Annuaire de l'Université de Sofia "St. Kliment Ohridski"
Faculte de Biologie
2017, volume 102, livre 4, pp. 218-232
Youth Scientific Conference "Kliment's Days", Sofia 2016

TROPHIC STATUS AND ECOLOGICAL POTENTIAL OF RESERVOIRS IN BULGARIA BASED ON SELECTED PARAMETERS

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Keywords: physical and chemical parameters, chlorophyll *a,* Carlson's trophic state index, reservoirs, Bulgaria

Abstract: The Water Framework Directive (WFD) aims to achieve good ecological status (potential for heavily modified water bodies) of surface waters. Ecological status is characterised by the quality, structure and functioning of aquatic ecosystems. It is quantified through chemical and ecological parameters, with standard biological quality elements (BQE) for lake ecosystems (natural or artificial) being phytoplankton, macrophytes, phytobenthos, benthic macroinvertebrate and fish communities. The trophic state of reservoirs indicates their biological productivity and is usually assessed from data on phosphorus, chlorophyll *a* concentrations and Secchi depth. Our aim was to study the physical and chemical parameters of the water column, as well as the primary productivity (quantified as chlorophyll *a*). Here we present some preliminary results for eight Bulgarian reservoirs: Bebresh, Gorni Dabnik, Telish, Sopot, Sinyata Reka, Konush, Chetiridesette Izvora and Pchelina Reservoirs. Samples were collected from several stations and different horizons in spring and summer 2016.

INTRODUCTION

The Water Framework Directive requires the European Union member states to assess the ecological status of surface waters based on biological elements (Directive 2000/60/EC), whereas hydromorphological, chemical and physical features support this assessment. Physical and chemical quality elements of water should not exceed the levels outside the prescribed range in order to guarantee the correct functioning of typology-specific ecosystems and the achievement of the values specified for each BQE.

Abiotic and biotic conditions of standing water bodies are a result of a complex interplay. Some physical and chemical processes are particularly sensitive to temperature changes. Reservoirs with lower pH tend to be less buffered and more susceptible to perturbations from environmental changes (Alabaster and Lloyd, 1982; CCREM, 1991; Klontz, 1993) or can trigger adverse effects on physiological functioning of aquatic communities (USEPA, 1986b; CCREM, 1991). Dissolved oxygen is the most important factor controlling the fluctuations in nutrients and heavy metals (Forstner and Wittmann, 1981; Salomons and Forstner, 1984, 1988; Forstner and Salomons, 1991).

Further, nutrients are essential for primary productivity in aquatic ecosystems. Under optimal temperature and light, they are assimilated quickly, often causing eutrophication (Bergman, 1999). Ammonia is a biologically active compound present in most waters as a normal biological degradation product of nitrogenous organic matter. It is used up quickly or converted to nitrate in the upper layer in well-oxygenated waters and the uptake by algae is usually rapid (Bergman, 1999). As spring progresses, nutrient levels decrease while algal production increases. According to Jarosiewicz (2009) periodic increases of ammonia occur in summer and may represent an algal crash where there is a small but measureable increase in ammonia due to algal decomposition. Other factors, such as weather and periodic mixing, may cause short-term increases in ammonia (Jarosiewicz, 2009). Both nitrate and ammonia concentrations are highly variable during reservoirs seasonal cycles. For the trophogenic zone of shallow reservoirs, both concentrations would be lower during periods of maximum primary productivity (Quiros, 2001).

Secchi transparency is an important indicator of the state of the environment, and the normal course of production processes in the aquatic ecosystem (Likens, 1975). It is a function of light absorption characteristics of water, which is impacted by dissolved and particulate matter (organic material such as plankton or inorganic material such as suspended sediments). Moreover, it reflects both the seasonal thermal structure and the plankton productivity in the reservoir. Typically chlorophyll *a* concentrations (chl *a*), an estimate of total algal biomass, are used to estimate productivity and the trophic status of an aquatic system (Likens, 1975; Kenderov et al. 2014). The multiannual disparity in water transparency might not be a result of increases in chl *a* concentration (e.g. algal biomass) but rather could be partially owing to drawdown in the reservoir and the introduction of suspended sediments into the water column. As phosphorus often is a limiting nutrient in algal growth (Horne and Goldman, 1994), TP is commonly considered in the assessment of trophic status. Algal concentration can be estimated indirectly by determining chl *a*. Higher concentrations of chl *a* correspond to higher abundance of phytoplankton and more eutrophic state of the lake (Carlson, 1977).

