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Original Research

Long-Term Changes in Some Chemical and Biological Characteristics of the Grošnica Reservoir Water, Serbia

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Abstract

The Grošnica Reservoir is the oldest water-supply reservoir in Serbia. Investigations carried out monthly during the two-year period of 1996-98 revealed certain changes of some chemical and biological characteristics in relation to investigations performed almost 50 years earlier. Changes were noticed in composition of the plankton community and in some physical and chemical parameters. Although it could be expected that eutrophication would occur in time, the results do not confirm it. Total P, Secchi disk, and chlorophyll α values indicate that the Grošnica Reservoir belongs to the category of mesotrophic waters. The noticed differences can be attributed to raising of the dam's height and increasing the lake's volume, resulting in reduction of the influence of turbid currents, as well as to forestation of the reservoir's banks.

Keywords: long-term changes, reservoir, trophic status, zooplankton, nutrients

Introduction

As artificial ecosystems, reservoirs differ in a number of characteristics from natural lakes [1] and are relatively less stable [2]. Reservoirs are exposed to the processes of more rapid ageing and maturing in comparison to natural lakes [3]. Variations in their chemical and biological characteristics are caused by the presence of clearly separate zones (riverine and lacustrine), an increase in depth from the former to the latter, and heavy introduction of sediments into the riverine zone by erosive processes and their deposition in large quantities in the lacustrine zone, as well as by other physical attributes of reservoirs [4]. Stable conditions in reservoirs are thus often disturbed and a certain time-period is necessary for their re-stabilization [3]. Due to the fact that reservoirs differ from lakes in shorter retention times and in more pronounced horizontal heterogeneousness caused by tributaries [5], changes in plankton species composition may occur [5, 6].

Eutrophization is still one of the most widespread water quality problems [7]. In the formation of characteristics of reservoirs, an important role is also played by the catchment's area, whose characteristics (size, bedrock, soil, and vegetation) strongly affect the influx of nutrients, pH of the water, and its color [8]. Increased introduction of nutrients (primarily N and P) causes changes within the plankton community [9, 10], while measures aimed at preventing nutrient influx into eutrophic lakes lead to changes in the composition of phyto- and zooplankton [11, 12].

For all of these reasons, correct interpretation of both seasonal and long-term changes in reservoirs is often difficult to achieve.

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Reservoir Grošnica, built on Grošnica River, before the Second World War, represents the oldest reservoir for water supply in Serbia. It is bound to water supply of the city of Kragujevac in the center of Serbia. Within the period 1950-52 large-scale hydro biological research (phyto- and zooplankton, macrobenthos, and macrophytes) were made [13]. The results of the plankton community analysis of the research brought the author to conclude that this reservoir has eutrophic water characteristics. After this period, no new research was conducted for decades.

More than 40 years after the previous examination, the investigation of the zooplankton and macrophite community was done as well as physical and chemical analyses of the water. In the previous period, the activities were undertaken in order to improve the quality of water in reservoir by rising dams and foresting the banks. Besides, another new, considerably bigger reservoir for water supply of Kragujevac was built, which lessened the necessity for overtaking water from Grošnica Reservoir. These activities were done in order to improve trpohic status of water in the reservoir and the so-called re-oligotrophication [7]. It is known from the literature that in the course of time many lakes change from oligotrophic into eutrophic [14], but also that this process can be delayed or even drawn to the wrong direction by human activity [15]. It is also known that the activities that we undertake in order to improve the quality of water in resorvoirs are not always effective [7]. The aim of this investigation was to find out whether any changes occured in the previous period and whether the reasons for those changes could be determined.

Description of Investigated Locality

The dam was constructed during the period of 1931-37, and the reservoir was filled in 1938. Volume of the reservoir at that time was 2.17 x 10^6 m^3. Destruction and thinning of the surrounding forest during the Second World War caused intensive erosion. Surface erosion introduced a large quantity of eroded material, which gradually filled the lake's basin. During the period of 1938-50, the reservoir received 3,202.70 m^3 of sediment. Forestation of the banks was therefore carried out in 1957, and the decision was taken to raise the height of the dam. During the period of 1960-62, the dam was raised by 7.3 m. Already in the course of construction, it was clear that the enlarged reservoir with its raised dam would not be capable of supplying the amount of water needed. For this reason, a temporary reservoir was created on the Dulen River (near the Grošnica River): formed in 1964, water from it was diverted to the Grošnica Reservoir.

Today total volume of the Grošnica Reservoir is 3.53 x 10^6 m^3, surface area is 22 ha, and catchment area is 30 km^2. Length of reservoir is 1,750 m, maximum width is 250 m, and minimum width is 150 m. Maximum depth is near the dam (23 m). The Grošnica Reservoir is located at an altitude of 312 m a.s.l. Zone of protection is 180 ha. Retention time is 309 days. The number of domestic economy in protection zone is about 10.

In the wider surrounding of the lake, forest vegetation of the left bank hosts a *Fagetum montanum* (Rudski 1949) Jov. 1967 association, and the one the right bank hosts *Quercetum confertae-cerris* Rudski 1940 and *Querco Carpinetum moesiacum* Rudski (1940) 1949 associations. Forestation with species *Robinia pseudoacacia* L. has been carried out on a protective zone 5m wide. Along the shoreline, species *Salix alba* L. and *Cornus sanguinea* L. are present where the river flows into the lake. In view of the appearance of the reservoir banks and the conditions prevailing on them, it is understandable that hydrophites are represented by exceptionally few species.

Today, as in 1951-52 [13], a true meadow is formed in the shallowest part of the reservoir, this meadow being primarily composed of *Polygonum amphibium* L. populations. Due to periodic cleaning of the lake and cutting back of its vegetation, *Typha latifolia* L. is today present only in small populations several meters upstream from the mouth of the river, and nothing suggests that there is any danger of its choking the lake, which occurred 38 years ago according to the results of Janković [13].

