ecological potential of lake types in Bulgaria. *Biotechnol. & Biotechnol. Eq.,* **24** (SE): 14–25.

Elliott, J., A. Irish and C. Reynolds, 2002. Predicting the spatial dominance of phytoplankton in light limited and incompletely mixed eutrophic water column using PROTECH model. *Freshwater Biology*, **47:** 433–440.

Elliott, J., 2012a. Predicting the impact of changing nutrient load and temperature on the phytoplankton of England's largest lake, Windermere. *Freshwater Biology*, **57**: 400–413.

Elliott, J., 2012b. Is the future blue-green? A review of the current model predictions of how climate change could affect pelagic freshwater cyanobacteria. *Water Research,* **46**: 1364–1371.

Elliott, J. and L. May, 2008. The sensitivity of phytoplankton in Loch Leven (UK) to changes in nutrient load and water temperature. *Freshwater Biology,* **5:** 32–41.

Elliott, J., I. Jones, and S. Thackeray, 2006. Testing the sensitivity of phytoplankton communities to changes in water temperature and nutrient load, in a temperate lake. *Hydrobiologia,* **559**: 401–411.

Grover J. and T. Chrzanowski, 2006. Seasonal dynamics of phytoplankton in two warm temperate reservoirs: association of taxonomic composition with temperature. *Journal of Plankton Research*, **28:** 1–17.

Hubenov, Z., 2005. Dreissna (Bivalvia: Dreissenidae) – Systematics, Authochthonous and Anthropogenic Areas. *Acta Zool. Bulg*., **57** (3): 259–268.

ISO 10260. 1992. Water quality – Measurement of biochemical parameters – Spectrometric determination of the chlorophyll-a concentration.

ISO 9963-1. 1994. Water quality – Determination of alkalinity. Part 1: Determination of total and composite alkalinity.

Kalchev, R., 1994. Investigations on the "Iskar" reservoir primary production and its connection with related and derivative variables. *Khidrobiologiya*, **39:** 58–71 (Bg).

Kalchev, R., 1999. The water quality gradients in some Bulgarian reservoirs expressed by the changes of the phytoplankton abundance. In: Proceedings of the 6th science-practical conference: "Technologies and management of water quality in Bulgaria", BNAWQ, 20–22 February, Sofia, pp. 108–115 (Bg).

Kalchev, R. and Ch. Boumbarova, 1996. Allometric and nonalometric correlation for chlorophyll – biomass and pigment diversity – species diversity relationships in the phytoplankton of Koprinka reservoir. *Khidrobiologiya,* **40:** 88–98 (Bg).

Kalchev, R., M. Beshkova, Ch. Boumbarova, R. Tsvetkova and D. Sais, 1996. Some allometric and non-allometric relationships between chlorophyll-a and abundance variables of phytoplankton. *Hydrobiologia,* **341**: 235–245.

Kalchev, R., M. Beshkova, I. Botev, H. Kalcheva, D. Kozuharov and T. Trichkova, 2013. Effect of Dreissena polymorpha (Bivalvaia: Dreissenidae) on physicochemical characteristics of Zhrebchevo reservoir (Central Bulgaria). *Comptes rendus de l'Acade'mie bulgare des Sciences,* **66** (11):1571–1578.

Kalchev, R., M. Beshkova, A. Kurejeshevich and D. Saiz, 2004. Influence of division predominance and algal size on relationship between chlorophyll-a and biovolume of phytoplankton. *Journal of Balkan Ecology*, **7:** 59–65.

Kalchev, R., M. Beshkova and D. Saiz, 2003. Algal size influence on relationship between Chlorophyll-a and biovolume of phytoplankton. *Journal of Balkan Ecology*, **6:** 403–408.

Kalff, J., 2002. Limnology: Inland Water Ecosystems. *Prentice Hall*, New Jersey, 592 pp.

Kozuharov, D., 1994. Analyses of zooplankton composition in the system Struma River – Pchelina reservoir in 1990–1992. *Khidrobiologiya,* **39:** 33–46 (Bg).

Kozuharov, D., 1996. Dynamics of quantitative parameters of the zooplankton in the system River Struma – "Pchelina" Reservoir and influence of the ecotone zone on them. *Khidrobiologiya*, **40:** 55–64.

Kozuharov, D., 1999. Dynamics of the zoobenthos of the system Struma River – Pchelina Reservoir dunring the period 1990–1992. *Acta Zool. Bulg.,* **51:** 79–88.