Temperate lakes and reservoirs generally stratify in summer into three identifiable layers: epilimnion, metalimnion and hypolimnion. The density change in the metalimnion acts as a physical barrier that prevents mixing of the epilimnion and hypolimnion for several months during the summer stratification period (Armantrout, 1998). The trophic status of each lake corresponds to the biological response to the input of nutrients in the water column (Nauman, 1929). Nutrient effects may be modified by seasonal variations, grazing of phytoplankton and mixing depth of the water (Carlson and Simpson, 1996). Determining the trophic status could be done through using several diverse metrics, such as concentration of nutrients, productivity, oxygen availability and lake morphometry (Carlson, 1977) and could be used to quantify the degree of lake eutrophication. Trophic state index allows describing the abiotic and biotic conditions of water bodies, and the relationships between chemical and biological parameters (Carlson and Simpson, 1996; Matthews et al. 2002; Wetzel, 2001).

Our aim was to study the physical and chemical parameters of the water column, together with the primary productivity of eight selected reservoirs in Bulgaria. We looked at the seasonal differences between spring (mixing of the water column) and summer samples (presence of a thermocline). Further, we determined the trophic status of the studied reservoirs, based on our results for the water chemistry and the primary productivity (quantified as chl *a* in the water column), as well as on historical data.

MATERIALS AND METHODS

The samples were collected from eight reservoirs: Bebresh, Sopot, Gorni Dabnik, Chetiridesette Izvora, Pchelina, Telish, Konush and Sinyata Reka Reservoirs (Fig. 1, Table 1), in spring and summer of 2016. The sampling stations were selected near the dam where the greatest depth is expected to be found. The physical and chemical parameters of the water were measured using standard methods (ISO 5667), both at the lake surface and from a composite sample. The composite sample was made of equal parts of water sample collected along the water column at a step of 5 m (where possible depending on the depth of the reservoirs) using a bathometer. Temperature, oxygen and conductivity were measured using WTW portable meters (series 330) from the surface and from the water column at a step of 5 m where possible. Water transparency (Secchi depth, SD) was measured using a Secchi disk with diameter of 0.25 m.

Fig. 1. Map of Bulgaria with locations of the studied reservoirs:
1-Bebresh, 2-Sopot, 3-Gorni Dabnik, 4-Telish, 5-Sinyata Reka, 6-Konush,
7-Chetiridesette Izvora, 8-Pchelina.

Table 1. Basic morphological and hydrological parameters.

Reservoirs	**Spring date**	**Summer date**	**Lake type**	**Lake area (dka)**	**Max depth (m)**	**Latitude N**	**Longitude E**	**Altitude (m a.s.l.)**
Bebresh	19.5.2016	11.8.2016	L2	736	20	42,84597	23,77806	454
Sopot	1.6.2016	12.8.2016	L12	5 350	28	43,00786	24,42786	374
Gorni Dabnik	24.5.2016	11.8.2016	L14	11 800	23	43,36828	24,32742	171
Chetiridesette Izvora	15.5.2016	13.8.2016	L17	489	30	42,0053	24,93836	240
Pchelina	20.5.2016	14.8.2016	L13	5380	19	42,51723	22,84385	664
Telish	24.5.2016	12.8.2016	L16	2 320	28	43,3163	24,24247	230
Konush	15.5.2016	13.8.2016	L17	376.7	5	42,08147	25,03406	237
Sinyata Reka	1.6.2016	13.8.2016	L17	528	6	42,46888	24,70333	309

The concentrations of nutrients ($N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, N-tot, $PO_4\text{-}P$, P-tot) and pH were determined from the composite samples according to respective colorimetric methods using portable photometer WTW, pHotoFlex Turb. The concentration of chl *a* was measured following ISO 10260: 2002 - Determination of biochemical parameters and spectrometric determination of the concentration of chl *a*. Additionally, historical data on $N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, N-tot, $PO_4\text{-}P$, P-tot measured from a composite sample from the monitoring system of the Ministry of Environment and Waters were used.