Material and Methods

Monthly sampling was carried out from October 1996 to September 1998. (Because of bad weather conditions, it was impossible to conduct field investigations from January to April of 1997 and in April of 1998; also, it was impossible to take samples from the shallowest part of the lake during December of 1997 and January of 1998.) In order to gain as accurate as possible a picture of the state of affairs in this artificial ecosystem, three permanent sampling points were selected for qualitative and quantitative sampling:

I. directly beside the dam as the deepest part of the lake, where its depth varied (from 16 to 23 m), depending on the water level;
II. the central part of the lake (with a depth from 6 to15 m; and,
III. the shallowest part of the lake, about 200 m from its end, which is under water even when its level is lowest (with a depth of 0.8 to 5 m).

Samples of plankton were taken at every 3 m of depth during stagnation and at every 5 m during circulation.

Qualitative samples of zooplankton were taken with a plankton net (mesh size 25 μm), while quantitative samples were collected with 2-liter Ruttner hydrobiological bottles and then filtered across a plankton net. Samples were preserved with 4% Formalin at the collection site and later counted using an inverted microscope for identification to species level.

More recently obtained zooplankton analysis data were compared with the data of Janković [13] for 1950-52. The sampling procedure was the same (monthly sampling at the same localities and depths).

Samples for the analysis of chlorophyll-*a* were taken during May 1997 – September 1998 at the same depths as the samples for the analysis of zooplankton. The content of

Table 1. Average values of some physical and chemical parameters and chlorophyll-*a* of the Grošnica Reservoir in 1996-98 (data are calculated from three sampling points – mean monthly values).

	1996			1997							1998							
	X	XI	XII	V	VI	VII	VIII	IX	X	XI	I	II	III	V	VI	VII	VIII	IX
Temperature (ºC)	15.0	9.8	5.5	10.3	15.4	16.6	18.5	16.6	14.1	8.1	4.0	4.1	4.2	14.0	17.0	18.1	21.3	16.9
Secchi depth (m)	1.9	2.5	1.7	2.0	2.0	2.4	2.6	2.6	2.5	2.0	2.1	1.0	2.5	2.4	1.7	1.8	2.0	2.1
pH	7.88			8.29	8.17	8.15	8.07	8.12	8.03	8.09	8.07	8.11	8.24	8.18		7.87	7.81	7.88
$KMnO_4$ consump. (mg L^{-1})	10.8	9.4	7.9	8.5	11.7	11.5	15.4		12.3	8.9	9.8	8.8	7.4	9.1		8.8		8.7
Nitrates (mg L^{-1} N)	0.247	0.343	0.356	0.791	0.601	0.265		0.575		0.450		0.820	0.000	0.000		0.249		0.257
Nitrites (mg L^{-1} N)	0.015	0.011	0.015	0.006	0.017	0.022	0.015	0.012	0.005	0.008	0.036	0.006	0.009	0.009		0.007		0.007
Ammonia (mg L^{-1} N)	0.087	0.341	0.109	0.000	0.113	0.092		0.053	0.072	0.063		0.030	0.009	0.083		0.136		0.337
Sulphates (mg L^{-1} SO_4)			41.8								40.3	35.7	43.4					
SiO_2 (mg L^{-1})										6.1	7.4			11.8		4.6		11.1
Total P (mg L^{-1} P)	0.017				0.018	0.005	0.003	0.003	0.018	0.080		0.010	0.051	0.268		0.013		0.033
Cl^- (mg L^{-1} Cl)	10.0	5.5	6.0	6.4	7.1	4.9	6.6		6.6	3.8		3.1	5.8	5.7		5.8		6.1
Fe (mg L^{-1})	0.00		0.17	0.00	0.00	0.00				0.01		0.00	0.00	0.00		0.03		0.04
Mn (mg L^{-1})	0.16	0.50	0.16	0.00	0.05	0.02	0.22			0.01		0.00	0.00	0.00		0.05		0.14
Conductivity (µS cm^{-1})	418		489	462	471	439	385		387	374	350	390	393	412		390	376	392
Dissolved O_2 (mg L^{-1} O_2)	7.34	8.59	11.10	10.4	6.25	6.11	7.12	5.80	6.78	7.58	11.92	11.40	11.75	9.43		6.80	5.44	6.09
Saturation (%)	72.3	76.6	83.7	93.4	59.8	60.1	79.6	59.2	65.2	61.8	93.0	85.2	89.9	88.7		71.7	62.2	61.6
BOD_5 (mg L^{-1} O_2)	2.42	5.61	6.46	4.95	0.88	1.82	1.89	2.96	1.30	1.75	2.53	1.58	1.73	1.50		1.30		1.71
Chlorophyll *a* (µg L^{-1})				3.2	3.8	2.0	4.7	5.0		4.9	3.9	4.1	3.4	3.9	4.1	4.0	6.1	6.7

Table 2. Average values of some chemical parameters of Grošnica Reservoir (1951-52) – according to Janković [13].

	1951						1952					
	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI
Nitrates (mg L^{-1} N)	0	0	0	0	1.6	2.0	2.3	4.5	2	0	0	0
Cl^- (mg L^{-1} Cl)	3.3	4.4	3.7	4.1	3.6	3.7	3.3	3.6	4.3	4.1	4.1	4.8
Fe (mg L^{-1})	0.01	0.00	0.01	0.007	<0.001	0.005	<0.001	0.01	0.00	0.01	0.007	<0.001
$KMnO_4$ consumption (mg L^{-1})	8.22	8.85	10.11	8.85	9.84	8.22	6.95	7.58	7.58	8.21	6.32	6.95
Total P (mg L^{-1} P)	0.001	0.000	0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.000	0.001	<0.001	<0.001

Table 3. Average values of dissolved oxygen and saturation in Grošnica Reservoir (1951-52) – according to Janković [13].