Kozuharov, D., V. Evtimova and D. Zaharieva, 2007. Long-Term Changes of Zooplankton and Dynamics of Eutrophication in the Polluted System of the Struma River – Pchelina Reservoir (South-West Bulgaria), *Acta zool. bulg.,* **59:** 191–202.

Kozuharov, D., T. Trichkova, I. Botev, Z. Hubenov and L. Füreder, 2009. Invasion of Dreissena Polymorpha (Pallas, 1771) to reservoirs in the Struma River Basin (Aegean Sea drainage basin, southwest Bulgaria). *Biotechnol. & Biotechnol. Eq.,* **23** (SE): 192–196.

Michev, T. and M. Stoyneva (eds.), 2007. Invetory of Bulgarian Wetlands and their Biodiversity. *Elsi-M*, Sofia, 364 pp.

Mihailova, P., I. Traykov, A. Tosheva and M. Nachev, 2013. Changes in Biological and Physicochemical Parameters of River Water in a Small Hydropower Reservoir Cascade. *Bulg. J. Agric. Sci.*, **19** (2): 286–289.

Naidenow, W., 1970. The formation of fauna in Bulgarian barrage lakes. In: Proceedings of the IBG – UNESCO Symposium on productivity problems of freshwaters, Warshaw – Krakov. 901–908.

Naidenow, W., 1984. Composition and ecology of the zooplankton of Danube River and inland water basins in Bulgaria. DSc. Theses. Institute of Zoology, BAS. Sofia, (Bg).

Naidenow, W. and N. Baev, 1987. Changes of the zooplankton parameters in the river to reservoir ecotone under anthropogenic influence. *Khidrobiologiya,* **31:** 3–14 (Bg).

Paerl, H. and J. Huisman, 2008. Blooms like it hot. *Science,* **320**: 57–58.

REI (2013)**.** Regional environmental inspectorate – A report for a data request for the period 2000–2012.

Reynolds, C., 1984. Phytoplankton periodicity: the interactions of form, function and environmental variability. *Freshwater Biology*, **14:** 111–142.

Saiz, D., 1981. Development of phytoplankton in the Tundzha River – Zhrebchevo reservoir system. *Khidrobiologiya,* **15:** 8–22 (Ru).

Savchovska, M., A. Tosheva and I. Traykov, 2013. Macrophytes Mapping and Spatial Heterogeneity of Some Physicochemical Parameters in Ognyanovo Reservoir. *Bulg. J. Agric. Sci.*, **19** (2): 267–270.

Stanachkova, M., D. Kozuharov, T. Trichkova, I. Botev and V. Tyufekchieva, 2010. Changes in Zooplankton Community of Jrebchevo Reservoir Before and After Infestation by Dreissenapolymorpha (Pallas, 1771). In: Youth Scientific Conference "Kliment's Days", 22–23 November, Sofia.

Stanachkova, M., D. Kozuharov, T. Trichkova, I. Botev and Y. Topalova, 2012. Development of Zooplankton of Ogosta Dam within 2009–2010 Period in Relationship with Mussels from Dreissena Genus. In: Proceedings International Conference Ecology – Interdisciplinary Science and Practice, 25–26 October 2012, Sofia, pp. 108–116.

Stoichev, S. and E. Danova, 2012. Contribution to the study of the free-living freshwater Nematoda fauna of the Zhrebchevo reservoir (South-East Bulgaria). *Lauterbornia,* **74:** 129–133.

Tosheva, A. and I. Traykov, 2012. – Abundance and Macrophyte Composition in Reservoirs with Different Trophic Status. In: Morel (Eds). Proceedings of BALWOIS 2012 Ohrid, FY Republic of Macedonia, 28 May – 2 June.

Traykov, I., 2005. Factors, determining the trophic state of Kurdzhali reservoir. PhD Thesis. Sofia University "St. Kl. Ohridski", 183 pp. (Bg).

Traykov, I., A. Tosheva and E. Uzunova, 2010: Physicochemical Characteristics of Dam Lakes in Southwestern Bulgaria. *Bulg J Agric Sci.*, **16:** 350–357.

Wetzel, R. and G. Likens, 2000. Limnological Analysis. *Springer*, 429 pp.

Yoshev, L., 1972. Chidrochemical investigation in Ovcharitsa reservoir. Izv. TNIRPD po ribno stopanstvo Plovdiv, (Fisheries bulletin). **9:** 16–71.

Zhivkov, M. and G. Groupcheva, 1987. Chidrochemical state, development of the ichtiofauna and fisheries potential of the coolant reservoir Ovcharitsa. *Khidrobiologiya,* **30:** 23–36 (Bg).