Trophic state indices (TSI) were calculated following Carlson (1977). The variables used for these equations included SD (m), chl *a* content ($\mu g/dm^{-3}$) and concentration of total phosphorus (TP, $mg.dm^{-3}$) in the epilimnion (Table 2). Generally, TSI below 40 corresponds to oligotrophy, between 40 and 60 – mesotrophy, from 60 to 80 – eutrophy and above 80 – hypertrophy (Table 3; see Bajkiewicz-Grabowska 2007). The following expressions use Carlson's method to calculate the TSI (Carlson and Simpson 1996, as cited in USEPA 2000b):

TSI (chl a) = 30.6 + 9.81 ln (chl *a*) (chl *a* in mg/m^3)

TSI (SD) = 60 - 14.41 ln (SD) (SD in m)

TSI (TP) = 4.15 + 14.42 ln (TP) (TP in mg/m^3)

Table 2. Completed Carlson's trophic state index and associated parameters after Carlson (1977).

TSI	**SD (m)**	**TP ($mg.dm^{-3}$)**	**Chl a ($\mu g.dm^{-3}$)**
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

Table 3. Carlson's trophic state index values and classification of lakes (Carlson, 1996).

TSI	SD (m)	TP ($mg.dm^{-3}$)	Chl a ($\mu g.dm^{-3}$)	Trophic class
<30-40	>8-4	0-12	0-2.6	oligotrophic
40-50	4-2	12-24	2.6-20	mesotrophic
50-70	2-0.5	24-96	20-56	eutrophic
70-100+	0.5<0.25	96-384	56-155+	hypereutrophic

RESULTS AND DISCUSSION

During the sampling period, the studied lakes had pH from 8.5 (Chetiridesette Izvora) to 9.54 (Sinyata Reka; Table 4). At all sampling sites the pH values decreased with increasing depth. Higher pH values at the surface could reflect more abundant algae and a higher photosynthetic rate in the upper layers of the water column (Wetzel, 1975). We recorded more pronounced decreases in pH levels in the water column in the summer when the reservoirs were strongly stratified and may be influenced by decomposition processes, as well as photosynthesis and respiration (Wetzel, 1975).

The average values in all of them corresponded to a high environmental potential. The highest conductivity at the surface was recorded in Pchelina Reservoir (644.5 $mS.cm^3$) in spring 2016.

Our data on oxygen levels indicated excellent environmental conditions in five of the studied reservoirs (Bebresh, Gorni Dabnik, Pchelina, Telish and Konush) with values above 7$mg.dm^{-3}$, with the highest mean value in Pchelina Reservoir (15.55 $mg.dm^{-3}$; Table 4). These high oxygen levels in Pchelina Reservoir might be owing to blooms of phytoplankton. The lowest oxygen levels (3.5 $mg.dm^{-3}$) and dissolved oxygen (44%) were measured during the summer in the Sinyata Reka Reservoir.

The highest was the temperature in the two shallow reservoirs Konush and Sinyata Reka, for both seasons. In the other reservoirs surface water temperature had very similar values. Phytoplankton blooms were observed in spring in Sopot and Pchelina Reservoirs and in Sinyata Reka Reservoir in the summer.

Table 4. Average concentrations of physical and chemical parameters (± std. dev) based on measurements from spring and summer 2016. Legend: Be – Bebresh, So – Sopot, Gd – Gorni Dabnik, Ch – Chetiridesette Izvora, Pc – Pchelina, Te – Telish, Ko – Konush, Sr – Sinyata Reka.