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Dissolved O_2 (mg·L^{-1} O_2)	1951					7.47	2.67	2.14	2.98	3.39	8.38	9.51
	1952	10.29	11.21	11.00	8.19	6.32	4.35	2.90	2.32	4.65	4.49	9.70
Saturation (%)	1951					74.43	30.49	23.64	35.74	35.51	76.1	83.28
	1952	76.13	83.43	87.33	73.67	58.41	45.11	33.97	26.59	48.19	43.14	80.55

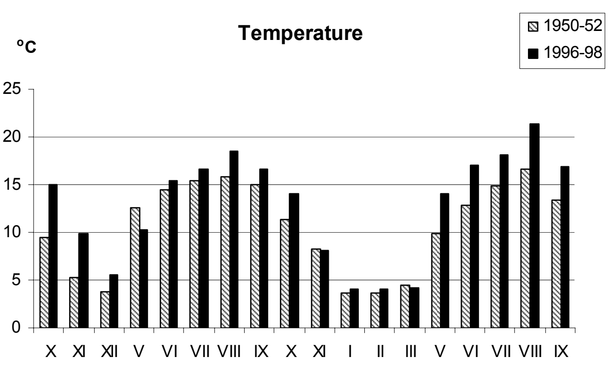

Fig. 1. Changes in mean monthly values of water temperature in Grošnica Reservoir.

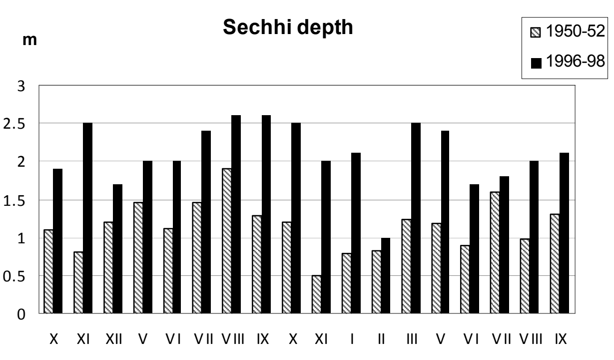

Fig. 2. Changes in mean monthly values of Secchi depth in Grošnica Reservoir.

chlorophyll *a* was determined by the spectrophotometric method using 90% acetone as the extracting agent [16].

An aquatic macrophytes survey in the Grošnica Reservoir was conducted during the period 2002-04. Field work was carried out bimonthly from May to October. Aquatic macrophyte was surveyed in four parts of variable length, depending of vegetation distribution patterns and relative plant abundance of species populations. Plants growing on the shore and in water to a depth of 5m were collected and recorded. The collected plant material was herbarized or preserved with 4% formaldehyde.

Samples for the analysis of chemical characteristics were taken together with those for quantitative analysis of zooplankton. Analyses of chemical parameters were performed by standard methods [17].

The obtained results of chenical characteristics were compared by application of Student's test, and analyses of variance (ANOVA). The mean monthly values calculated for all three localities in relation to water level were used in statistical analysis.

Results

The results of analysis of physical and chemical characteristics for the period October 1996 – September 1998 are shown in Table 1. Mean values are calculated for all three localities in relation to water level. The recorded values are characteristic for aquatic ecosystems of moderate regions. The only exception was the extremely high value of total phosphorus (total P) 0.268 mg L^{-1} in May 1998. This may be due to rainfall in the period and surrounding catchment area through which a certain amount of P entered the reservoir. It should be pointed out that similar values were never recorded again during further investigation.

In order to determine whether any changes in the examined characteristics had occurred, our results were compared to the data obtained by Janković [13] for the period 1951-52. (In 1950, chemical analyses of water were not carried out, while temperature and transparency were measured – Tables 2 and 3). Those tables include the values of the parameters that were measured both then and now. It can be seen that the values of almost all parameters increased with the passage of time. The only exception was nitrate content, primarily due to the extremely high values recorded in certain months during 1951-52 (Table 2). But this is, perhaps, a consequence of the less sensitive methods that were used in this period.

Both previously and these examinations, water temperature and transparency were regularly measured. Figs. 1 and 2 show the comparable review of those parameters for the periods 1950-52 and 1996-98.

The results of descriptive statistical analysis are shown in Table 4. Statistically significant changes were recorded for $KMnO_4$ consumption, saturation, chloride and sulfate content, temperature and Secchi depth. For the remaining parameters, the recorded differences were not statistically significant. This is particularly important in the case of nutrients.

The comparable review of species composition of zooplankton for the periods 1950-52 and 1996-98 [18] are shown in Table 5. These investigations revealed a considerably higher number of taxons (105 in comparison to 33 – Table 5) in comparison to the previous. Since in the paper by Janković [13], there were no data on total zooplankton production and their components in the investigated months, but only maximum mean monthly values, descriptive statistical analysis was not done. Yet Table 6 shows comparable maximum mean monthly values for total zooplanktons and most frequent taxons for both investigated periods. A considerable increase in the abundance of zooplankton can be seen, primarily due to the great abundance of Rotatoria, while a lower abundance was recorded for Protozoa and Cladocera.

Table 7 summarizes the parameters that define the trophic of the reservoirs, including total phosphorus and chlorophyll-a concentrations, and the water transparency measured as Secchi depth.

Whereas Janković [13] previously listed 20 plant species, the hydrophilic flora of the Grošnica Reservoir is represented by 30 plant species today (14 species are recorded for both periods), of which 21 species are mesophytes and hygro-heliophytes, while only 9 are aquatic hydrophytes [19]. They grow in a small sector of the reservoir by the river mouth and resemble a swamp, with the accumulation of sediment and a muddy bottom. This small zone rapidly gives way to gorge-like banks. The formation of this vegetation was absent in the greater part of the littoral at the time of the earlier investigation, and this is also the case today. The appearance of *Najas minor* L. as a pioneer species is evident at only two places along the shoreline.