Reservoir	**T** (°C)	**O_2** ($mg.dm^{-3}$)	**O_2(%)** ($mg.dm^{-3}$)	**pH**	**Cond.** ($mS.cm^3$)	**N-NH_4** ($mg.dm^{-3}$)	**N-NO_3** ($mg.dm^{-3}$)	**N-NO_2** ($mg.dm^{-3}$)	**N-tot** ($mg.dm^{-3}$)	**PO_4-P** ($mg.dm^{-3}$)
Be	20.05	8.3	76	8.66	166.6	0.014	0.66	0.008	1.7	0.36
	±7	±0.71	±24.04	±0.23	±13.86	±0.007	±0.51	±0.004	±1.06	±0.5
So	23.1	7	89	8.72	283.5	0.013	1.26	0.008	0.7	0.11
	±3.82			±0.18	±29	±0.014	±1.61	±0.001	±0.14	±0.1
Gd	23.4	7.8	98	8.72	241	0.08	0.81	0.007	2.8	0.31
	±3.82			±0.007	±12.73	±0.014	±0.55	±0.003	±1.27	±0.43
Ch	23.8	6.5	82	8.5	331	0.075	2. 25	0.027	3.8	0.0062
	±3.82			±0.11	±22.63	±0.004	±1.38	±0.014	±2.02	±0.000036
Pc	20.6	15.55	182	8. 52	644.5	0.31	3.18	0.1555	5.7	0.11
	±5.8	±7.42	±69.3	±0.23	±10.6	±0.007	±4.27	±0.07	±2.27	±0.12
Te	23.5	7.1	87	8.74	211	0.55	0.75	0.11	2.6	0.3
	±1.13			±0.12	±18.38	±0.007	±0.36		±1.56	±0.43
Ko	25.45	13.8	184	8.9	610.5	0.21	1.06	0.16	6.6	0.09
	±3.61			±0.45	±9.19	±0.007	±1.2	±0.18	±3.04	±0.0028
Sr	23.75	3.5	44	9.54	392	0.97	3.72	0.0095	4.7	0.019
	±1.2			±0.2	±31.11	±1.14	±4.65	±0.0007	±3.39	±0.009

During the summer, for six of the studied reservoirs the presence of a thermocline was established in the water column between 5 and 10 meters. Our results confirm the findings of Angelov (1968) who reported that the thermocline in large reservoirs in Bulgaria was between 5-7 m. It corresponded also to the stratification of the dissolved oxygen (Figs. 2a-g). In the Sinyata Reka Reservoir we observed a complete mixing of the water column.