Discussion

Statistical processing of the results of analyzing chemical characteristics of the Grošnica Reservoir's water (Table 4) show that the recorded differences are statistically significant for certain characteristics, but not for nutrients, the presence of which is the most important prerequisite for the development of phytoplankton and, indirectly, for the development of zooplankton as well. However, greater abundance of zooplankton was recorded in the more recent investigations. To what can the increased abundance of zooplankton be attributed?

The earlier investigations [13] were carried out during the period before the dam's height was raised and water was diverted from the Dulen Reservoir, as well as before the reservoir's banks were forested. According to the indicated author, water of the reservoir was very turbid and transparency for the most part did not exceed 1 m. Phytoplankton abundance was low, which the author attributed to the presence of so-called "turbid" currents arising as a consequence of the enormous amount of suspended material. In certain periods, its concentration amounted to more than 600 $mg \cdot L^{-1}$. Such a situation was primarily caused by the large quantity of sediments introduced by tributaries, as well as by erosive processes, since the reservoir's banks at the time of formation were poorly forested. This phenomenon was exacerbated by the terrain's steep inclination, whose average value is about 30º. Inadequate forestation enabled strong winds to cause turbulent water movement, which raised bottom particles and created waves that washed dirt from the banks.

In addition to this, an extremely unfavorable situation prevailed at that time in the reservoir's catchment area, where only 40% of the land surface was under forests and meadows. Moreover, vegetation had not yet formed at the time of the first investigations, when the reservoir was still young. Considerable variations of the water level (of even more than 6 m) prevented the development of macrophytic aquatic vegetation.

All of the given factors gave rise to strong erosive processes and the presence of large amounts of suspended particles in the water. Due to such turbidity, conditions were not ideal for the development of phytoplankton, which resulted in low abundance of both planktonic algae and zooplankton [13]. These conditions of great turbidity were favourable for Ciliata; therefore, their abundance in the period 1950-52 was much greater in comparison to the period 1996-98 (Table 6). It can be seen in Table 6 that the abundance of Cladocera was slightly greater in the previous investigations primarily due to the abundance of *Bosmina longirostris*, which is nowadays considerably less present in the Grošnica reservoir. Possible reasons for this event will be discussed later.

Total volume of Grošnica Reservoir was increased and a program of forestation of the reservoir's banks was carried out after raising the dam's height and divertind water from the Dulen Reservoir. Moreover, the Gruža Reservoir was constructed in 1984. Also built to meet the water supply needs of Kragujevac, this reservoir today represents the

Table 4. Desriptive statistics.

		N	Range	Minimum	Maximum	Mean	Std. error	Std. deviation	Variance	t-test
Nitrates (mg L^{-1})	1951-52	12	4.50	0.00	4.50	1.03	0.42	1.46	2.12	1.61
	1996-98	13	0.52	0.00	0.82	0.382	0.07	0.26	0.07	
Cl (mg L^{-1})	1951-52	12	1.50	3.30	4.80	3.92	0.13	0.46	0.21	3.49**
	1996-98	14	6.90	3.10	10.00	5.96	0.43	1.59	2.54	
Fe (mg L^{-1})	1951-52	12	0.01	0.00	0.01	0.007	<0.001	0.005	<0.001	0.95
	1996-98	12	0.17	0.00	0.17	0.020	0.001	0.049	0.002	
trftsWidthA3 Total P (mg L^{-1})	1951-52	12	0.001	0.000	0.001	<0.001	<0.001	<0.001	<0.001	1.99
	1996-98	12	0.265	0.003	0.268	0.043	0.02	0.074	0.005	
$KMnO_4$ consumption (mg L^{-1})	1951-52	12	3.79	6.32	10.11	8.14	0.33	1.15	1.32	2.65*
	1996-98	15	8.00	7.40	15.40	9.93	0.53	2.08	4.32	
O_2 (mg L^{-1})	1951-52	18	12.19	2.14	14.33	6.56	0.89	3.76	14.16	1.68
	1996-98	17	6.48	5.44	11.92	8.23	0.56	2.29	5.24	
Saturation (%)	1951-52	18	63.69	23.64	87.33	56.43	5.35	22.71	515.76	2.75**
	1996-98	17	34.20	59.20	93.40	74.35	3.09	12.76	162.70	
Temperature (ºC)	1951-52	18	13.0	3.6	21.6	10.60	1.10	4.68	21.86	4.35*
	1996-98	18	17.3	4.0	16.6	12.75	1.31	5.58	31.09	
Secchi depth (m)	1951-52	18	1.4	0.5	1.9	1.15	0.079	0.34	0.11	8.73*
	1996-98	18	1.6	1.0	2.6	2.1	0.097	0.41	0.17	

*p<0.05; **p<0.01; ***p<0.001

main source of the city's drinking water. From that period on, smaller amounts of water were drawn from Grošnica Reservoir. The increase of stability in the reservoir was made possible by decreased utility of water through the outlet in hypolimnion [20]. All of this resulted, among other things, in smaller fluctuations of the water level, weaker influence of "turbid" currents, and significantly greater transparency (which varies during the year between 2 and 3 m). In addition, the increase in abundance of daphnids also contributed to the increase of transparency. Daphnids are known for their positive contribution to water quality, e.g. through effective removal of particles [21]. The more stable level of the reservoir has made possible somewhat better development of its macrophytic vegetation.

A somewhat greater abundance of nutrients in comparison to previous investigations is present in Grošnica Reservoir today. While in the beginning, the nutrients originated mainly from the catchment area, now they are the result of decomposition of dead plankton organisms to a greater extent. Since the surrounding catchment area also affects the chemism of water [8], the foresting of reservoir banks made drainage of mineral phosphorous from forest soil possible. Relatively small amounts of nutrients can be explained by minumum human activities in the catchment area near the reservoir. Without industrial objects and with minimum agricultural activities (a small number of households are near the resrvoir), there is no flow of nutrients into the reservoir.