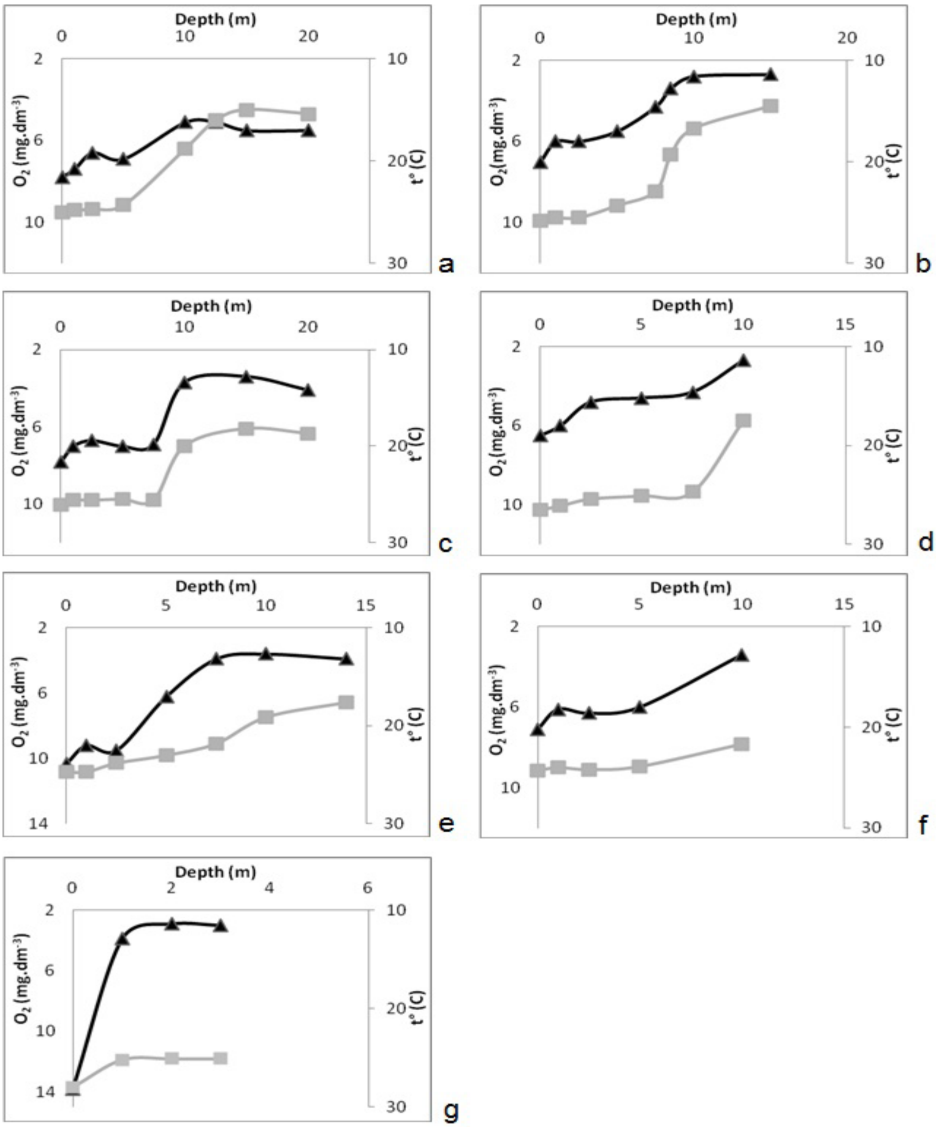

Fig. 2. Summer stratification of oxygen content and water temperature: a) Bebresh; b) Sopot; c) Gorni Dabnik; d) Chetiridesette Izvora; e) Pchelina; f) Telish; g) Konush Reservoirs; ▲ black line – dissolved oxygen, ■ grey line – temperature.

We recorded the highest depths for the Chetiridesette Izvora (30 m deep), Sopot (28 m deep) and Telish (28 m deep) Reservoirs (Table 1). The highest measured SD was 3.7 m and the lowest 0.5 m. Often, chl *a* correlates with SD transparency: shallower SD may coincide with greater chl *a* concentrations (Cole, 1979). Greatest concentrations of chl *a* occurred in Telish (36.72 µg.dm^{-3}) in spring, when Secchi depths were 0.5 m. Chlorophyll *a* ranged from 1.7 to 36.72 µg.dm^{-3} for both of seasons. We found that chl *a* concentration and water transparency were highly correlated (R^2 = 0.8) for the reservoirs with greater primary productivity. High concentrations of chl *a* were recorded for Konush, Telish, Chetiridesette izvora and Pchelina Reservoirs where were measured the lowest Secchi transparency (Fig. 3).

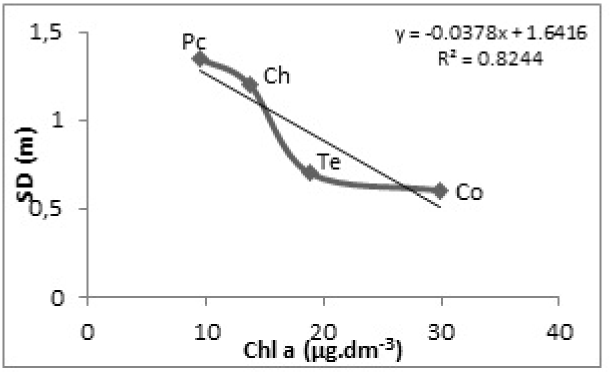

Fig. 3. Relationship between chlorophyll *a* and water transparency. Legend: Ko - Konush; Te - Telish, Ch - Chetiridesette Izvora, Pc – Pchelina Reservoirs.

Our results for nutrients ($N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, N-tot, $PO_4\text{-}P$, P-tot) and water transparency for both spring and summer demonstrated changes in the water of all studied reservoirs with values being higher in the summer. Nutrient loading is highest in Konush and Sinyata Reka Reservoirs, where the highest concentrations of N-tot and P-tot were measured. We could speculate that this might be owing to the ability of the ecosystem of these shallow lakes to absorb nutrients. According to Taylor et al. (1980) eutrophication is the nutrient enrichment of waters which results in stimulation of an array of symptomatic changes, i.e. increased production of algae and macrophytes, deterioration of fisheries, deterioration of water quality and other symptomatic changes. We recorded a seasonal peak of

3.72 mg.dm^{-3} nitrate-nitrite nitrogen from the composite sample in Sinyata Reka Reservoir in the summer. The nitrate-nitrite nitrogen levels (average from both seasons) ranged from 0.008 to 3.72 mg.dm^{-3} at all reservoirs in the study. The ammonia nitrogen levels ranged from <0.013 to 0.97 mg.dm^{-3} from both seasons corresponding to high, good and moderate ecological potential.

The orthophosphorus (PO_4) levels ranged from 0.006 mg.dm^{-3} in Chetiridesette Izvora Reservoir to 0.360 mg.dm^{-3} in Bebresh Reservoir in spring. Total phosphorus includes various soluble and insoluble organic and inorganic forms but it is the orthophosphorus (PO^4) that is immediately available for algal uptake and growth (Cole, 1979). The ratio TP:PO_4 ranged from 5:1 to 4:1 for all reservoirs averaged from both seasons, indicating that much of the phosphorus in the water contained low levels of orthophosphorus.

The ratio TN:TP often is a good indicator of the limiting nutrient in aquatic systems (Reynolds, 1986). The results for TN:TP ratio can be different for different lake trophic states and between deep and shallow lakes (Reynolds, 1986). When this ratio is greater than 7:1 then algal growth is limited by the amount of phosphorus present in the water, and TN:TP > 1:7 indicates nitrogen limiting conditions (Reynolds, 1986). We recorded TN:TP ratio lower than 7:1 for all reservoirs based on the averaged values from both seasons, indicating phosphorus limitation.

Historical data for the Pchelina Reservoir demonstrated high mean values of nutrients in the period 2010-2016 (Tables 5 and 6). According to the WFD and Regulation N4/2012 they correspond to a moderate ecological potential. With higher values of nutrients for the same period were Gorni Dabnik, Chetiridesette Izvora, Telish and Sinyata Reka Reservoirs, especially in summer. Bebresh and Sopot Reservoirs maintained low values of nutrients during the period 2010-2016, which corresponds to high and good ecological potential. No records were found during this period for the Konush Reservoir.

Table 5. Average concentrations of physical and chemical parameters in spring for the period 2010-2016. Data are for composite samples from the monitoring system of the Ministry of Environment and Waters. Legend: Be – Bebresh, So – Sopot, Gd – Gorni Dabnik, Ch – Chetiridesette Izvora, Pc – Pchelina, Te – Telish, Sr – Sinyata Reka.

Reservoir	**T** (°C)	**O_2** ($mg.dm^{-3}$)	**pH**	**Cond** ($mS.cm^3$)	**N-NH_4** ($mg.dm^{-3}$)	**N-NO_3** ($mg.dm^{-3}$)	**N-NO_2** ($mg.dm^{-3}$)	**N-tot** ($mg.dm^{-3}$)	**PO_4-P** ($mg.dm^{-3}$)	**P-tot** ($mg.dm^{-3}$)
Be	13.23	7.23	7.96	167.6	0.027	0.56	0.02	0.74	0.005	0.03
So	10.32	6.7	8.23	287.3	0.23	0.32	0.005	0.8	0.016	0.08
Gd	13.76	7.4	8.27	262.2	0.235	0.15	0.008	1.9	0.024	0.8
Ch	23	13.16	8.2	356	0.08	0.3	0.05	0.9	0.006	1.71
Pc	16.15	7.25	8.32	676.4	0.21	1.8	0.065	2.92	0.083	0.3
Te	11.95	7.4	8.17	251.5	0.18	0.21	0.024	1.5	0.03	0.77
Sr	19.98	7.6	9.56	420	0.14	1.26	0.022	2.5	0.076	0.4

Table 6. Average concentrations of physical and chemical parameters in summer for the period 2010-2016. Data are for composite samples from the monitoring system of the Ministry of Environment and Waters. Legend: Be – Bebresh, So – Sopot, Gd – Gorni Dabnik, Ch – Chetiridesette Izvora, Pc – Pchelina, Te – Telish, Sr – Sinyata Reka.

Reservoir	**T** (°C)	**O_2** ($mg.dm^{-3}$)	**pH**	**Cond** ($mS.cm^3$)	**N-NH_4** ($mg.dm^{-3}$)	**N-NO_3** ($mg.dm^{-3}$)	**N-NO_2** ($mg.dm^{-3}$)	**N-tot** ($mg.dm^{-3}$)	**PO_4-P** ($mg.dm^{-3}$)	**P-tot** ($mg.dm^{-3}$)
Be	20.73	5.6	7.62	168.6	0.02	0.27	0.007	0.04	0.006	0.031
So	23.43	6.2	7.84	248.3	0.16	0.08	0.011	0.6	0.017	0.9
Gd	22.8	7. 22	7.94	209.8	0.17	0.66	0.006	3.7	0.16	0.08
Ch	26.5	6.5	8.6	315	0.1	4.2	0.007	6.6	0.006	0.03
Pc	21.7	6.3	8.26	597.5	0.5	1.84	0.089	3.68	0.24	0.41
Te	18.63	7.3	8.25	330	0.17	0.97	0.03	2.16	0.06	0.46
Sr	26.5	8.14	9.4	426	0.28	1.47	0.015	3.48	0.24	0.42