Although statistical analysis showed that differences in nutrients were not significant (Table 4), the amount of available nutrients and statistically significant increase of transparency (Secchi depth) (Table 4) allowed greater production of planktons. In addition, a statistically significant increase of water temperature (Table 4) made more favourable conditions for the development of phytoplankton.

Such changes are largely in agreement with the results of Jeppesen et al. [22] who studied trophic dynamics in turbid and clearwater shallow lakes with special emphasis on the role of zooplankton for water transparency. Namely, zooplankton grazing diminishes concentrations of detritus and inorganic suspended solids either directly by grazing or more indirectly. Thereby, zooplankton grazing may increase water transparency.

To comment on the changes in the zooplankton community, it is necessary to say something about the changes in the phytoplankton community. Here we may refer to the results obtained by Janković [13] for the period 1950-52 and Ranković et. al [23] for the period November 1997-March and September 1998 (Table 8). Although those investigations were not similar in respect of their range and lenth of time, some changes in phitoplankton composition can be perceived. In both investigated periods Bacillariophycea and Chlorophyceae were predominant, although the same species were not reported. Although substitution of species composition might have occurred, different identification is also possible as was the case in some other investigations [24]. On the other hand, differences were recorded in quantitative composition, since total production showed an increase. Whereas a maximal abundance of 2,100 ind·L^{-1} was recorded in the earlier investigations, Ranković et al. [23] record a maximal abundance of 4,418 ind·L^{-1}. A finding similar in both investigations was that dominance with respect to abundance was invariably exhibited by the species *Asterionella formosa* (Bacillariophycea) and species of the Dynophycea group (*Ceratium hirundinella* and *Peridinium cinctum*). It is interesting to note that only one species of Cyanophyceae (*Oscillatoria limnetica* Lemmermann) was recorded in both investigations.

Such results are in accordance with the propositions by Horn [7], that even in the waters in moderate regions with relatively small amounts of P, it is difficult to predict the dynamics of plankton. This is due to the importance of hydro-physical factors (such as temperature and light). Since in the Grošnica Reservoir activities on diminishing effects of erosion, turbid flow and increase of transparency have been undertaken, the conditions for better development of phytoplankton were provided although the amount of nutrients was not statistically significantly increased.

Differences in the faunistic composition of zooplankton during the investigated periods were considered in greater detail in a previous communication [18]. Considerably more taxa (Table 5) and greater abundance (Table 6) of zooplankton were recorded in the more recent investigations than in the earlier ones [13]. Some species are no longer registered, while many species are now recorded that previously did not occur [18]. Even more interesting are the changes of abundance (Table 6). A great increase of minute forms, primarily Rotatoria, is noticeable. Also of great importance is the change in abundance of certain representatives of planktonic Crustacea. Complete dominance of the species *Bosmina longirostris* was formerly well expressed, whereas today the abundance of this species is considerably lower. Among the possible explanations of this is that *B. longirostris* has a selective advantage in the detritus food chain [25]. "Turbid" currents containing a large amount of detritus were formerly pronounced in the Grošnica Reservoir [13], but their influence today is much weaker, which is in keeping with the decline in the abundance of B. longirostris. Moreover, the species *Bosmina coregoni* Baird has appeared: not present previously, its abundance is almost equal to average values recorded for *B. longirostris.* At the same time, increases have occurred in the content of nutrients and the quantity of edible algae, which gives *Daphnia cucullata* a selective advantage. In addition, cyanobacteria were slightly present in the Grošnica reservoir during the previous period and their abundance did not increase (only *Oscilatoria limnetica* was found in the composition of phytoplankton). This also allowed better development of daphnids [26].

Table 5. Comparison in number of zooplankton taxa between investigated periods in Grošnica Reservoir.

No. of taxa*	1950-52	1996-98
Protozoa	4	25
Rotatoria	22	58
Cladocera	5	14
Copepoda	2	8
Total	33	105

*species or subspecies

Table 6. Comparison in zooplankton abundance between investigated periods in Grošnica Reservoir (most abundant taxa in both periods).

Maximum monthly average abundance (ind L^{-1})		
	1950-52*	1996-98
PROTOZOA	564	380
ROTATORIA	616	1,772
Keratella cochlearis	382	1,006
Polyarthra dolichoptera	145	271
Synchatea sp.	69	842
CLADOCERA	264	208
Bosmina longirostris	255	9
Daphnia longispina	95	-
Daphnia cucullata	-	174
COPEPODA	253	288
nauplius Cyclopoida	163	56
nauplius Calanoida	-	32
copepodit Cyclopoida	65	53
copepodit Calanoida	-	18
Thermocyclops sp.	30	125
TOTAL ZOOPLANKTON	650	2,508

*according to Janković [13].

Because we have no data on the ichthyofauna (investigations of the ichthyofauna in the Grošnica reservoir have not been performed), its influence on changes in the plankton community cannot be estimated, although the ichthyofauna is known to be capable of causing unpredictable changes [27]. However, the pronounced dominance of minute forms of zooplankton indirectly leads us to conclude that the fourth trophic level (piscivorous fish) is not very strongly developed, with the result that large zooplankton is exposed to the pressure of planktivorous fish. The relatively favorable quantity of nutrients ensures sufficient production of edible algae, so the zooplankton community in Grošnica

Table 7. Mean Values of Trophic Status Index parameters for Grošnica Reservoir, 1996-98.

Mean Total P (μg L^{-1})	Chl-*a* mean (μg L^{-1})	Chl-*a* maximum (μg L^{-1})	Mean SD (m)	Minimum SD (m)
32.2	4.3	10.5	2.1	1.0

Reservoir is subject to the combined action of bottom-up (an adequate amount of edible alga, for whose production the required concentration of nutrients exists) and, to a considerably lesser extent, top-down (the possible absence of piscivorous fish, which permits the development of planktivorous fish that eliminate large zooplankton) control. Janković [13] wrote that during that period specimens of chub (*Leuciscus cephalus* L.), carp (*Cyprinus carpio* L.), and bleak (*Alburnus alburnus* L.) were recorded in small numbers in the reservoir. These are benthivorous species that exert no direct influence on zooplankton.

On the other hand, increases in the abundance of daphnids (Table 6) and the appearance of *Eudiaptomus gracilis* and the relatively large *Bosmina coregoni* suggest that the abundance of plantivorous fish probably is not great enough to exert any significant influence on the abundance of larger zooplankton. This is in accordance with the statements by Korponai et al. [26] that when "bottom-up" prevails, larger forms of zooplankton with more efficient grazing dominate. Besides, the presence of benthivorous fish provides the increase in P input through bioturbation, thus facilitating greater phytoplankton production [28]. In lakes with a well developed population of zooplanktivorous fish, their stronger influence on large zooplankton in relation to smaller forms is clearly evident [29, 30]. Only more detailed studies of the ichthyofauna could give a precise idea of the status of trophic relations in Grošnica Reservoir. That zooplankton in Grošnica Reservoir is primarily under bottom-up control is also indicated by the abundance of the predatory species *Leptodora kindti* (a species that was not present at the time of the earlier investigations), which was encountered exclusively during the warm months in the shallowest part of the reservoir and whose average abundance never exceeded 1 ind·L^{-1}. A similar phenomenon was identified by Horn [20] in the Saidenbach reservoir in Germany.

Comparison of the present results on the hydrophilic flora of Grošnica Reservoir with the data given by Janković [13] reveals similarity in that this flora today is likewise very poorly developed, with slight covering of the lake by vegetation and a very small number of submerged and emerged species (they are found only sporadically at just two locations in the guise of a few individuals each). Hydrophilic vegetation is particularly poorly developed and occurs only mosaically in places where wave action is weak. It can be seen from such a comparison that no significant qualitative increase has occurred in the number of existing species. High values of the Sørenson similarity (56%) and Jaccard index (38.39%) indicate slowed development of the hydrophilic flora in the last 38 years, which is influenced by conditions of the environment [19]. It can be concluded that the flora changes slowly and not dramatically.

Can the changes of physical and chemical characteristics of water in Grošnica Reservoir and the changes in the communities of zooplankton and macrophytic vegetation be explained by the increase of trophic level? On the basis of composition and abundance of its zooplankton, Janković [13] already concluded that the Grošnica Reservoir was eutrophic, although she herself admitted that the results of phytoplankton analysis did not support such a conclusion. On the basis of composition and abundance of the most frequently occurring species of zooplankton, it could be asserted that dominance of species characteristic of water with an elevated trophic status is present [18]. However, the fact is that some changes in species composition do not support that assertion. To be specific, contrary to the observed reality that elimination of the species *Bosmina coregoni* and dominance of *B. longirostris* occur with an increase of trophic status [31] while the abundance of Calanoida declines and that of Cyclopoida increases [32], *B. coregoni* and *Eudiaptomus gracilis* were recently recorded in the latest investigations of Grošnica Reservoir. The appearance of *E. gracilis* cannot be attributed to changes of trophic status, since it has been established that no clear correlation exists between the dynamics of *E. gracilis* populations and trophic status [14].

That the highest levels of eutrophication have not yet been reached is also supported by results obtained in analysis of trophic status parameters (total P, Secchi depth, and chlorophyll α values) [33], which indicate that Grošnica Reservoir belongs to the category of mesotrophic waters (Table 5), according to the basis of criteria used in limnology Vollenweider [34] and Jones & Lee [35].

Stable conditions in Grošnica Reservoir were maintained during the previous period owing to the reduction of some leading agents of eutrophication to the minimum (such as intensive procession of catchment area and influx of untreated waste). The activities on the improvement of water quality such as dam rising and thus increasing volume, foresting of surrounding area and decreasing erosion effects and impact of turbid flow, as well as increased transparency also contributed to the stability of the reservoir. All these provided favourable conditions for the formation of a stable plankton community. In addition, decreased utility of water from the reservoir within the previous twenty years contributed to smaller fluctuation levels and development of macrophytic vegetation.

Conclusions

Results of the present study likewise indicate that it is difficult to give a precise explanation for long-term changes in the composition of plankton. Although such changes are

Table 8. Floristic composition of phytoplankton of Grošnica Reservoir.

Species	1950-52*	1997-98**
CYANOPHYCEAE		
Oscillatoria limnetica Lemmermann		+
Oscillatoria tenuis Agardh ex Gomont	+	
BACILLARIOPHYCEAE		
Asterionella formosa Hass.	+	+
Asterionella formosa v. acaroides Lemm.	+	
Cyclotella bodanica Eulenstein		+
Cyclotella comta (Ehrenb.) Kütz.		+
Cyclotella glomerata Bachm.		+
Cyclotella kützingiana Thwaites		+
Cyclotella meneghiniana Kuetz.		+
Cyclotella sp.	+	
Cymatopleura solea (Brab) Smith	+	
Fragilaria crotonensis Kitton		+
Gyrosima sp.		+
Melosira granulata (Ehr.) Ralfs		+
Melosira varians Ag.		+
Navicula gracilis Ehr.		+
Navicula lanceolata (Ag.) Kütz.		+
Navicula radiosa Kütz.		+
Nitzchia palea (Kuetz.) W. Sm.		+
Nitzchia sigmoidea (Nitzsc.) W. Sm.	+	+
Nitzschia vermicularis (Kütz) Grun	+	
Surirella robusta Ehr.	+	
Synedra acus Kuetz.	+	+
Synedra actinostroides Lemm.	+	
Synedra ulna (Nitzsch.) Ehr.		+
Pinnularia sp.		+
Surirella sp.		+
EUGLENOPHYCEAE		
Lepocinelis texta Duj Lemm	+	
Trachelomonas planctonica Swir.	+	
Trachelomonas volvocina Ehr.		+
CHLOROPHYCEAE		
Characium falcatum Shroeder	+	
Characium limneticum Lemm.	+	
Closterium acutum Brébisson	+	
Closterium setaceum Ehr.	+	
Closterium praelongum Breb.	+	
Closterium venus Kütz		+
Coelastrum microporum Neag.	+	

Table 8. Continued.