Carlson's TSI for all studied reservoirs ranged between 30 and 80 based on our data and showed seasonal differences in spring and summer. According to our findings as typical mesotrophic reservoirs were identified Bebresh, Sopot, and Gorni Dabnik Reservoirs (Table 7). Eutrophic were Pchelina, Chetiridesette Izvora, Telish, and Sinyata Reka Reservoirs with values of 50-70. The Trophic state index classified Konush Reservoir as hypereutrophic. Our results are similar to those of Bergman (1999) where it is observed pronounced decrease in Secchi depth transparency with the increase in TP and chl *a* concentrations. Trophic state monitoring is an important part in assessing and managing lake ecosystems.

Table 7. Values of TSI based on our data from composite sample for both seasons in the studied reservoirs.

Reservoir	SD (m)	TP ($mg.dm^{-3}$)	Chl a ($\mu g.dm^{-3}$)	TI	TSI trophic class
Be	2.55	0.975	7.45	40-50	meso
So	3	0.5	4.08	40-50	meso
Gd	3	0.44	5.67	40-50	meso
Ch	1.2	0.87	13.72	50-60	eu
Pc	1.35	1.83	9.43	50-60	eu
Te	0.6	0.425	18.81	50-60	eu
Ko	0.7	0.84	29.94	70-80	hyper
Sr	0.65	0.85	3.01	50-60	eu

Our results confirm previous studies that the thermocline in Bulgarian reservoirs is between 5 and 10 m deep. The shallow Konush and Sinyata Reka Reservoirs were exceptions. According to Regulation N4/2012, five of the studied reservoirs maintain high ecological potential based on the high oxygen levels, while the measured low conductivity classified all the reservoirs with high ecological potential.

Moreover, we confirmed also the relationship between chl *a* and water transparency. The highest concentrations of chl *a* were recorded in the reservoirs with the lowest water transparency. The highest values of nutrients, chl *a* and water temperature were measured in Telish, Konush and Chetiridesette Izvora Reservoirs in the summer season.

Further, the concentrations of nutrients based on our measurements and on the data of the monitoring system of the Ministry of Environment and Waters (2010-2016) indicated moderate to good ecological potential for the studied reservoirs. On the other hand, TSI classified the studied reservoirs as meso-, eu- or even hypertrophic (Konush Reservoir) conditions.

CONCLUSIONS

The results for the various parameters included in the Bulgarian legislation did not result into unambiguous assessment of the conditions in the studied reservoirs. For instance, according to operating legislation, and namely Regulation N4/2012:

(i) all reservoirs maintain high ecological potential based on the measured conductivity;

(ii) oxygen levels suggest that only five of the studied water bodies maintain high ecological potential while the other three are in good and moderate ecological potential;

(iii) nutrients values indicate moderate, good or high ecological potential.

Nutrients are directly related to the trophic conditions in the water bodies. Given that lakes with higher eutrophication could maintain higher oxygen levels during the day (when measurements and sample collection are done) and conductivity is affected by the mineral composition of the studied water body, we could speculate that nutrients might be more reliable for assessment of the conditions in these water bodies.

Our findings suggest that Carlson's trophic state index is likely to reflect the ecological potential of the studied reservoirs more adequately than the existing criteria used in the national legislation. Therefore, we recommend its use in future assessment and monitoring programmes. Among its advantages is also the use of the cheap and easy to measure Secchi transparency. According to our results the lowest water transparency was measured in the reservoirs with high concentrations of chl *a* for which the values of TSI suggested deterioration of conditions.

Acknowledgments: This work was supported by "*Updating the typology and qualification system for the assessment of surface water bodies category river, lake and transitional waters during the first RBMP*" progect (2015-2016). We would like to thank Stefan Kazakov and prof. Dr. Roumen Kalchev for assistance in the laboratory work. We are grateful to the anonymous referee for their insightful comments that have helped us to improve the manuscript.

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