Species	1950-52*	1997-98**
Crucigenia quadrata Morren	+	
Crucigenia rectangularis (Al.Br.) Gay	+	
Dictyosphaerium ehrenbergianum Nägeli	+	
Ooocystis solitaria Wittr.	+	+
Pandorina morum (Müll.) Bory	+	
Pediastrum duplex Meyen	+	
Pediastrum duplex var. genuinum Braun	+	
Pediastrum duplex var. reticulatum Lagerh	+	
Pediastrum duplex f. cohaerens Bohl.	+	
Scenedesmus alternans Reinsch		+
Scenedesmus arcuatus Lemm.	+	
Scenedesmus bicaudatus (Hansg.) Chodat		+
Scenedesmus ecornis (Her. Ex Ralfs) Chodat	+	+
Scenedesmus intermedius Chod.	+	
Scenedesmus obliquus (Turp.) Kuetz.		+
Scenedesmus quadricauda (Turp.) Breb.		+
Scenedesmus seriatus Chod.	+	
Sphaerocystis planctonica Bourr.		+
Sphaerocystis schroëteri Chod.	+	+
Staurastrum paradoxum Meyen	+	
Staurastrum polymorphum Breb.	+	
Staurastrum anatinum Cooke	+	
Tetraëdron minimum (Braun) Hansg.		+
Tetrastrum staurogeniaeforme (Schroeder) Lemm.	+	
DINOPHYCEAE		
Ceratium hirundinella (O.F.M.) Bergh		+
Glenodium sp.	+	
Peridinium bipes Stein.		+
Peridinium cinctum (O. F. M.) Ehr.	+	+
Peridinium inconspicium Lem.	+	+
CHRYSOPHYCEAE		
Dinobryon divergens Imhof	+	+

*according to Janković [13];
**according to Ranković et al. [23].

often attributed to altered trophic status, there are also data indicating that the zooplankton species composition of Lake Rotrua (New Zealand) remained stable for 40 years despite great changes in the inputs of nutrients [15].

The results of analysis of chemical characteristics showed that values of many parameters increased. However, statistical analysis showed that they were not always significant. Thus, the changes in the plankton community cannot be explained only by changes in the amount of nutrients, but also by hydro-physical conditions.

In analyzing the causes of changes in the composition and structure of phytoplankton and (especially) zooplankton, it is therefore necessary to take into account other factors as well. The engineering work involved in raising the dam's height and forestation of the reservoir's banks led to the establishment of a more stable water level and to reduction of the influence of turbid currents, promoting an increase of transparency. Together with a somewhat increased quantity of nutrients, these things created conditions for more vigorous phytoplankton development. Since edible species are prevalent in composition of the reservoir's phytoplankton, while the presence of Cyanobacteria is wholly neglible, the diversity of zooplankton and its production increased. Also contributing to this were the development of macrophytic vegetation (a refuge for zooplankton) and the absence of strong predatory pressure from planktivorous fish.

Our results (total P, Secchi disk, and chlorophyll *a* values) show that Grošnica Reservoir ranks as mesotrophic water. Therefore, it can be concluded that various measures that have been undertaken (increasing dam height, foresting the shore, transferring water from other reservoirs, and decreasing the amount of water that is caught) led to the decrease of trophic level, because Janković [13] specifies that Grošnica Reservoir was eutrophic in the mid 20th century. However, these propositions should be taken with reserve because the author herself made conclusions based on zooplankton composition, although she concomitantly proposed that it was not confirmed by the results of phytoplankton analysis. In addition, the values of nutrient composition do not support the assertion that Grošnica Reservoir was eutrophic at the time. Therefore, it can be assumed that those propositions were not valid, and the claim that the reservoir transferred from eutrophic to mesotrophic should not be taken with certainty.

Based on the obtained results, it can be concluded that the changes in abundance and composition of zooplankton and macrophytic communities occurred. However, these changes are difficult to explain completely. The data presented here support the conclusions of many authors to the effect that the causes of long-term changes in biocenoses are complex and can be more precisely ascertained only in light of the results of long-term monitoring.

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References

1. DE BERNARDI R., GIUSSANI G. Biomanipulation in Lakes and Reservoirs Management, Guidelines of Lake Management, **7**, ILEC, **1995**.
2. THORNTON K.W. Perspectives on reservoir limnology. In: Reservoir Limnology. (Eds Thornton K.W., Kimmel B.L., Payne F.E.), 1-13. John Wiley and Sons, Inc., New York, **1990**.
3. STRAŠKRÁBOVÁ V., ŠIMEK K., VRBA J. Long-term development of reservoir ecosystems – changes in pelagic food webs and their microbial component. Limnetica, **24,** (1-2), 9, **2005**.
4. BERNOT R., DODDS W.K., QUIST M.C., GUY C.S. Spatial and temporal variability of zooplankton in a great plains reservoir. Hydrobiologia **525**, 101, **2004**.
5. MATSUMURA-TUNDISI T., TUNDISI J. G. Calanoida (Copepoda) species composition changes in the reservoirs of Sao Paulo State (Brazil) in the last twenty years. Hydrobiologia **504**, 215, **2003**.
6. HRBÁČEK J., BRANDL Z., STRAŠKRABA M. Do the long-term changes in zooplankton biomass indicate changes in fish stock? Hydrobiologia **504**, 203, **2003**.
7. HORN H. The relative importance of climate and nutrients in controlling phytoplankton growth in Saidenbach Reservoir. Hydrobiologia **504**, 159, **2003**.
8. BRÖNMARK C., HANSSON L.A. The Biology of Lakes and Ponds, 2nd Edition. Oxford University Press, **2005**.
9. KOBAYASHI T., CHURCH A. Role of nutrients and zooplankton grazing on phytoplankton growth in a temperate reservoir in New South Wales, Australia. Marine and Freshwater Research **54,** (5), 609, **1997**.
10. BÜRGI B., HELLER C., GAEBEL S., MOOKERJI N., WARD J. Strength of coupling between phyto- and zooplankton in Lake Lucerne (Switzerland) during phosphorus abatement subsequent to a weak eutrophication. Journal of Plankton Research **21**, 485, **1999**.
11. PECHAR L. Long-term changes in fish pond managements as 'an unplanned ecosystem experiment': importance of zooplankton structure, nutients and light for species composition of cyanobacterial blooms. Water Science and Technology **32,** (4), 187, **1995**.
12. ANNEVILLE O., GINOT V., DRUART J.C., ANGELI N. Long-term study (1974-1998) of seasonal changes in the phytoplankton in Lake Geneva: a multi-table approach. Journal of Plankton Reserach **24,** (10), 993, **2002**.
13. JANKOVIĆ M.J. Limnological investigations of the Grošnica Reservoir. PhD thesis. University in Belgrade, Serbia. **1965** [In Serbian].
14. LØVIK J.E., KJELLBERG G. Long-term changes of the crustacean zooplankton community in Lake Mjøsa, the largest lake in Norway. J. Limnol. **62,** (2), 143, **2003**.
15. CHAPMAN M.A., GREEN J.D. Crustacean zooplankton communities in a New Zeeland lake during four decades of trophic change. New Zeeland Journal of Marine and Freshwater Research **33**, 361, **1999**.
16. CREITZ G.I., RICHARDS F.A. The estimation and characterization of plankton populations by pigment analysis. III A note on the use of "Millipore" membrane filters in the estimation of plankton pigments. J. Mar. Res., **14,** (3), 211, **1955**.

17. APHA. Standard methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington DC, **1992**.
18. OSTOJIĆ A. Effect of eutrophication on changes in the composition of zooplankton in the Grošnica Reservoir (Serbia, Yugoslavia). Hydrobiologia **436**, 171, **2000**.
19. TOPUZOVIĆ M., PAVLOVIĆ D. Physical organization of two reservoirs in Serbia as a crucial factor in development of their hydrophilic flora: a comparative study. Hydrobiologia **525**, 293, **2004**.
20. CASAMITJANA X., SERRA T., COLOMER J., BASERBA C., PÉREZ-LOSADA J. Effects of the water withdrawal in the stratification patterns of a reservoir. Hydrobiologia **504**, 21, **2003**.
21. HORN, W. Long-term development of the crustacean plankton in the Saidenbach Reservoir (Germany) – changes, causes, consequences. Hydrobiologia **504**, 185, **2003**.
22. JEPPESEN E., JENSEN J.P., SONDERGAARD M., LAURIDSEN T. Trophic dynamics in turbid and clearwater shallow lakes with special emphasis on the role of zooplankton for water clarity. Hydrobiologia **409**, 217, **1999**.
23. RANKOVIĆ B., ČOMIĆ LJ., SIMIĆ S., OSTOJIĆ A. Phytoplankton of the Grošnica Reservoir. The 28th Annual Conference of Yugoslav Water Pollution Control Society "Water Pollution Control 1999", Conf. Proc., pp. 157-160, **1999** [In Serbian].
24. PATALAS K., SALKI, A. Crustacean plankton in Lake Winnipeg: variation in space and time as a function of lake morfology, geology, and climate. Canadian Journal of Fisheries and Aquatic Sciences **49,** (5), 1035, **1992**.
25. SCHARF W. Restoration of the highly eutrophic Lingese Reservoir. Hydrobiologia **416**, 85, **1999**.
26. KORPONAI J., PAULOVITS G., MÁTYÁS K., TÁTRAI I. Long-term changes of cladoceran community in a shallow hypertrophic reservoir in Hungary. Hydrobiologia **504**, 193, **2003**.
27. HORPPILA J., PELTONEN H., MALINEN T., LUOKKANEN E., KAIRESALO T. Top-down or Bottom-up Effects by Fish: Issues of Concern in Biomanipulation of Lakes. Restoration Ecology **6,** (1), 20, **1998**.
28. TÁTRAI I., PAULOVITS G., MÁTYÁS K., KORPONAI J., POMOGYI P. Long-term food web interactions in Kis-Balaton Reservoir. Int. Rev. Hydrobiol. **83**, 515, **1998**.
29. JOHNSON T.B., KITCHELL J.F. Long-term changes in zooplanktovorous fish community composition: implications for food webs. Can. J. Fish. Aquat. Sci. **53**, 2792, **1996**.
30. MAIER G. Differential succes of cyclopoid copepods in the pelagic zone of eutrophic lakes. Journal of Marine Systems **15**, 135, **1998**.
31. MAKARCEVA E.S. Species composition, abundance and biomass of zooplankton. In: Reaction of lake's ecosystem. Ed (DRABKOVA V.G.), 110-116. Akademiya Nauk SSSR, Leningrad. **1983** [In Russian].
32. MAIER G. Copepod communities in lakes of varying trophic degree. Arch. Hydrobiol. **136,** (4), 455, **1996**.
33. OSTOJIĆ A., ĆURČIĆ S., ČOMIĆ LJ., TOPUZOVIĆ M. Effects of anthropogenic influences on the trophic status of two water supply reservoirs in Serbia. Lakes & Reservoirs: Research and Management **12**, 175, **2007**.
34. VOLLENWEIDER R. Les bases scientifiques de l'eutrophisation des lacs et des eaux courantes sous l'aspect particulier du phosphore et de l'azote comme facteurs d'eutrophisation. Tech. de l'eaux **292**, 43, **1968**.
35. JONES R.A., LEE G.F. Recent advances in assessing impact of phosphorus loads on eutrophication – related water quality. Review. Water Res. **16**, 503, **1982**.